#343 SEPTEMBER 2018

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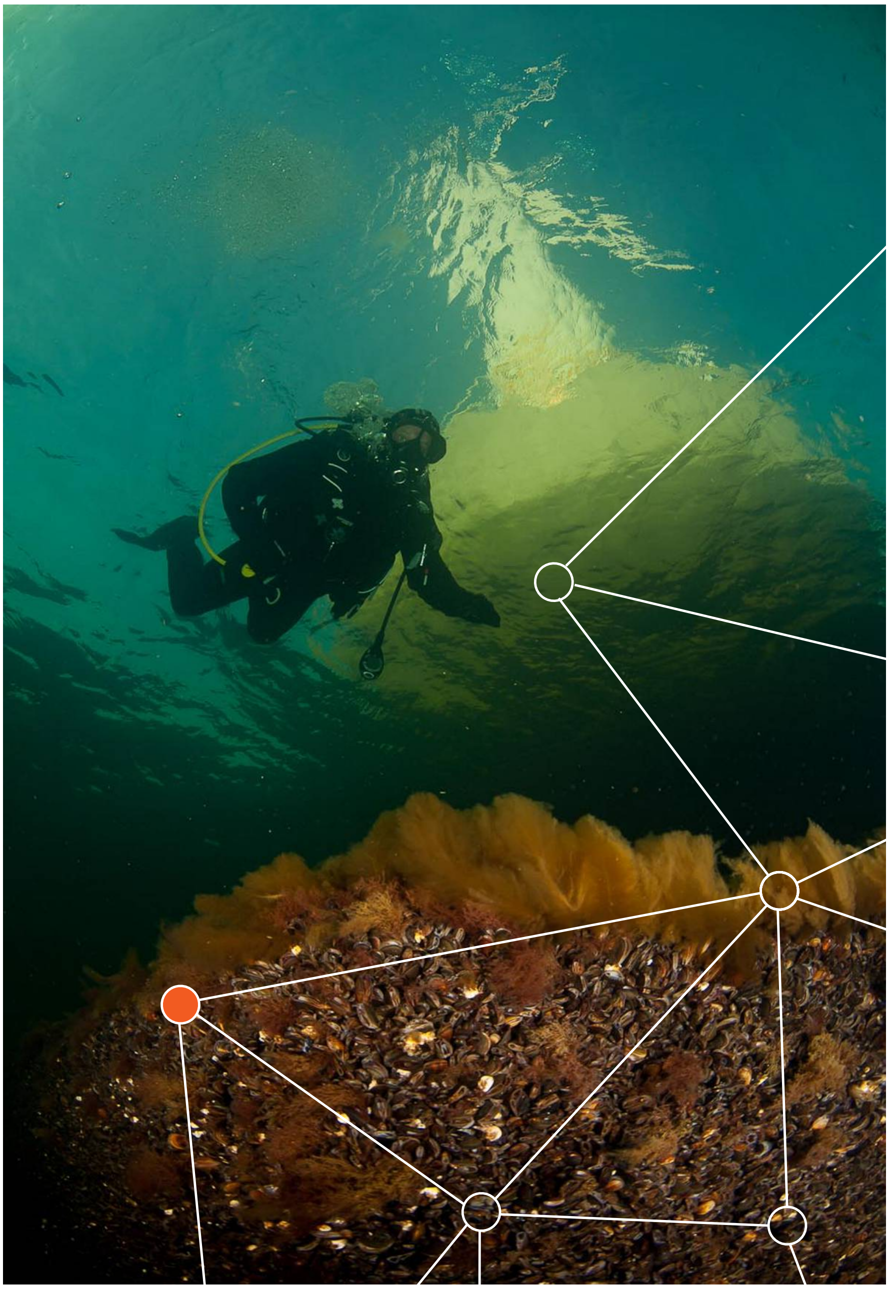

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Fifty years of marine tag recoveries from Atlantic salmon

Editors

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Recommended format for purposes of citation:

Ó Maoiléidigh, N., White, J., Hansen, L. P., Jacobsen, J. A., Potter, T., Russell, I., Reddin, D., *et al*. 2018. Fifty years of marine tag recoveries from Atlantic salmon. ICES Cooperative Research Report No. 343. 121 pp. http://doi.org/10.17895/ices.pub.4542

Series Editor: Emory D. Anderson

DOI http://doi.org/10.17895/ices.pub.4542

ISBN 978-87-7482-219-6

ISSN 1017-6195

Contents

1 Background

The number of wild Atlantic salmon (*Salmo salar* L.) has periodically declined throughout their native range (Chaput, 2012; ICES, 2015). This has been offset to some degree by historical management initiatives such as habitat protection and restoration, harvest restrictions, and fish health actions which have mitigated some declines. For at least two decades, however, declines in abundance have continued (ICES, 2015) and mitigation options are limited (Parrish *et al.*, 1998), which has led to the call for more focused marine research to assess the reasons for this persistent decline. The status of the wild salmon populations in both North America and Europe has shown a clear geographical pattern over the past 30 years, with most populations in the southern extent of their range in decline, with more northerly populations being generally stable, while populations at intermediate latitudes have been more variable (e.g. Parrish *et al.*, 1998; ICES, 2002). While some of the problems can be attributed to the construction of dams, pollution (including acid rain), water abstraction, overfishing, changing ocean conditions, and intensive aquaculture, many declines cannot be fully explained.

Most countries bordering the North Atlantic have had extensive tagging programmes for salmon at different life stages over the past 50 years, with large numbers of tagged salmon recaptured in oceanic fisheries throughout the North Atlantic. While the objectives of these tagging programmes varied widely, they have provided valuable information about marine migration and survival of Atlantic salmon during that period. Despite consistent recoveries in distant waters, until recently, no attempt was made to collate and analyse the recovery data or combine the information covering all years and tagging methods.

There have also been tagging programmes at sea, both at Greenland and in the Norwegian Sea, with tagged adults recovered in home-water countries providing information on adult migration routes and timing of returns from high seas fisheries. Initially, results from these studies had only been reported as single experiments and not analysed as a whole.

Several initiatives have been undertaken by the North Atlantic Salmon Conservation Organization (NASCO) and the International Council for the Exploration of the Sea (ICES) to improve our understanding of the distribution and migration of salmon at sea and the underlying causes of marine mortality of salmon. In support of these efforts, ICES organized a series of four workshops (2006–2012) to compile and analyse the available historic Atlantic salmon marine tag data:

- Workshop on the Development and Use of Historical Tagging Information from Oceanic Areas (WKDUHSTI; ICES, 2007),
- Workshop on Salmon Historical Information – New Investigations from Old Tagging Data (WKSHINI; ICES, 2008a),
- Workshop on Learning from Salmon Tagging Records (WKLUSTRE; ICES, 2009),
- Workshop on Salmon Tagging Archive (WKSTAR; ICES, 2012).

The first three workshops (WHDUHSTI, WHSHINI, and WKLUSTRE) reviewed published information on tagging studies, including the grey literature, evaluated release and recapture data (quantity and quality) available from different countries, compiled an inventory of available databases, and evaluated metadata for georeferencing. These workshops also made significant progress with preparing historical tag-recovery data in a standardized format and modelling the results using a GIS approach. The final workshop (WKSTAR) ensured that the data compiled by the previous groups would be fully archived and documented to make it accessible for future studies, and produced an outline for this CRR and two peer-reviewed publications which were subsequently published in the proceedings of the ICES/NASCO symposium “Salmon at Sea: Scientific Advances and their Implications for Management” (Hutchinson, 2012), held in La Rochelle, France in October 2011 (Jacobsen *et al*., 2012; Reddin *et al*., 2012). Annex 1 contains a complete list of workshop participants, while Annex 2 provides a list of the literature considered at the workshops.

This CRR compiles information from the four workshops and key results from the relevant papers presented at the ICES/NASCO salmon symposium to assess the distribution of the tagged fish in space and time. It provides a compilation of information from salmon tagged in home waters and subsequently recaptured in the oceanic salmon fisheries around the Faroe Islands, Greenland, and in the Norwegian Sea, as well as information from adults tagged in oceanic areas around the Faroes and West Greenland and subsequently recaptured in home waters. The data are arranged according to an agreed framework recommended at the 2007 workshop (WKDUHSTI; ICES, 2007) and stored for easy access and retrieval as four datasets: (i) Faroese recaptures, (ii) Greenland recaptures, (iii) adult tagging in Norwegian waters, and (iv) adult tagging in Faroese waters. The datasets together are referred to as the North Atlantic Salmon Tag Recovery database (NASTR) in this report and will be maintained by ICES Data Centre. Each country’s dataset has been thoroughly examined to remove duplicates and correct errors and inconsistencies, as far as possible.

The following people contributed to the NASTR database or CRR analyses through active workshop participation or correspondence: Peter G. Amiro, Vegar Bakkestuen, Gerald Chaput, J. Brian Dempson, Gilles Euzenat, Jeronimo de la Hoz, Mark Fowler, Arni Isaksson, Richard Kennedy, Oleg Lapshin, Kjell Arne Mork, Terry Nicholls, Sumarlidi Oskarsson, Stig Pedersen, Gordon W. Smith, and Fred Whoriskey. Contact information for these individuals as well as the editors of this CRR is contained in Annex 3.

2 Introduction

Atlantic salmon are widely distributed in the North Atlantic (Figure 2.1) and have been harvested for many years in freshwater, estuaries, fjords, and coastal areas as well as in the feeding areas of the Norwegian Sea and along the west coast of Greenland. While the life history of salmon is complex, in general terms, smolts leave the rivers in spring, earlier in the south than in the north, and quickly move from coastal waters to the open sea. Salmon normally spend one to three years, and occasionally up to five years, feeding in the open ocean before returning “home” to their natal river to spawn (Mills, 1989).

When coastal fisheries 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. However, there was uncertainty regarding the distribution and migration of salmon in oceanic areas until oceanic fisheries developed in the 1960s in the seas of West Greenland and, later, in the northern Norwegian Sea. Research on material sampled from these fisheries was undertaken (Parrish and Horsted, 1980; Hansen and Pethon, 1985; Reddin *et al.*, 1988; Jacobsen, 2000) and while new knowledge was gained, these investigations did not address the distribution and ecology of fish outside the fishing seasons and areas.

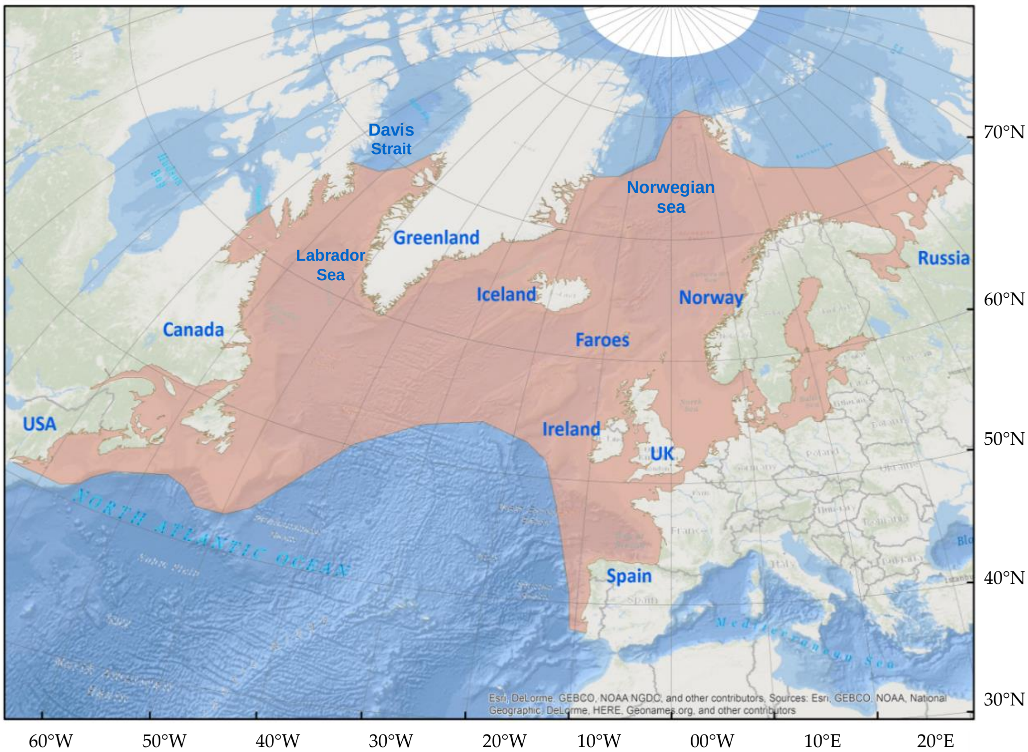


Figure 2.1. The North Atlantic with the geographic distribution of Atlantic salmon indicated in light red.

Atlantic salmon originating in many different rivers may be caught in the same oceanic area at the same time (Ritter, 1989; Hansen and Jacobsen, 2003). However, tagging experiments have demonstrated that Atlantic salmon from North America remain mostly in the western North Atlantic (Ritter, 1989), whereas fish from European and Norwegian populations are believed to largely feed in the Norwegian Sea (Holm *et al.*, 2003). European fish, particularly those from southern Europe, the UK, and Ireland, are also abundant around West Greenland (Swain, 1980). 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 tissues of salmon from the Northwest Atlantic, it has been suggested that some of those fish may move into the Northeast Atlantic area (Tucker *et al*., 1999; Spares *et al*., 2007). Recent genetic investigations of scale samples have confirmed this (Gilbey *et al.*, 2017; ICES, 2015). DNA analysis of scales taken from salmon caught in the 1993/1994 and 1994/1995 Faroese research fisheries indicated that 5.7% of the one-sea-winter (1SW) salmon and 20.5% of the multisea-winter (MSW) salmon sampled were of North American origin.

The status of the salmon populations in both North America and Europe shows a clear geographical pattern, i.e. most populations in southern areas appear to be in severe decline, the populations in the north are generally stable, and populations at intermediate latitudes are in variable states (Parrish *et al*., 1998; ICES, 2002). Although there are numerous identified stressors to Atlantic salmon, such as affects associated with the construction of dams, pollution (including acid rain), water abstraction, overfishing, changing ocean conditions, and intensive aquaculture, the causes of declines and variation in trends in abundance across the species range 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 freshwater (Doubleday *et al*., 1979; Ritter, 1989). Many factors affect smolt survival and consequently the return of adult salmon, although these factors are poorly documented (Dempson *et al*., 1998). While research on this subject has been strongly recommended by a number of organizations, only recently has there been 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; Sheehan *et al*., 2012). 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 the UK (Scotland) in May and June (Holm *et al.*, 1998; 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 salmon that had been tagged in April 1995 in western Ireland and southern UK (England and Wales) and recovered up to 2000 km farther north three months later, demonstrating post-smolts capacity for rapid travel.

There is evidence that the marine distribution of Atlantic salmon is related to temperature (Reddin and Shearer, 1987), but whether this is a direct causal relationship, or whether the distribution of prey items is an important factor influencing distribution is yet to be determined. The biomass of Atlantic salmon in the ocean relative to other pelagic oceanic fish species is extremely small. During its marine phase, salmon is thought to be an opportunistic pelagic predator, supporting a rapid growth rate by exploiting a wide range of invertebrates and fish prey.

When Atlantic salmon have reached catchable size, their capture in fisheries provides indications of their marine distribution, although there are very large areas where no salmon fisheries operate. Many countries have run major tagging programmes on smolts and adults, and some of these fish have been recaptured in distant-water fisheries.

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, it is likely that salmon fisheries developed in areas of high abundance of fish and that tag recoveries, therefore, reflect the distribution of a substantial proportion of the catchable fish during specific periods. However, Atlantic salmon have been documented over large areas in the Norwegian Sea (Holm *et al.*, 1982, Holm *et al.*, 1998, Holm *et al.*, 2000, Holm *et al.*, 2003, Holm *et al.*, 2004). This report primarily focuses on tags recovered in the distant-water fisheries around the Faroes and Greenland, which operate in a limited spatial and temporal part of the salmon marine life stage.

2.1 Faroes fishery

The fishery in the Faroes area commenced in the late 1960s and operated up to 70 miles north of the Faroes; catches increased slowly up to 40 t in 1977. Danish vessels participated in the fishery between 1978 and 1982, during which time catches increased rapidly owing to an extension of the fishing season, more vessels entering the fishery, and a shift in activities northward. Catches peaked at 1025 t in 1981 (Jacobsen *et al.,* 2012).

The Faroese Government agreed to a voluntary quota system beginning in 1982. A total catch of 750 t was introduced in 1982, with 625 t in 1983. Following the establishment of NASCO, agreed reductions in allowable catches were implemented following declines in forecasts of abundance, and the fishery has since been restricted to the Faroes EEZ. Although a small research fishery continued in some subsequent years until 2000, there has been no commercial salmon fishery around the Faroes since the early 1990s.

The fishery operated over winter, mainly November–May. Salmon caught here were thought to have originated almost entirely from Europe, although small numbers of tagged fish originating in North America were also recaptured. Genetic analysis of scales from salmon caught in the 1980s and 1990s, however, suggest that North American fish may have made up a larger contribution to the Faroes fishery than originally indicated (ICES, 2015). Further studies of archival and contemporary material are required to estimate the historical and current extent of this contribution.

For the Faroese fishery, catch data are available by numbers and weight, usually grouped into weight classes. Salmon were landed and sold in seven weight classes, with the highest prices paid for the largest salmon. Landings were monitored on shore and recorded in a landings file. Vessels were obliged to use a logbook to record fisheries information from the daily sets (i.e. number of hooks used and number of salmon caught along with the time and position when the longline was hauled). A database of the fishery data is held by the Faroe Marine Research Institute (Laksabasa) and covers the fishery from the late 1970s until 1991, and the research fishery thereafter until 2000.

2.2 Greenland fishery

Limited salmon fishing around West Greenland was reported as far back as the early 1900s. The present fishery dates from 1959, with a rapid expansion along the coast. The mid-1960s saw the introduction of offshore driftnets, operating up to 40 km offshore.

Because of improvements in gear, catches rose quickly to a peak of almost 2700 t in 1971. Fishing by non-Greenlandic vessels was phased out from 1972 to 1975; however, the total catch remained at around 2000 t until 1976 when a TAC of 1190 t was set. The fishery has been regulated since. In June 1998, in response to declining stocks, NASCO agreed that the West Greenland catch should be restricted to, "that amount used for internal consumption in Greenland, which in the past has been estimated at 20 tonnes." Since then, the export of salmon from Greenland has been banned. From 2002 to 2011, only the sale of salmon to hotels, institutions, and local markets by licensed fishers was permitted together with an unlicensed fishery for private consumption.

Small catches of salmon have also been made on the east coast of Greenland, although these are sporadic and restricted by the small number of communities in this area and by drifting polar ice. This fishery mainly operates August–October and catches salmon from both North America and Europe. Regulatory measures have been agreed for most years since the establishment of NASCO, resulting in greatly reduced allowable catches that reflect the declining abundance of the contributing stocks.

For the West Greenland fishery, Swain (1980) analysed a time-series of smolt tagging programmes in European rivers in relation to recaptures off West Greenland, as did Ruggles and Ritter (1980) for North American smolt tagging programmes. Jensen (1980a) used tag recoveries from West Greenland in 1972 to assess the distribution along the West Greenland coast of salmon originating in 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 in the West Greenland fishery comprised equal proportions of salmon from North America and Europe. It was more difficult to determine the country of origin, but Canada was thought to account for most of the North American component and the UK (Scotland) for most of the European fish (Jensen, 1980a). In recent years, the proportion of salmon originating in Europe has decreased (Reddin and Friedland, 1999; ICES, 2015). Of 5756 recoveries in West Greenland waters of salmon tagged as smolts in home waters, 2552 originated from the United States, 1847 from Canada, 403 from the UK (Scotland), 393 from UK (England and Wales), 148 from Norway, 146 from Ireland, 24 from Iceland, 3 each from Spain and Northern Ireland, and 1 from the Faroe Islands. Recaptures do not necessarily represent contribution to the fishery as the number of tag recoveries is also highly influenced by the number of tags released.

2.3 Norwegian Sea fishery

In the Northeast Atlantic, salmon are found in large areas of the Norwegian Sea. In the 1970s, there was an important commercial longline fishery in the far north of the Norwegian Sea from February until May. International concerns about 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 freshwater fisheries of salmon tagged in the Norwegian Sea suggested that Norwegian salmon were most abundant, although fish from the UK, Sweden, and Russian Federation 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, salmon fishing was banned in the northern Norwegian Sea and limited to the area within the Faroese Exclusive Economic Zone (EEZ).

With increasing salmon farming activity in recent years, the abundance of escapees from aquaculture facilities has become relatively high in some areas. In the Norwegian Sea, large numbers of escaped farmed salmon are present, and, it has been estimated that up to 40% of the salmon in the commercial catches at the Faroes were of farmed origin (Hansen *et al.*, 1999). In North America, escapes from Maine, New Brunswick, and Newfoundland fish-farming facilities are known to occur but the fish do not seem to range as widely in the ocean or around Greenland as they do on the eastern side of the Atlantic (Hansen *et al.*, 1997).

In 2008, an EU project (SALSEA Merge) was funded for a period between 2008 and 2011. This was a merging of ecological sampling and genetic stock identification of salmon post-smolts and adults at sea on both sides of the Atlantic. Genetic baselines for salmon, collected in hundreds of rivers in home-water countries and sampled multiple times, have allowed the areas of origin (and even natal rivers in some cases) of salmon caught at sea to be identified using DNA profiling. The results from this project have provided much new information on salmon migration and distribution and have allowed the formulation of a hypothetical model of migration for many different stocks (Mork *et al.*, 2012).

Recently, the results of genetic analysis of archival and contemporary scale samples collected at the Faroes and Greenland have provided new information on the stock composition of salmon catches in the areas (ICES, 2015; Bradbury *et al.*, 2016; Gilbey *et al.* 2017). Summary results are provided for comparison with tag recovery information in sections 5.2 (Faroes) and 6.2 (Greenland).

The objectives of this work have been to:

- produce a permanent record of historic tag recoveries,
- make such data available for future analyses,
- undertake initial analysis to provide summary statistics and descriptions of tag recoveries and implied salmon distributions, and,
- demonstrate the basis and concepts for future analysis of these tag-recovery data.

3 Tagging programmes by country

Systematic tagging studies have been carried out by countries around the North Atlantic from as early as 1935 (Figure 3.1). The largest of these programmes are described here to provide an overview of tagging in each country, including information on the objectives, the periods involved, numbers of fish tagged where available, river (smolt/kelt) or marine (adult) fish tagging, and whether the tagging was of hatchery, wild fish, or both. The specific tagging programmes that have contributed to the current North Atlantic Salmon Tag Recovery database (NASTR) and the analyses in this CRR are indicated. Any specific issues relating to data or its use have been highlighted where possible. Not all of the national tagging efforts have resulted in tag recoveries in the Faroes or Greenland fisheries or entry into the NASTR database.

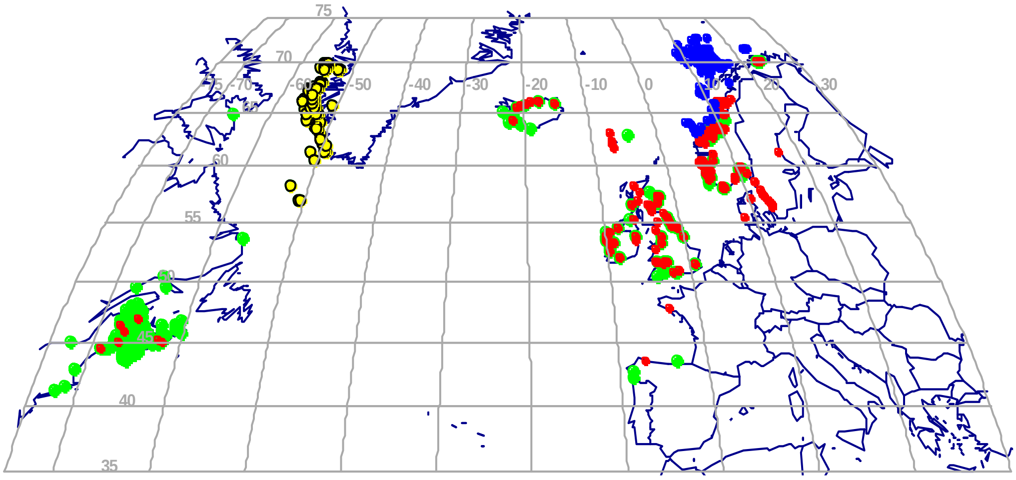


Figure 3.1. Juvenile tagging locations of salmon recovered around the Faroes (●) and Greenland (●) and adult tagging locations in the Norwegian Sea (●) and Davis Strait/ Labrador Sea (○).

3.1 Canada

3.1.1 Newfoundland and Labrador Region

There has been tagging within the Newfoundland and Labrador Region since the 1940s. Data from the following studies have been included within the NASTR database (Figure 3.2):

1. Sand Hill tagging. Wild salmon smolts/kelts from the Sand Hill River were tagged from a counting fence between 1969 and 1973, and returns were recorded from various fisheries from 1969 to 1976 (Anderson, 1985). This is the only tagging dataset available that describes the distribution at sea of any Labrador salmon stock. In total, 1035 recaptures of salmon at various ages are available.
2. Marine data. Wild adult salmon were tagged in coastal areas in the Newfoundland and Labrador Region between 1940 and the early 1980s. In total, 3495 salmon of various sea ages were tagged with Carlin tags and released back into the sea. Of these, 892 (26%) were recaptured at various locations in the sea and freshwater (Reddin and Lear, 1990). Recaptures were reported from North America, Greenland, and Europe (Scotland).

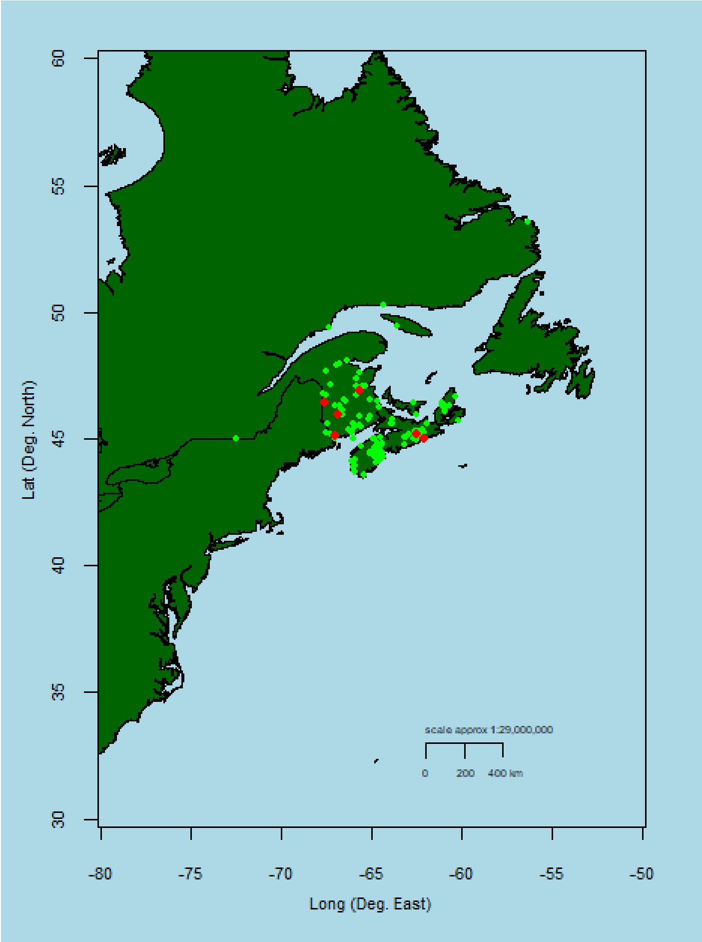


Figure 3.2. Canadian tagging locations of salmon recovered around the Faroe Islands (●) and Greenland (●).

3. Offshore distribution/tagging of adult fish. Distributional/tagging studies took place in the Labrador Sea and Greenland area in 1965 mainly in response to the expanding Greenland commercial fishery (Templeman, 1967, 1968). While there were not many recaptures from this tagging programme, the location of recapture is available for each salmon and provides the best information on distribution at sea based on tagging. In total, 2241 salmon were tagged at sea in the Greenland and Irminger Sea areas.

3.1.2 Gulf Region

There are three sources of data on tagging and recoveries in the North Atlantic Salmon Tag Recovery (NASTR) database.

Fisheries Research Board[1] of Canada historical data

The Fisheries Research Board has records for 17 370 tagged salmon (adults and smolts) dating from 1957 to 1975. Overall, 13 378 records have complete tagging and recovery dates. Most of the tag recoveries were from smolt tagging programmes, followed by

[1] Until its transfer into the Department of the Environment (1973–1979), the Fisheries Research Board was the principal federal research organization working on aquatic science and fisheries in Canada.

adult salmon tagging, with the majority of the tagged fish being wild. A large percentage (72%) of the recoveries were made in freshwater, primarily in the Miramichi River, which was the primary location of study during those years. The majority of marine recoveries were obtained from smolt tagging programmes. Adult grilse and salmon tagging programmes were carried out as fish were returning to the river to spawn, with the majority of the recoveries occurring in the same year and generally in the river of tagging. Freshwater recovery areas were defined as the recapture locations and were specified to a river, a tributary, and, in some instances, a location on a river. Estuary recoveries were defined on the basis of the name of the recapture location. Coastal recoveries were those that were not specific to a river or a known embayment.

Within the salmon tag recovery records, 851 recaptures were recorded from West Greenland and are included in the NASTR database. Of these, 428 records include complete information. Based on rough geographic groupings, 9 recoveries came from Labrador, 487 from Newfoundland, and 37 from Quebec.

Most of the codes relate to statistical districts within the Maritimes, Quebec, and Newfoundland provinces. Recoveries in the high seas relate to the International Commission for the Northwest Atlantic Fisheries (ICNAF) subareas and divisions.

Information from TAGRET – Oracle database held at Bedford Institute of Oceanography, Dartmouth, NS

There are 8233 records of tag recoveries for the tagging years 1966–1983 from programmes in the Gulf Region. Recaptures were evenly split between smolt and adult tagging programmes, with recaptures as fresh-run adult returns and silvering kelts, respectively. Within the adult programmes, most of the fish tagged were of wild origin, whereas for smolts, ca. two-thirds were of hatchery origin. The majority of the tagged fish were released in the Miramichi River, with lesser amounts in the Restigouche River.

Most recaptures were reported from locations within the Gulf Region, with the vast majority of these from freshwater locations. More than 2500 recoveries were in non-Gulf Region waters, with just under 1000 from West Greenland. Based on the recaptures which occurred within three years post-tagging, the West Greenland recoveries were primarily of reconditioned kelts from adult salmon tagged the previous year and as non-maturing 1SW salmon one year post-tagging at the smolt stage. Most recoveries were made from August to October. The single reported tag recovery from the Faroes was a smolt tagged in 1974, but did not include recovery date information.

From adult tagging in Labrador, most recoveries were kelts. Recoveries of salmon originally tagged as smolts occurred as 1SW, two-sea-winter (2SW), and three-sea-winter (3SW) adults.

Adult salmon tagged in Newfoundland were recovered on their return over the following two years as kelts, presumably as repeat spawners. Recaptures of smolts tagged in Newfoundland occurred as 1SW, 2SW, and 3SW adults.

Department of Fisheries and Oceans (DFO) Canada: Science Branch Gulf Region Adult and Smolt Tagging Programmes, 1985–present

Since 1985, fresh-run adult salmon have been tagged at several locations within Gulf Region rivers as part of assessment programmes to evaluate adult returns. Since 1998, smolt assessment programmes in the three main rivers of the Gulf Region (Restigouche, Miramichi, and Margaree) have tagged upwards of 10 000 wild smolts annually using individually numbered streamer tags. Recaptures of post-spawned adult salmon and post-smolts were reported from numerous locations in the North Atlantic including Quebec, Newfoundland, Labrador, and West Greenland.

The recapture data have not been assembled and reported in any previous publication. Tag recoveries from West Greenland have been reported by ICES Working Group on North Atlantic Salmon when they occurred.

3.1.3 Maritimes Region: Atlantic coast of Nova Scotia to the US border

Data describing the application, distribution, and recovery of individually identifiable tags applied externally to Atlantic salmon initiating mostly, but not exclusively, from Canadian government-funded research in the years prior to 1985 were registered with the Atlantic Salmon Tag Clearing House of the Department of Fisheries and Oceans, Science Branch, Maritimes Region. The data for this region are held in an Oracle database at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada. The majority of tags applied were plastic Carlin tags in two sizes, with the size of the tag depending on the size of the fish. The dataset comprises tag recoveries made in the Maritimes Region between 1964 and 1985.

Information is available on tag code, recovery dates and locations, biological measurements, fish taken for broodstock, and re-release. Release information for 2 613 919 tags is available, with specific recovery data on 36 069 reported recaptures.

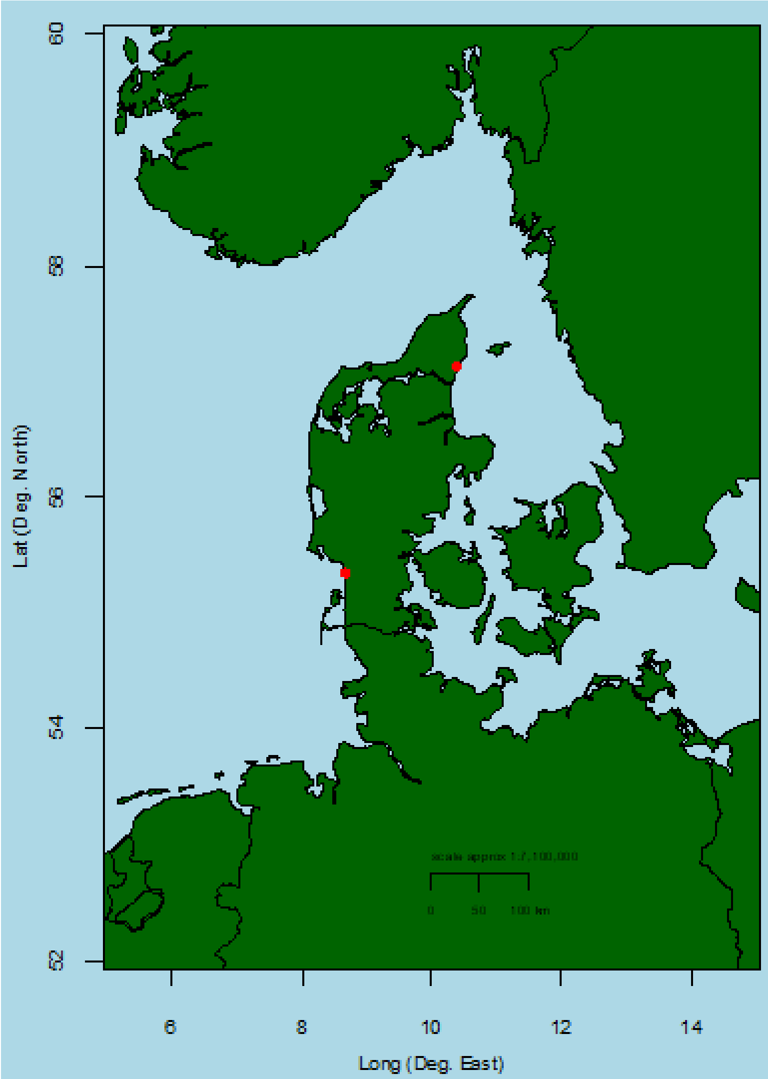


Figure 3.3. Danish tagging locations of salmon recovered around the Faroe Islands (●).

3.2 Denmark

Information is available from recaptures of salmon tagged with Carlin tags from 13 different Danish streams (Figure 3.3). The majority of smolts were released between 1965 and 1979, with some more recent releases (1991–1993) in one river. In total, ca. 56 000 smolts were tagged and released. The released fish originated from different strains including many hatchery and Swedish strains. Approximately 160 recaptures were reported from waters outside Denmark, with the majority of these in Norwegian waters, followed by recaptures in Swedish waters. All recaptures near the Faroe Islands have been included in the NASTR database. Tags were also reported from West Greenland, but have not been included in the database owing to a lack of detail. A small number of tags were recovered in Irish coastal fisheries and south of Denmark, in German and Dutch coastal waters.

3.3 Iceland

External tagging of Icelandic salmon smolts with Floy and Carlin tags started at Kollafjörður Experimental Fish Farm in the early 1960s. Microtagging with coded wire tags (CWTs) started in 1974 and peaked in the mid-1990s when a number of commercial ranching operations were releasing CWT tagged salmon. From 1982 to 1995, > 3 million smolts were tagged with CWTs and released in Iceland. Annual releases of smolts with CWTs decreased considerably after those operations closed in the late 1990s and have averaged 150 000 smolts annually since 1997.Fifty-five salmon of Icelandic origin were caught in distant areas from 1967 to 1995 (Figure 3.4). Forty-four of these were tagged with CWTs and were found in systematic surveys in the marine fisheries. The remaining 11 salmon, mostly from the 1960s and 1970s, were carrying Carlin or Floy anchor tags. Out of the 55 salmon caught in distant areas, 26 were recaptured in the Faroese fishery and 24 in the Greenland fishery. In addition to the area and date of recapture, information was also included on the type of tag, year of release, sex, length, and weight when available. The exact location of recapture is not given for most of the Greenland recaptures (location of landing is specified); however, more precise location data are provided for the recoveries in the Faroese fishery.

Out of 2.2 million smolts tagged with CWTs and released in southern and western Iceland between 1987 and 1994, 14 were recovered in sampling programmes in the West Greenland fishery and 1 in the Faroes. Out of 0.8 million smolts released in northern and northeastern Iceland, 22 were recovered around the Faroe Islands and 4 in the West Greenland fishery. In total, 1.4 CWT tagged smolts per 100 000 released from Iceland have been caught in distant fisheries from 1982 to 1995.

Icelandic ranched salmon released from west coast ranching stations have been recaptured in western Norway (1), a Faroese lake (1), a Faroese ranching operation (1), the River Don in the UK (Scotland) (1), and off the east coast of England (1).

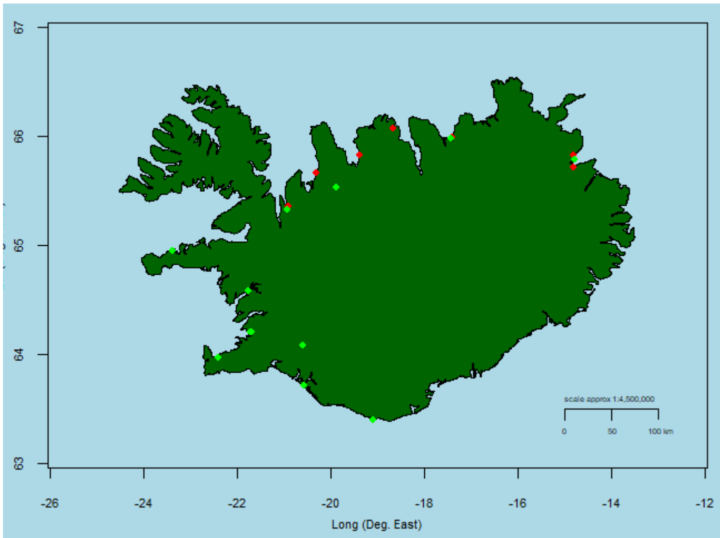


Figure 3.4. Icelandic tagging locations of salmon recovered around the Faroe Islands (●) and Greenland (●).

Recoveries in Icelandic home-water fisheries of five fish tagged in other countries comprised salmon tagged as smolts in the River Screebe, Ireland (1) and a Faroese ranching station (1), and adult salmon tagged in West Greenland (1), the Faroes (1) and a salmon possibly tagged in the Russian Federation (1).

In summer 1985, there was a joint Icelandic–Greenlandic fish-finding survey east of Greenland in two locations: Skjoldungen and Angmagsasalik. At Skjoldungen, 398 salmon were caught, including 5 without adipose fins. Of these, two were tagged with CWTs, one from Iceland and one from Ireland. At Angmagsasalik, three salmon were landed. Of these, one had been tagged in Ireland. A Norwegian-origin Carlin tag was also recovered by a local fisher in this area.

In 2010, the Icelandic Directorate of Fisheries (IDF) started a screening programme to investigate the incidence of salmon bycatch in mackerel (*Scomber scombrus*) and herring (*Clupea harengus*) fisheries. Four tagged salmon were caught in 2010, three from Norway and one from Ireland. In 2011, one Norwegian and one Irish tagged salmon were caught. In these two years, no Icelandic tags were recovered. For each tagged salmon, information was recorded on the date and place (coordinates) of capture, along with the length, weight, and sex of the fish. In 2011, additional samples were taken for sex and maturity determination, tissue for DNA analyses, and stomachs for diet examination; the head of the fish was also retained to permit CWT recovery.

3.4 Ireland

Salmon tagging has been reported in Ireland since the late 1800s. While initially restricted to hatchery kelts using external tags, more consistent and extensive tagging programmes commenced in 1948 (Went, 1964). Few external tags were recovered in waters outside Ireland and the UK from these programmes. The main tag recovery data derive from the National Coded Wire Tagging and Tag Recovery Programme, which was initiated in 1980 (Browne, 1982), and include tag recoveries from West Greenland and the Faroes (Figure 3.5).

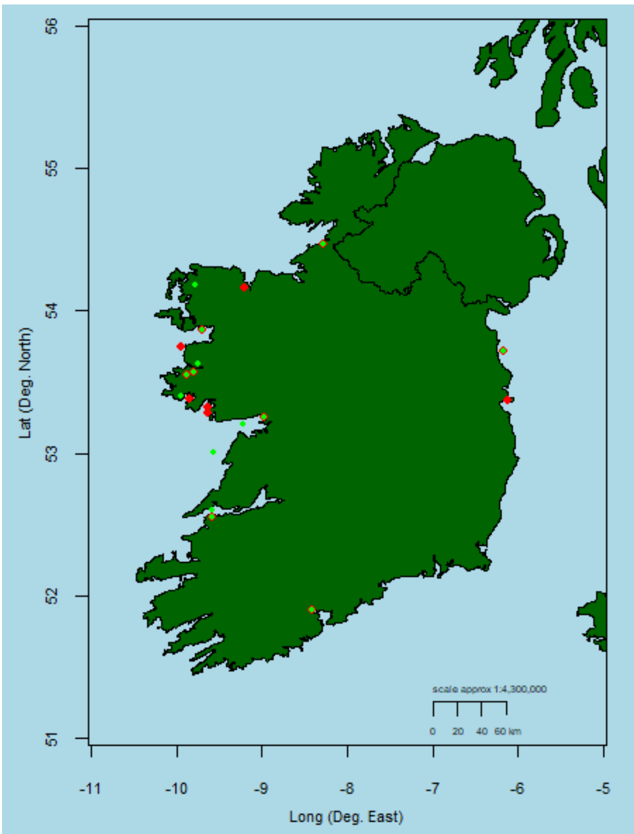


Figure 3.5. Ireland tagging locations of salmon recovered around the Faroe Islands (●) and Greenland (●).

The objectives of the national programme remain as originally proposed, i.e. to:

- estimate the fishing exploitation rate on local salmon stocks in the Irish fisheries and on Irish salmon stocks in high seas fisheries;
- investigate changes in marine and freshwater survival rates over time;
- provide information on coastal and oceanic migrations of Irish salmon stocks;
- investigate the potential for a sea ranching industry; and

- provide the basis for research on factors affecting salmon migration and survival using tagged experimental release groups of salmon.

Salmon smolts have been tagged and released annually from eight rivers in Ireland since 1984 (Browne *et al*. 1994; Ó Maoiléidigh *et al*., 1994a). Apart from 1991, when over 500 000 salmon smolts were released in an effort to increase tag recovery from the fisheries of Greenland and the Faroes, tag output was generally more than 150 000 salmon smolts annually until 2000 and between 250 000 and 300 000 thereafter. The hatchery fish are generally one year old on release. The total release of coded wire tagged salmon between 1980 and 2012 was over 8 million.

While the vast majority of tagged smolts were of hatchery origin, over 3000 wild smolts have also been tagged annually from one river on the west coast of Ireland, with more sporadic tagging on another two west coast rivers and one east coast river. The river age of tagged wild smolts has been predominantly two years old. The total number of wild fish tagged between 1980 and 2012 was close to 100 000. More than 177 000 tags from hatchery-reared fish and more than 3000 tags of wild fish were recovered between 1980 and 2012, with the vast majority of these recovered in Irish rivers and home waters as part of a systematic home-water catch-scanning programme. Since 2007, the coastal mixed-stock driftnet fishery and some inshore draft (local specialized seine nets) fisheries have been closed for conservation reasons, resulting in a significant decline in tag recoveries in fisheries, but an increase in the recovery of tags in hatchery broodstocks. Although low in number, there have also been consistent recoveries in Greenland (ca. 140 tags) and the Faroes (ca. 158 tags) during the time of the commercial distant-water fisheries and also in subsequent marine research fisheries in the Norwegian Sea, Icelandic waters, and East Greenland. Details of all the recoveries of Irish-origin coded-wire tags have been placed in the NASTR database.

The majority of Faroes recaptures derive from 1SW fish which were <60 cm in length (normally discarded), although some MSW salmon (35) have also been taken (Browne *et al*., 1994; Jacobsen *et al.*, 2012). In the early 1990s, investigations (Browne *et al*., 1994; Ó Maoiléidigh *et al*., 1994b) of exploitation rates of Irish stocks suggested that while exploitation of 1SW stocks was low at the Faroes, ca. 18% of an Irish-tagged hatchery stock was taken as 1SW salmon in the West Greenland fishery. These fish would have been destined to return as 2SW fish to Ireland.

The vast majority of tagged post-smolt salmon captured in experimental post-smolt salmon trawling operations in the Norwegian Sea since the early 1990s, (Holm *et al.*, 2003) and more recently during the SALSEA Merge project (Anon., 2011), were derived from the CWT marking programme in Ireland. These provide valuable information on the distribution and timing of the migration of salmon from NASCO's southern North East Atlantic Commission (NEAC) area. In addition, owing to the nature of the coastal net fishery, significant recoveries of tagged salmon originating in other countries were made while this fishery operated until 2006 (Table 3.1). With the closure of the coastal mixed-stock driftnet fishery, there have been no further recoveries of foreign tags in the tag recovery programmes in Ireland. Note that tag recoveries by the Irish coastal fishery have not been incorporated in the NASTR database.

Table 3.1. Recaptures of salmon in Irish marine salmon fisheries that were tagged in other countries.

Fishing year	UK (NI)	UK (EW)	UK (Sc)	France	Spain	Norway	Denmark	Germany	Faroe Is
1985		7	129						
1986		22	114						
1987	143	66	65						
1988	122	128	78						
1989	101	68	17	6					
1990	33	111	81	2					
1991	221	57	57						1
1992	429	107	5	5					
1993	172	101	2	1	8	1			
1994	86	80	3		4	1			
1995	51	147	4	62	3		23		
1996	98	77	10	1	3		1		
1997	168	44			2				
1998	51	34	7		16		14		
1999	46	118		2	7		35	1	
2000	153	113	2	1	17			1	
2001	198	54			8				
2002	86	41	2		6		1	1	
2003	58	27			17			1	
2004	32	8	2		2		2		
2005	28	10			7		1	5	
2006									
Total	2276	1420	578	80	100	2	77	9	1

3.5 Norway

In Norway, there has been systematic tagging of Atlantic salmon since 1935, and numerous experiments have been carried out to investigate life history, behaviour, and exploitation. Salmon have been tagged and released at different life stages, mainly using external tags. Both wild and hatchery-reared smolts have been tagged and subsequently released in a number of rivers and fjords and in some fjord areas, with 1760 caught in the Faroese fishery and 148 caught in the Greenland fishery between 1968 and 2009 (Figure 3.6). Furthermore, salmon have been caught with longlines in the Norwegian Sea, tagged, and released back into the sea, with many recaptured later. These results are detailed in Section 7.4. Similarly, a large number of adult salmon have been captured in Norwegian coastal bag nets, tagged, and released.

From April to June in the period 1969–1972, 4225 salmon were caught with longlines in the Norwegian Sea, tagged, and released; the position of capture (latitude and longitude) was recorded. A total of 520 of these tagged salmon were recaptured. These recapture sites have been made available for the NASTR database at three levels of geographical precision, defined as high, medium, or low. High-precision data are those with exact information on both tagging and recapture sites (latitude and longitude are known). Medium-precision data are those where recapture sites can be related to a specific geographical site (e.g. 50 nautical miles northwest of Andenes). In such cases, the longitude and latitude can be estimated. Finally, low-precision data are those where the recapture site is related to a large but defined geographical area (e.g. north of the Faroes, or northern Norwegian Sea). Data on dates of release and recapture and size of the fish at release and recapture have also been provided when available.

Similarly, information from the last 35 years has been digitized in spreadsheets and databases, representing the recapture details of ca. 2.5 million smolts that have been tagged and released. These data have been made available for the NASTR database.

Salmon tagged in Norway and recaptured in other oceanic areas, particularly in West Greenland and Ireland, were also made available. These are significant, owing to their number and recapture locations, indicating feeding grounds and migratory ranges of northern European-origin salmon. While relatively few of these recapture data include latitude and longitude, they can be linked to a specific site or area. The numbers of recaptures in areas outside Norway, including those from coastal areas and freshwater in Sweden, Denmark, the Russian Federation, and the UK are show in Figure 3.7.

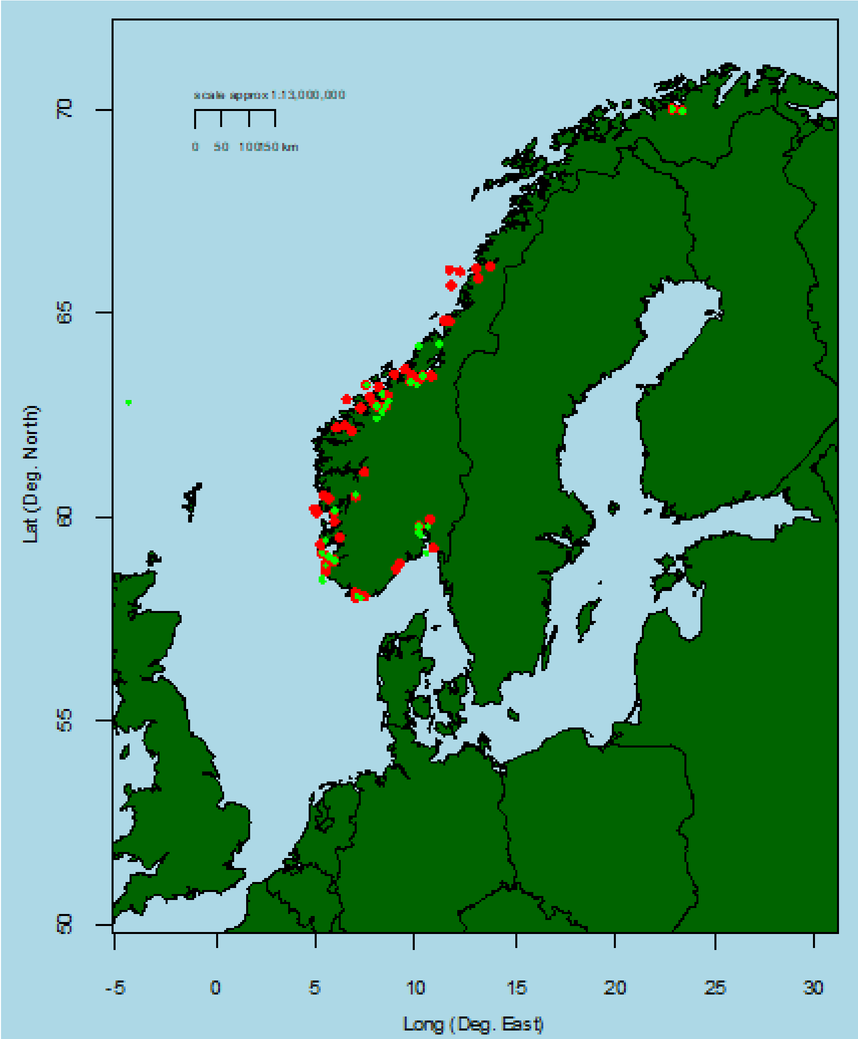


Figure 3.6. Norwegian tagging locations of salmon recovered around the Faroe Islands (●) and Greenland (●).

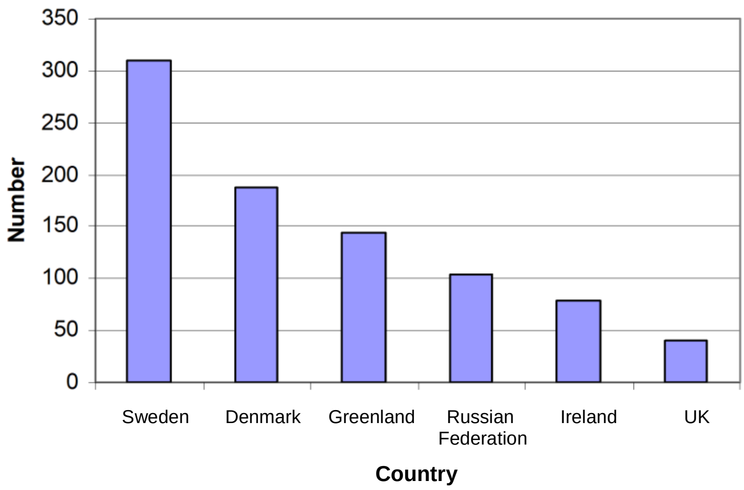


Figure 3.7. Number of Norwegian-origin salmon tags recovered in countries outside Norway.

3.6 Russian Federation

Between 1969 and 1974, 13 606 smolts from various rivers and hatcheries of the former USSR were tagged with external tags. By early 1975, 120 salmon had been recaptured (Bakshtansky and Yakovenko, 1976), including 12 tags returned from abroad. Seven tagged salmon were caught in the Norwegian Sea and five other salmon were also caught in the territorial waters of Norway, closer to shore.

The first adult Atlantic salmon tagging experiments conducted in the coastal zone of Norway (near Breivik, Finnmark) showed that Atlantic salmon from Russian rivers made their feeding migrations in the Norwegian Sea and returned to their native rivers through Norwegian coastal waters (Bakshtansky, 1970). The first salmon with a Norwegian tag caught in the USSR was in the Vyg River, White Sea Basin in 1935 (Berg, 1948). This salmon had been tagged in nearby Trondheim. In 1936, 18 salmon tagged in Norwegian coastal waters were caught (Danilchenko, 1938) in different rivers and coastal areas of the USSR.

Bakshtansky and Nesterov (1973), in their work on the impact of foreign fisheries on Atlantic salmon from Russian rivers, presented some data on tagged Atlantic salmon recaptured in Russian home waters. Over a period of 11 years (1962–1972), 240 tagged salmon were recaptured. Information on location and date of tagging was available for only 38 of those fish. Most of them were tagged near Breivik, Finnmark and recaptured between 9 and 97 days after tagging (mean = 59). Two fish were recaptured in the Pechora River more than one year after tagging, suggesting that some salmon from Russian rivers may have been on their outward migration to feeding areas, while others were on their homeward spawning migration (Bakshtansky and Nesterov, 1973).

Antonova and Chuksina (1987), with reference to the report by the Direktoratet for Jakt, Viltstell og Ferskvannsfiske (Anon., 1974), analysed data on the recapture rate of Pechora salmon tagged among other Atlantic salmon in different areas of the Norwegian Sea between 1962 and 1973. In that period, 5228 salmon, taken from bendnet and bagnet catches near Breivik, Finnmark and from catches by driftnets at Sørøy, Norwegian Sea, were tagged. Of these, 162 salmon were recaptured in Russian home waters, including 14 fish caught in the Pechora River. Also, between 1968 and 1972, 4899 salmon from longline catches were tagged in different areas of the Norwegian Sea. Of these, 71 were recaptured in Russian home waters, including 25 fish in the Pechora River (Antonova and Chuksina, 1987).

According to Bakshtansky and Yakovenko (1976), 1923 kelts were tagged with external tags in the Varzuga River from 1968 to 1971, with 72 fish subsequently recaptured. Of these, 37 were repeat spawners recaptured in the Varzuga River and 35 were caught in different saltwater areas, including two in the Norwegian Sea. One of these (tagged in 1969) was caught by a Danish fishing vessel northeast of Vesteraalen on 18 February 1970. The other (tagged in 1971) was caught by a Norwegian fishing vessel near Nordkapp on 15 June 1972 (Bakshtansky and Yakovenko, 1976).

There are no reports in the NASTR database of salmon tagged in the Russian Federation and recovered in the Faroese or Greenland fisheries.

3.7 UK (England and Wales)

Salmon tagging programmes in the UK (England and Wales) have been carried out since the late 1950s. Most of the tagging focused on juveniles (mainly smolts, but also some parr), and both wild and hatchery-reared fish have been tagged. Small numbers of fish have also been tagged as adults and as kelts. The UK (England and Wales) also holds certain international tagging and tag recovery data derived from previous international collaborative programmes.

In earlier years (1958–1984), juvenile salmon from a variety of catchments were tagged with external tags (Carlin tags and predecessors). In total, around 250 000 fish were tagged over this period. Wild smolts were tagged in 11 catchments, although some of these programmes were only carried out for 1 year, caught few fish, and resulted in no recaptures outside home waters. Hatchery parr/smolts were tagged and released in ten catchments.

The NASTR database holds records of 52 fish tagged in the UK and caught in the Faroese fishery and 393 caught in the Greenland fishery between 1961 and 2009 (Figure 3.8). Details of each tag recovery have been extracted from paper records and are now held in the NASTR database. Information on release location is available for all recoveries, and origin of the fish (wild or hatchery) is available for many fish. For most entries, the date of tagging is also available, although in some cases this is only reported as month, season, and/or year. For the high seas recoveries (West Greenland and Faroes), the precision of the recapture information varies considerably. Of the 308 fish recovered from West Greenland, precise position (latitude and longitude) is only available for 68 fish (22%). For other West Greenland recoveries, the recapture position is either reported as a specific place (in many cases the port of landing) or simply as West Greenland. All the tags recovered in the Faroes fishery over the period are simply reported as Faroes area. The information for Greenland and the Faroes is available in the NASTR database. Recoveries in other countries are usually given for a particular fishery area or port. For all fisheries, there is considerable variation in the precision with which date of recovery is reported (day, month, season, or year). A range of other information may also be associated with recovered tags, e.g. fish length and weight.

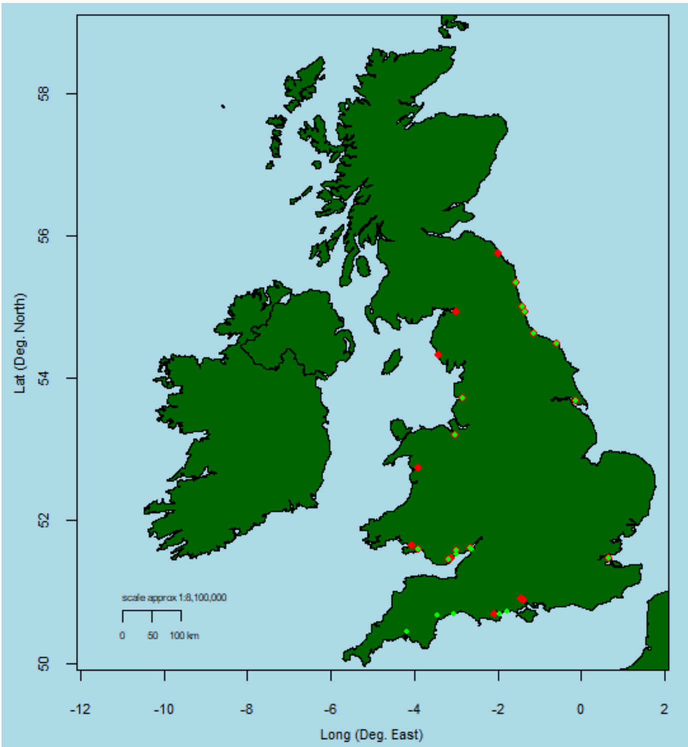


Figure 3.8. UK (England and Wales) tagging locations of salmon recovered around the Faroe Islands (●) and Greenland (●).

There has been limited tagging of adult fish and kelts in the UK (England and Wales) and some studies have focused on relatively local issues (e.g. adult fish tagged in the English northeast coast fishery and recovered in the northeast of England and eastern Scotland). These latter data have not been included in this report or in the NASTR database. However, 979 kelts were tagged on the River Axe in Devon between 1960 and

1965, resulting in 8 recaptures in the West Greenland fishery. Tagging and recapture information is as for the externally tagged smolts. Precise recovery locations (latitude and longitude) are available for two of these fish.

Coded wire microtagging programmes started in the UK (England and Wales) in 1983 and continue to the present time. To date, > 3.3 million hatchery fish and ca. 200 000 wild smolts have been tagged. Fish have been released into 40 different catchments. Recoveries of CWTs require targeted screening programmes, and these have operated in the high seas fisheries at the Faroes and Greenland for many years, in the net and angling fisheries and broodstock collections in Ireland, the net fisheries in the UK (Northern Ireland), and in the net fisheries along part of the east coast of the UK (Scotland). Information on recoveries in Greenland and the Faroes is included in the NASTR database.

3.8 UK (Northern Ireland)

A CWT programme was initiated in the UK (Northern Ireland) in 1983. The tagging has focused on juveniles (mainly smolts) and both wild and hatchery-reared fish have been tagged. Distinct age groups of hatchery smolts (1+ and 2+) have been tagged annually. Around 900 000 salmon smolts have been tagged through the tagging programme conducted on the River Bush on the north coast of County Antrim.

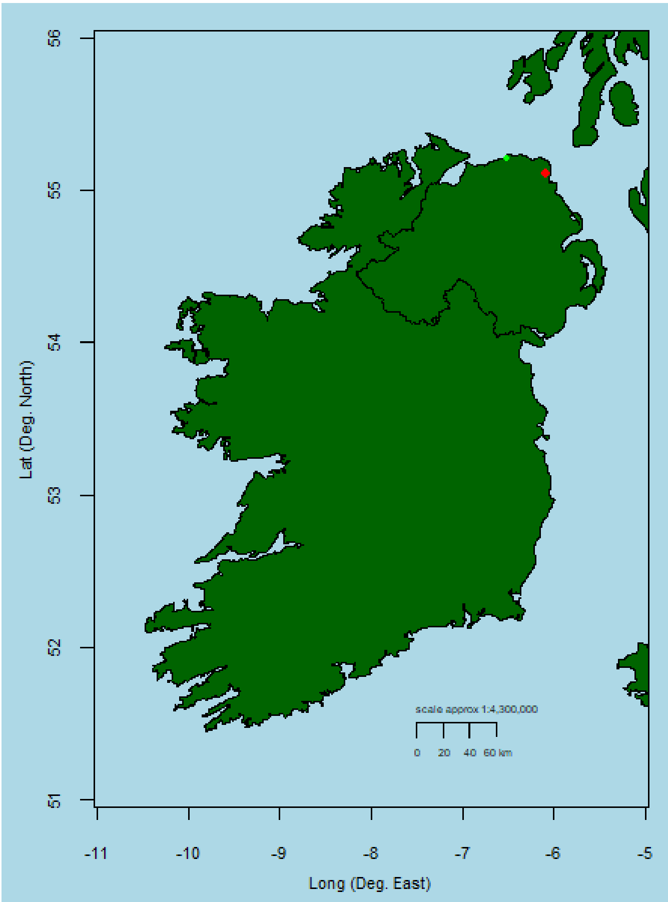


Figure 3.9. UK (Northern Ireland) tagging locations of salmon recovered around the Faroe Islands (●) and Greenland (●).

A CWT screening programme was operated around the coastal fisheries in the UK (Northern Ireland) whenever the commercial net fishery was operational. Details of each tag recovery have been digitized and held in spreadsheet form. The vast bulk of the recoveries were associated with local coastal fisheries and river returns. Relatively few fish tagged in the UK (Northern Ireland) were detected in either the Greenland (three) or Faroese (eight) fisheries (Figure 3.9), but recovery information for these tagged fish is included in the NASTR database.

3.9 UK (Scotland)

Tagging programmes in the UK (Scotland) have primarily focused on juvenile salmon (parr and emigrating smolts) from three areas: the North Esk, the Tay system, and the River Dee (specifically the Girnock and Baddoch tributaries). Information on release date and location, origin of the fish (wild or hatchery), and fork length are generally available from these studies as are, for a subsample of tagged fish, weight and river age from scale samples. Where available, these data have been collated with tag returns.

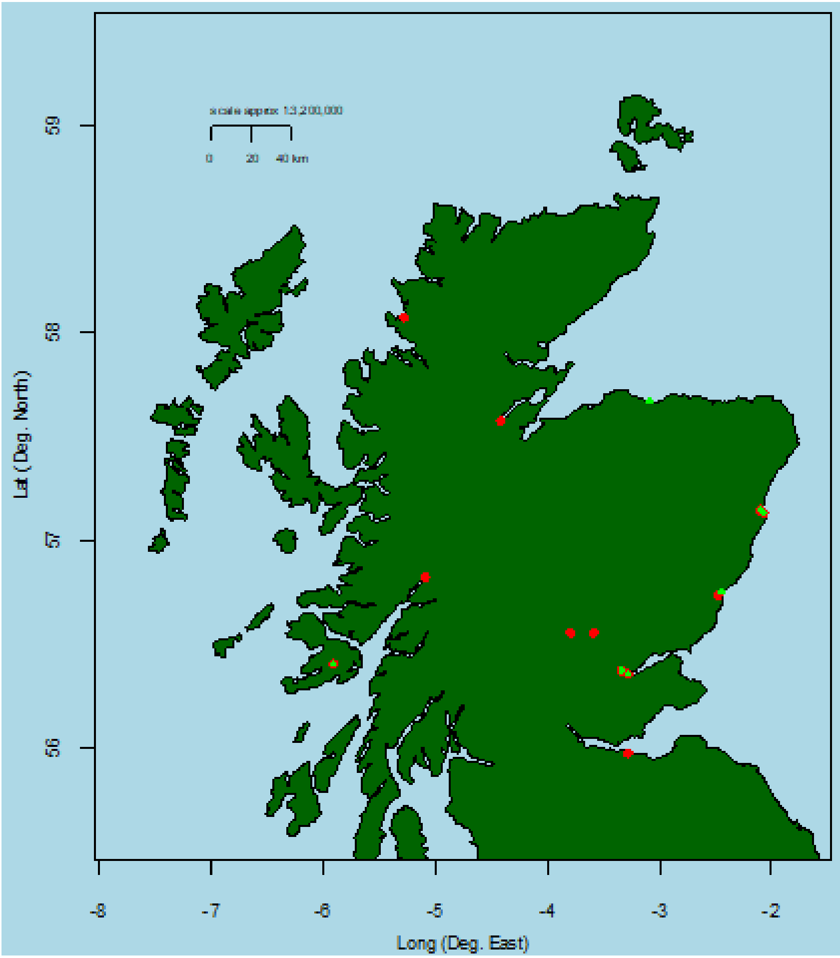


Figure 3.10. UK (Scotland) tagging locations of salmon recovered around the Faroe Islands (●) and Greenland (●).

A range of information may be associated with each recovered tag, including when and where recovered, fish length, and weight. As noted in previous sections, there is considerable variation in the precision with which date recovered (either day, month, season, year, or even decade) and location (country, NAFO division caught, grid reference caught, port landed, location where tag was recovered during fish processing) are recorded.

Tagging and recovery data for 135 external and CWT tagged salmon of Scottish origin, recovered between 1967 and 1993, are detailed in the NASTR database. Data are also available for recoveries of 77 Scottish tagged salmon in the Greenland fishery from 1980 to the present. A small number of records from earlier years are included where these were reported (Figure 3.10). Approximately 580 Scottish CWTs have also been recovered in the Irish coastal net fishery, mainly between 1985 and 1991 but these are not incorporated into the NASTR database. Relatively few were recaptured after this period as the CWT programme was considerably reduced. Since 2006, when the Irish mixed-stock coastal driftnet fishery was closed, there have been no recoveries of Scottish tagged fish. Details of release location and date, landing location, length, and date of capture are generally available.

3.10 USA

A detailed discussion and summary of the historical US Atlantic salmon tagging programmes (Carlin and CWT tag releases and recaptures) has been provided by Miller *et al.* (2012a, b).

3.10.1 Carlin tags

Over 1.5 million Carlin-tagged fish were released between 1962 and 1996. There are ca. 4000 records of high seas recaptures and 4500 home-water recaptures. Home-water recaptures were not considered further within the framework of this report. Less than one-third of the high seas recapture data have reliable latitude and longitude coordinates associated with them. The records without reliable recapture location have a community name, community code, NAFO Division, state/province, or country associated with each recapture. A standardized set of locations was developed so that all tag recaptures could be associated with a general recovery location according to the level of information available. The majority of the releases were of 1+ hatchery-reared smolts (64%) and 35% were of 2+ hatchery-reared smolts. Approximately 50% of the high seas recoveries came from Greenland, while eastern Canada (Maritimes, Quebec, Newfoundland, and Labrador) accounts for the majority of the rest. The Faroese and Saint Pierre et Miquelon fisheries each produced a single tag recovery, and a small number were returned from US territorial waters. Most of the recaptures came from Penobscot River releases (85%), with a few other river releases dispersed through the dataset. All Greenland recaptures were included within the NASTR database.

3.10.2 Coded wire tags (CWT)

A total of 6.4 million CWT tagged fish were released between 1982 and 1994. There are 420 records of high seas recaptures. None of the high seas recaptures have latitude and longitude coordinates associated with them, but they all have either a community name or a community code. A standardized location was assigned to each recapture as detailed above.

Overall, 92% of the releases were of hatchery-reared smolts, of which the majority (75%) were 1+ smolts. Over 77% of the recaptures came from Greenland, with the remainder coming from Canada (Newfoundland/Labrador). The largest number of tagged fish releases came from the Connecticut River; however, distant-water recoveries were dominated by fish originating in the Penobscot River (71%). Similar to the Carlin recoveries, the percentage of Penobscot River recoveries increased as fish progressed along their migration towards Greenland. Tagging locations of fish tagged in the US and recovered in the Faroes and Greenland fisheries are shown in Figure 3.11.

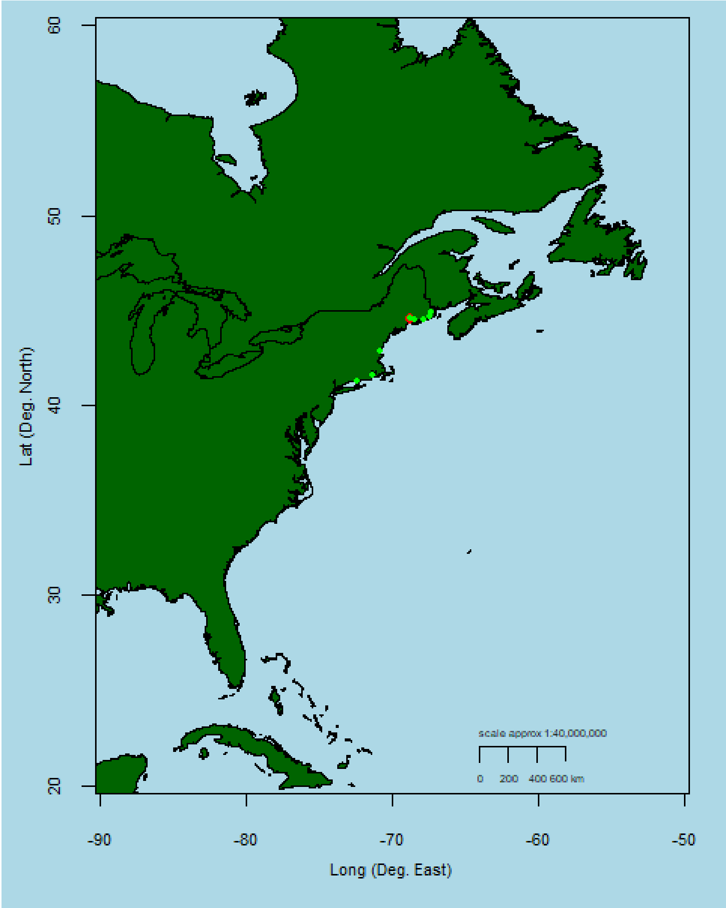


Figure 3.11. USA tagging locations of salmon recovered around the Faroe Islands (●) and Greenland (●).

3.10.3 Visible implant Elastomer (VIE) tags

A total of 1.5 million VIE tagged fish have been released since 2000. There have been only 11 recoveries recorded to date. None of the high seas recapture data have latitude and longitude coordinates associated with them but they all have an associated community name which has been assigned a standardized location as detailed above.

All of the releases were of 1+ hatchery-reared smolts, and the majority of them (75%) were in the Penobscot River. All of the recaptures came from Greenland, having been released from either the Penobscot or Dennys rivers.

3.11 Faroes

Two adult tagging programmes have been undertaken in the Faroese area in addition to limited tagging in Faroese rivers. Exact tagging and recapture positions along with other relevant information are available for the most recent tagging programme undertaken from 1992 to 1995. The recapture by country from this experiment is shown in Figure 5.4, adjusted for home-water exploitation rates and tag reporting rates.

3.12 Greenland

An international ICES/ICNAF (International Commission for the Northwest Atlantic Fisheries) adult salmon tagging programme was undertaken in the West Greenland fishery between 1965 and 1972. In total, 4632 adult fish were tagged, just over 50% of these in 1972. Jensen (1980b) provides a summary of the recovery data. Detailed tagging and recapture information for 1972 is held by the UK (England and Wales) and has been entered into spreadsheet form; it is unclear whether detailed recapture information is available for the earlier years (1965–1971). These data include place of tagging, with a high level of precision (tagging carried out by research vessels), with 236 entries in the NASTR database. The precision of the recapture information is more variable. The majority of tag recoveries occurred within the West Greenland fishery (164) and just over half of these have position (latitude and longitude) recorded. Most of the others have either a place of recapture or port of landing given, although some are only reported as West Greenland. There are also 52 recoveries in home-water fisheries; for these, their home-water recovery locations are given as place of recapture, but they do not have associated latitude and longitude coordinates.

4 Tag recovery databases

4.1 Structure and format of the NASTR database

The tag-recovery databases comprise four Excel workbooks relating to Greenland salmon tag recoveries, Faroes salmon tag recoveries, Faroes tagged adult tag recoveries and Norwegian tagged adult tag recoveries which provide details of the recaptures of individual tagged salmon around the coast of Greenland and within the Faroes EEZ, and adult salmon captured, tagged, and released around the Faroe Islands, respectively. Also included in these data files are details of tag recoveries in home waters from the adult tagging experiments in Greenland and the Faroes. Each entry includes three groups of information related to: (i) the tag, (ii) the tagging and release (Tagging) event, and (iii) the recovery (Reporting) event. Annex 4 lists the individuals who participated in the collection and collation of tag recoveries.

The databases were largely compiled during two ICES workshops (WKDUHSTI; ICES, 2007 and WKSHINI; ICES, 2008a) by representatives from various countries. Further tag records were incorporated during subsequent workshops (WKLUSTRE; ICES, 2009 and WKSTAR; ICES, 2012), with some extra validation during the intervening periods.

Table 4.1 lists the fields included in the database and their descriptors. For Tagging, information is categorized into when (to refer to date), where (to refer to location), and what (to indicate the life stage, size (weight and or length), origin (wild or hatchery), and river age. Likewise, Reporting also details when (the date of recovery), where (the catch location), and what (details of the fish when caught, including size (weight and/or length) life stage, river and sea ages, sex, catch method, and if scales were collected).

For both sets of information (Tagging and Reporting), clear descriptions have been provided. Formats were standardized, and predefined entries were set where possible to limit variations between entries (Table 4.1). Weight and length measurements were set to metric units (g and cm, respectively), all dates were modified to dd/mm/yyyy format, and latitude and longitude were converted to decimal degrees, with west indicated by negative values. Drop-down lists were provided, giving standardized options for tag type, life-history stage, sex, recovery operation, how reported, and whether a scale sample was taken, and location-related entries were standardized to the greatest extent possible.

In most instances, not all details are available. Omissions in entries include release dates, districts, length and weights, hatchery or wild origin, river and sea ages, and sex. Incomplete records have been maintained in the database provided that the information includes release and recovery locations and years. Recovery data are grouped by tagging and release country/district/programme as appropriate, comprising 13 worksheets, as detailed in Section 6.

Table 4.1. The agreed data fields for recording tag recoveries from the oceanic areas frequented by salmon.

	Attribute table fields		Description	Format						
Tag information	Tag details	Tag #	Number/code physically associated with the tag	alphanumeric						
		Trace var	Information which, together with tag #, uniquely identifies individual tag	free format						
		Tag type	Description of type of tag applied	dropdown list:	CWT	Carlin	T-Bar	Lea	PIT	Other
		Taggingagency	Agency responsible for holding data	free format						
Tagging:	When	Day		dd						
		Month		mm						
Details of tagging occurrence		Year		yyyy						
	Where	Description	General description of tag site	free format or custom codes						
		Country	3 fields which allow the recovery site to be filtered to 3 levels of precision from the widest geographic range (country) to the narrowest (location)	free format						
		District		free format						
		Location		free format						
		NAFO	NAFO division code							
		ICES	ICES area code							
		ICES square	ICES statistical rectangle code							
		Lat	Latitude	decimal						
		Long	Longitude, west indicated by -ve values	decimal						
	What	Fork length (cm)		length in cm						
		Weight (g)		weight in						
		Wild/hatchery etc		drop down list:	Wild	Hatchery	Mixed	Unknown		
		Life-history stage		drop down list:	Parr	Smolt	Post-smolt	Adult	Kelt	Other
		River age	River age of fish in years							
Reporting:	When	Day		dd						
		Month		mm						
Details of tag		Year		yyyy						
	Where	Description	Comments field: general description of recovery site	free format						

	Attribute table fields		Description	Format						
recovery occurrence		Country	3 fields which allow the recovery site to be filtered to 3 levels of precision from the widest geographic range (country) to the narrowest (location)	free format						
		District		free format						
		Location		free format						
		NAFO	NAFO division code							
		ICES area	ICES area code							
		ICES square	ICES statistical rectangle code							
		Lat	Latitude	decimal						
		Long	Longitude, west indicated by -ve values	decimal						
	What	Fork length (cm)		length in cm						
		Round weight (kg)		weight in kg						
		Gutted weight (kg)		weight in kg						
		Life-history stage		drop down list:	Parr	Smolt	Post-smolt	Adult	Kelt	Other
		River age	River age of fish in years	free format						
		Sea age	Sea age of fish in years	free format						
		Sex		drop down list:	Male	Female	Unknown			
		Recovery operation	Code to indicate tag recovery process	drop down list:	Fishing	Landing	Processing	Tag found	Unknown	
		How reported	Was report part of a directed screening programme?	drop down list:	Report	Screen	Unknown			
		Gear type	Type of catch method	free format						
		Scale sample	Are scale samples available?	drop down list:	Yes	No				
		General comments	Comments field which allows any other useful comments	free format						

4.2 Permissions and restrictions on data use

The NASTR database is held at ICES Data Centre and documented throughout this report. The data will be accessible on ICES website (http://ices.dk/marine-data/) subsequent to this report being published.

Annex 5 lists the national tag clearing houses to which Atlantic salmon tags should be returned.

Access to the database will be restricted to the agencies and institutes that contributed the original data for three years from the date of publication of this report. After that time, the data will be freely available to all legitimate researchers, although the following acknowledgement should be included in any papers or reports:

We are grateful to all data providers for access to the tag recovery data used in this paper/report. These data are available through ICES Data Centre: www.ices.dk/marine-data.

There are several issues that need to be taken into account when using these data:

- The distribution of tag returns depends on the distribution of fishing effort, both temporally and spatially. Catch-per-unit-effort (CPUE) data from the Faroese longline fishery are available at the Faroe Marine Research Institute (formerly the Faroese Fisheries Laboratory) for the period since the late 1970s. The CPUE data are required to separate potential changes in the distribution of tag-recapture rates in various areas from changes in the fishery. Only very limited effort data are available for the West Greenland fishery. Alternative approaches may be used to take account of this in any analysis, such as considering proportions of tag recoveries.
- The Faroese and West Greenland fisheries have been subject to various management measures over the period, e.g. shortening of the fishing season and introduction of quotas and quota buyouts.
- The tag recaptures have not been adjusted by the number of fish released as this information was not available for all countries and years for the workshops and was not adjusted for the relative production of salmon in each country. Thus, for countries which tag only a small proportion of their production, the number of tags in the database may be very low, but could represent a large contribution of salmon from that population to the fishery. Data on the actual numbers of tags that were released from respective areas have been collated by ICES since 1985, and some earlier data on numbers of fish tagged by countries were included in the reports of ICES Working Group on North Atlantic Salmon prior to the closure of the Faroese fishery. Further information may be available from the national laboratories/agencies responsible for the tagging efforts.

5 Faroes tag-recovery database

5.1 Scanning programmes for tags at the Faroes

The Faroese salmon longline fishery commenced in the late 1960s and is described by Jacobsen *et al*., (2012). Initially, the fishery was close to the coastlines around the islands, with annual catches of less than 50 t comprising mainly (60–90%) 1SW salmon. In 1979, however, two years after the establishment of the 200 nautical mile Exclusive Economic Zone (EEZ) around the Faroes, the fishery increased substantially and extended northward, with almost no fishing south of the islands. Catches peaked in 1981 (1025 t) with significantly larger proportions of 2SW salmon (80%) in the catches (Jákupsstovu, 1988). Since the formation of NASCO in 1984, the fishery has been subject to internationally agreed quotas. The catches in the fishery fell from 630 t in 1984 to ca. 300 t in 1990. Since 1991, there has been no commercial fishing at the Faroes, but a research fishery was conducted in some years during the 1990s (Jacobsen, 2000). This small research fishery discontinued in 2000. The fishing season was November–April and was divided by a break at Christmas into autumn (November–December) and winter (January–April) seasons.

The tagging data in the Faroese Marine Research Institute repository is mainly recovery information of salmon tagged in rivers or in coastal areas in home waters of other countries. These fish have been identified in scientific catch-scanning programmes in the Faroese EEZ, and the principal gear type was floating baited longlines around and north of the Faroes. Data have, in most cases, been reported back to the tag clearing houses in the various countries of origin. Consequently, most of the data should be in duplicate form, one in the Faroes and the other in the country of origin (or at the tag clearing house). Prior to 1985, tag recaptures were also recorded from the areas north of the present 200-nautical-mile fishery limit, (from the areas north to Jan Mayen Island).

Many of the recaptures have latitude and longitude coordinates associated with them (Figure 5.1). Detailed information on each year's screening programme has been provided in annual ICES reports of the Working Group on North Atlantic Salmon.

5.1.1 Carlin tags

A large number of salmon carrying Carlin tags were recaptured in the salmon longline fishery at the Faroes during 1965–1995. A total of 2696 tagged salmon originating in 12 countries, were recaptured (Table 5.1). These data are in the NASTR database, providing release and recapture information as available.

5.1.2 Coded wire tags (CWTs)

Ireland has been the designated tag clearing house for CWTs recovered in the Faroese longline fishery and research fishery (Annex 5). All CWT data have been verified with the national tagging agencies, and the data are in duplicate form, held by Ireland and the Faroes, with country-specific information with the tagging agency of origin. This provides information for ca. 380 CWTs (Figure 5.2). These data are also in the NASTR database, detailing release and recapture information as available.

Figure 5.1. Geographical distribution and month of recapture of salmon tagged in Norway (●) and coded wire tag (CWT) recoveries for Ireland (●), in the Faroese commercial and research fishery scanning programme in the Norwegian Sea (1984–1996).

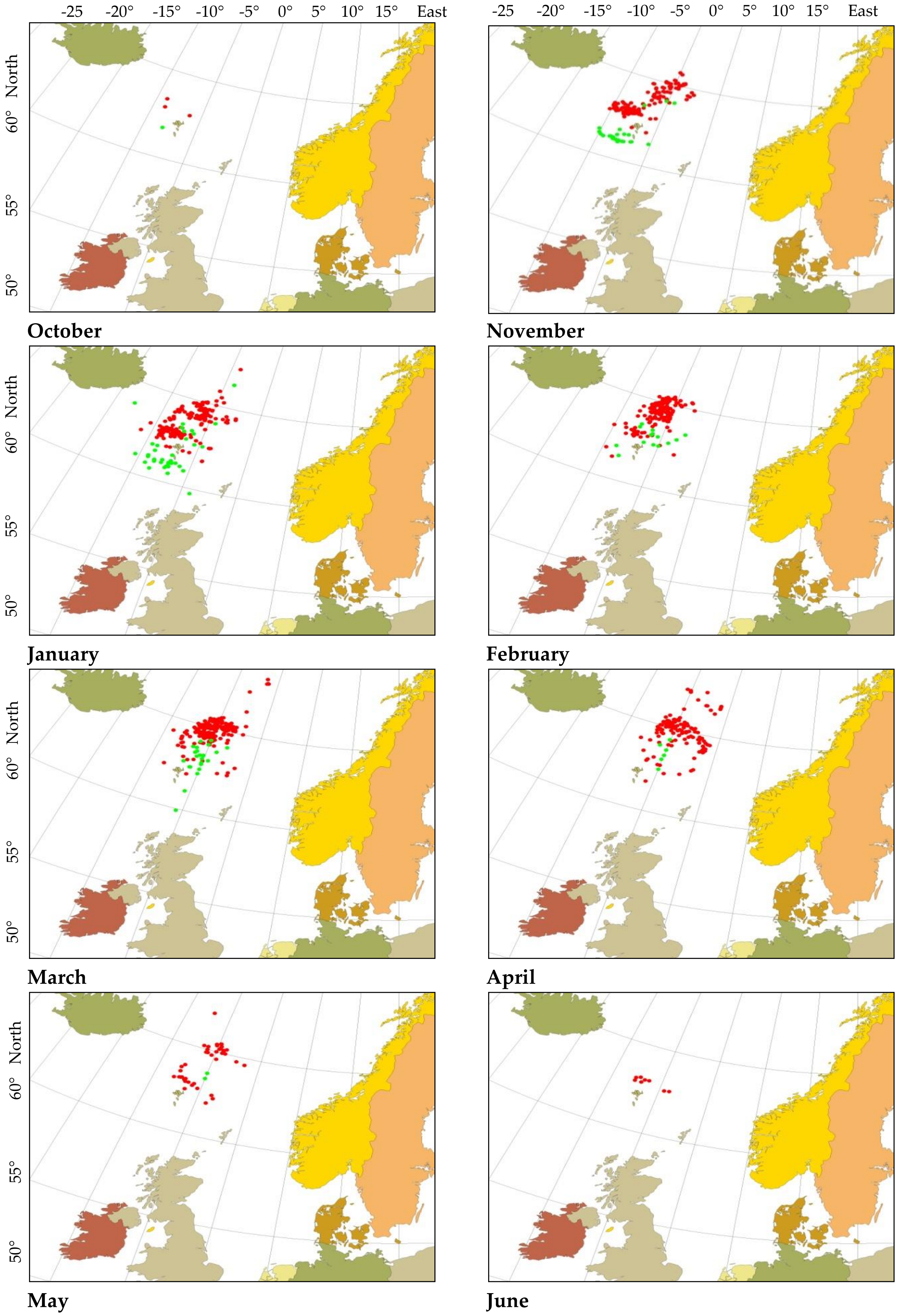


Figure 5.2. Geographical distribution and month of recapture of salmon tagged in Norway (●) and coded wire tag (CWT) recoveries for Ireland (●), in the Faroese commercial and research fishery scanning programme in the Norwegian Sea (1984–1996).

Table 5.1. Total number of external tags recaptured in the Faroes longline fishery, by country of origin, with indication of the accuracy of the recapture location. Recovery positions are detailed as Exact, with corresponding latitude and longitude, or regional as North of Faroes.

Country	Recovery position		Total
	Exact	North of Faroes	
Canada	3	-	3
Denmark	2	-	2
Faroe Is	175	5	180
France	2	-	2
Iceland	3	1	4
Ireland	1	1	2
Norway	1 267	739	2 006
Russian Federation	1	4	5
Sweden	228	168	396
UK (EW)	6	7	13
UK (Sc)	46	35	81
USA	1	-	1
Unknown	1	-	1
Total	1 736	960	2 696

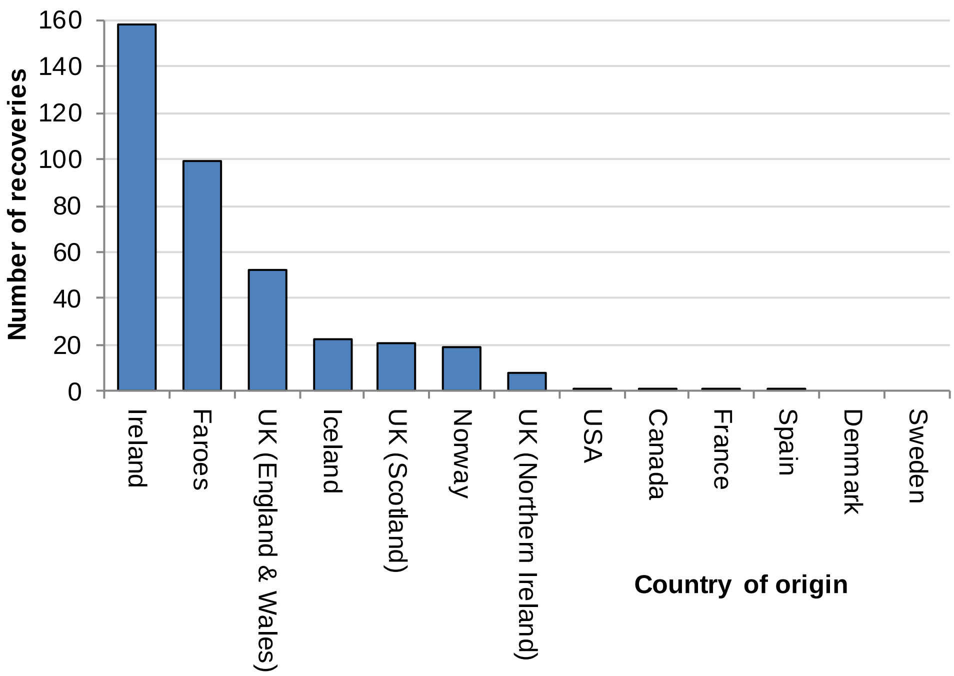


Figure 5.3. Coded wire tag recoveries in the Faroes longline fishery, 1984–1996.

5.2 Summary descriptions of tagging data

During the period 1968–2000, 2646 tags were recovered from the salmon fishery: 2258 individually numbered Carlin tags (Carlin, 1955), 383 batch-numbered CWTs, and 4 T-bar externals. These tags had been applied to salmon in 13 countries or jurisdictions (hereinafter countries): Canada, Denmark, Iceland, Ireland, Faroes, France, Norway, Spain, Sweden, the United States, and the UK (England and Wales, Northern Ireland, and Scotland). While information on tag recoveries is available for the Russian Federation, it was not sufficiently detailed for inclusion in the NASTR tag database.

The recovery data obtained from the fishery included tag number, recovery position, origin (country), date of tag recovery, and size of tagged salmon (Table 5.2). Of the 2646 tags, the tag-recovery location was known for 2551 salmon, while in other cases, location was coded to be inside the Faroese EEZ (north of the Faroes).

Sea ages of the salmon were calculated from the release dates to the dates of tag recovery. Salmon in their first winter at sea were termed 1SW salmon, irrespective of whether they were recovered before or after 1 January (i.e. November–December or January–May, respectively). The same rule was applied for 2SW and 3SW salmon, which were collectively termed MSW salmon. The implications of the sea-winter definition are that the sea age was considered to change by the end of October and not at the beginning of the year. Hence, salmon were assumed to have the same sea age throughout autumn and the following winter fishing seasons, i.e. from November in year i to October in year $i + 1$.

The Faroes tag database is compiled into one file comprising all of the tag recaptures from the various release countries and including the following (ordered by number recovered):

- **Norway:** 1760 tag recoveries derived from external tagging of smolts.
- **Sweden:** 376 tag recoveries derived from external tagging of smolts on the west coast of Sweden.
- **Ireland:** 158 tag recoveries derived from CWT tagging of smolts.
- **UK (Scotland):** 135 tag recoveries derived mainly from external tagging of smolts.
- **Faroes:** 99 tag recoveries derived from external tagging of salmon smolts released in the Faroes used in ocean ranching in the 1980s and early 1990s. The smolts were originally introduced from Norway (Sundalsøra, northwest Norway) for salmon farming.
- **UK (England and Wales):** 69 tag recoveries derived mainly from CWT tagging of smolts.
- **Iceland:** 27 tag recoveries derived mainly from CWT tagging of smolts.
- **UK (Northern Ireland):** Eight tag recoveries derived from CWT tagging of smolts on the River Bush.
- **Canada:** Six tag recoveries derived from five external and one CWT tagged smolts in Maritime Canada.
- **Denmark:** Four tag recoveries derived from Carlin-tagged smolts in west and north Jutland in the mid-1970s.
- **USA:** Two tag recoveries derived from one external and one CWT tagged smolts from the Penobscot River in 1987.
- **Spain:** One tag recovery derived from a CWT smolt tagged in the Eo River in 1993.
- **France:** One tag recovery derived from a CWT smolt tagged in a river in Brittany in 1990.

Table 5.2. Summary of the numbers of tagging entries by country in the Faroes tag-recovery database and a description of the information associated with the tag recoveries.

Tagging country	No. of recaptures	No. with known GIS position	Fork length	Round weight	Gutted weight	Origin			Sea age				Life stage when tagged				
						Unknown	Hatchery	Wild	Unknown	1SW	2SW	3SW	Unknown	Adult	Kelt	Parr	Smolt
USA	2	2	1	0	1	1	1	0	0	1	1	0	1	0	0	0	1
Canada	6	5	2	1	1	1	4	1	3	0	1	2	1	0	0	0	5
Denmark	4	1	4	1	0	0	4	0	0	2	1	1	0	0	0	0	4
Faroes	99	77	95	0	95	99	0	0	15	2	78	4	99	0	0	0	0
France	1	1	1	0	1	1	0	0	0	0	1	0	1	0	0	0	0
Iceland	27	22	25	0	24	22	5	0	0	5	20	2	22	0	0	0	5
Ireland	158	133	156	0	146	0	158	0	0	123	35	0	0	0	0	0	158
Norway	1 760	1 760	1 471	0	1 208	1 760	0	0	1	227	1 360	172	19	0	0	0	1 741
Spain	1	1	1	0	1	1	0	0	0	1	0	0	1	0	0	0	0
Sweden	376	370	53	45	189	0	376	0	3	73	258	42	0	0	0	0	376
UK (EW)	69	58	61	0	53	0	37	32	1	15	47	6	12	0	0	18	39
UK (NI)	8	8	8	0	8	7	1	0	0	5	2	1	7	0	0	0	1
UK (Sc)	135	113	33	0	62	14	9	112	18	25	73	19	15	2	2	0	116
Total	2 646	2 551	1 911	47	1 789	1 906	595	145	41	479	1 877	249	178	2	2	18	2 446

In addition to this report, the information contained in the Faroes recovery database was examined to describe the distribution of salmon of different origins and sea ages in the sea around the Faroe Islands for the ICES/NASCO Salmon Symposium held in La Rochelle, France in October 2011, and a range of analyses have subsequently been published (Jacobsen *et al*., 2012).

Tag recapture per country per year (Figure 5.3) demonstrated that the largest tag recoveries occurred for fish originating from Norway, Sweden, the UK (Scotland), and Ireland, with smaller numbers of recoveries of fish tagged in the UK (England and Wales), the Faroes, Iceland, Denmark, and Canada. Differences in annual recaptures were evident and linked in some years to the number of fish actually tagged in these countries. Tagging in the UK (Scotland) was much reduced, particularly after 1985. Similar reductions in the number of fish being tagged occurred in other countries over the years. Tagging programmes in Ireland and the UK (England and Wales) and the UK (Northern Ireland) remained relatively consistent for most of the period. Salmon tagged in USA, France, and Spain were also caught off the Faroes during the time-series. Most catches were recorded during the 1980s, peaking in 1983 at 454 tagged fish around the time when catches in the Faroes fishery peaked. Of the 2646 records, 56% were recovered between 1981 and 1986, 81% between 1981 and 1990, and 95% between 1978 and 1994.

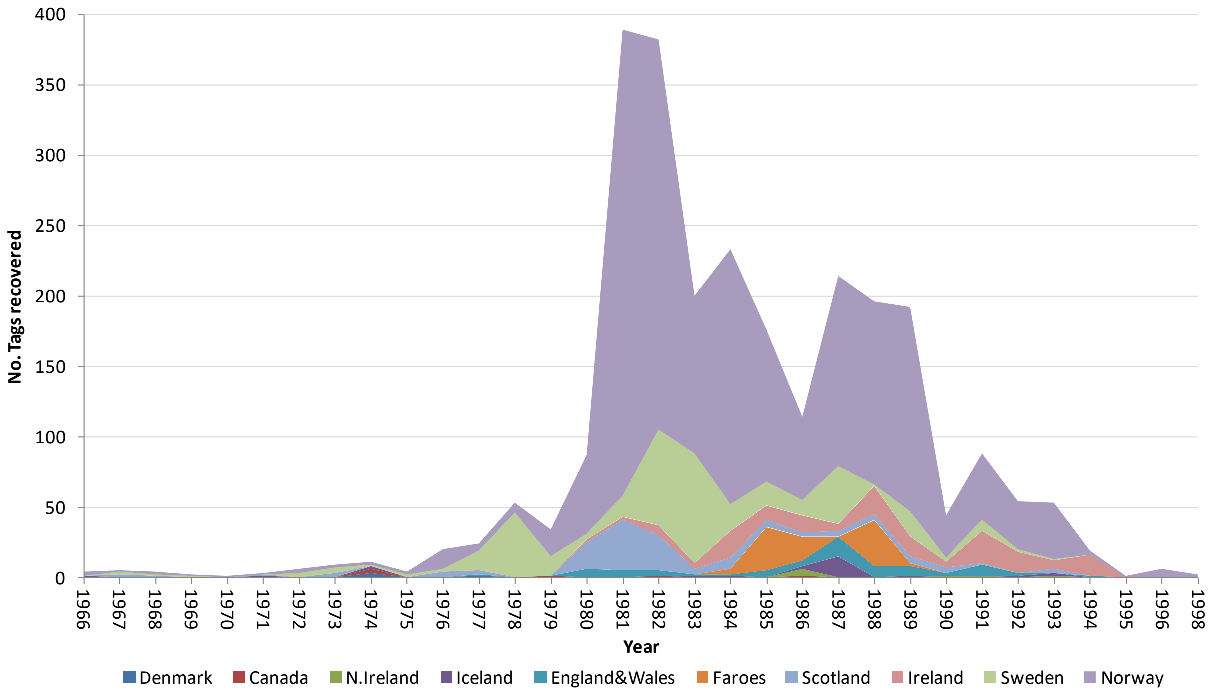


Figure 5.4. Tag recaptures at the Faroes by country of origin 1968–2000 (excluding countries with fewer than three tags: USA, Spain, and France).

While conventional tagging provides information on the distribution of national or regional stocks within a fishery temporally and geographically, it may not provide an accurate reflection of the proportion of fish from each country or region of origin as the tag recoveries have not been scaled to the total tag output. Recent genetic assignments reported to ICES (ICES, 2015) were made possible based on DNA extracted from 656 scale samples (87 1SW and 487 MSW non-farm-origin fish and 82 farmed escapees) collected during the 1993/1994 and 1994/1995 research fisheries and analysed against the genetic baseline of European salmon developed during the EU SALSEA-Merge project (Anon., 2011). These assignments were combined to give an overall 1SW stock composition of 84.2% southern European, 9% northern Europe, 1.2% Icelandic, and 5.7% North American and an overall composition of the MSW catch of 20.9% southern European, 58% northern Europe, 0.6% Icelandic, and 20.5% North American. A clear outcome from the genetic study was the higher prevalence of North American fish in the catches relative to the small number of tag recoveries recorded in the NASTR database from an extensive salmon tagging programme in North America. The new genetic results are thought to provide the best available data on the contribution of North American salmon to the Faroes fishery. However, a number of possible limitations to the study have been outlined including the age of the scale sample, the presence of significant numbers of farmed fish in the catches, the samples being provided from a research fishery as distinct from a full commercial fishery, and the restricted period from which the scales were derived (ICES, 2015).

5.3 Faroese adult tagging programmes

Two adult (subadult) tagging programmes have been carried out in the sea around the Faroes. The first took place 1969–1976 and the second 1992–1995 (Table 5.3).

Table 5.3. Tagging programmes around the Faroe Islands.

Area	Period	No. tagged	No. recaptured
Faroes	1969–1976	1 946	90
	1992–1995	5 448	106

Exact tagging and recapture positions along with other relevant information are available for the most recent tagging programme only in the NASTR database. The recaptures by country from this experiment are shown in Figure 5.4, adjusted for home-water exploitation and tag-reporting rates.

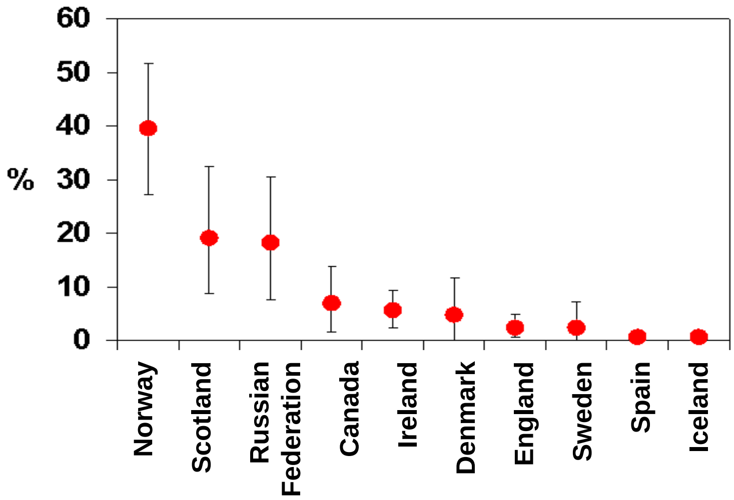


Figure 5.5. Estimated percentages of subadult salmon tagged off the Faroes while returning to different countries and caught in home waters. Recoveries were adjusted for home-water exploitation and tag-reporting rates. Data are from the tagging programme in 1992–1995. Error bars are 95% confidence limits.

6 West Greenland tag-recovery database

6.1 Scanning programmes for tags around West Greenland

6.1.1 CWT recoveries (all countries) from West Greenland scanning programme

Targeted screening of catches in the West Greenland fishery between 1985 and 1992 resulted in the recovery of 631 CWTs, 407 from USA and Canada and 224 from NEAC countries. These data are included in the NASTR database and provide information on release location and origin of the fish for most recoveries. The recapture location relates to the port in which the screening was carried out, and the recorded date to the date when the tag was detected at the landing facility. Recovery data are summarized in Table 6.1.

Table 6.1. Summary of CWT recoveries by country and year from the West Greenland catch screening programme, 1985–1992.

Year of recovery	NAC		NEAC				
	Canada	USA	Iceland	UK (Sc)	UK (EW)	UK (NI)	Ireland
1985	-	-	1	2	-	-	31
1986	19	7	2	2	22	-	18
1987	21	84	-	2	17	-	24
1988	22	61	3	1	8	-	17
1989	2	73	-	2	12	1	12
1990	9	37	3	-	2	-	3
1991	2	26	2	1	3	1	2
1992	15	36	5	1	4	-	20
Total	90	324	16	11	68	2	127

6.1.2 Tag detection in catch

CWTs were identified and recovered by scientific sampling efforts at fish processing centres with appropriate tag-detection equipment. This commenced in West Greenland in 1985, initially with Canadian and Danish scientists (Potter *et al.*, 1986), with support from US scientists from 1986 (Potter *et al.*, 1987). Subsequently, samplers from Ireland, UK (England and Wales), and UK (Scotland) were also involved.

Scanning took place in three fish processing plants on the west coast of Greenland: Sisimiut (NAFO Division 1B), Nuuk (NAFO Division 1D), and Paamiut (NAFO Division 1E), expanding to include Narssaq (NAFO Division 1F) in 1986. Other communities (Kangaamuit, (1C), Maniitsoq (1C), Qassimiut (1F), and Qeqertarssuarq (1A) were also intermittently sampled. Detailed information on each year's catch-screening programme and recoveries was provided annually to ICES. Recoveries in NAFO divisions 1C, D, E, and F showed two periods of heightened recoveries: between the late 1960s and mid-1970s and between the mid-1980s and early 1990s (Figure 6.1). A similar but less pronounced increase in recoveries in the mid-1980s and early 1990s was seen in divisions 1A and 9A, and for recaptures where NAFO division was not reported. The UK (England and Wales) is the designated tag-clearing house for CWTs recovered in the West Greenland fishery (Annex 5).

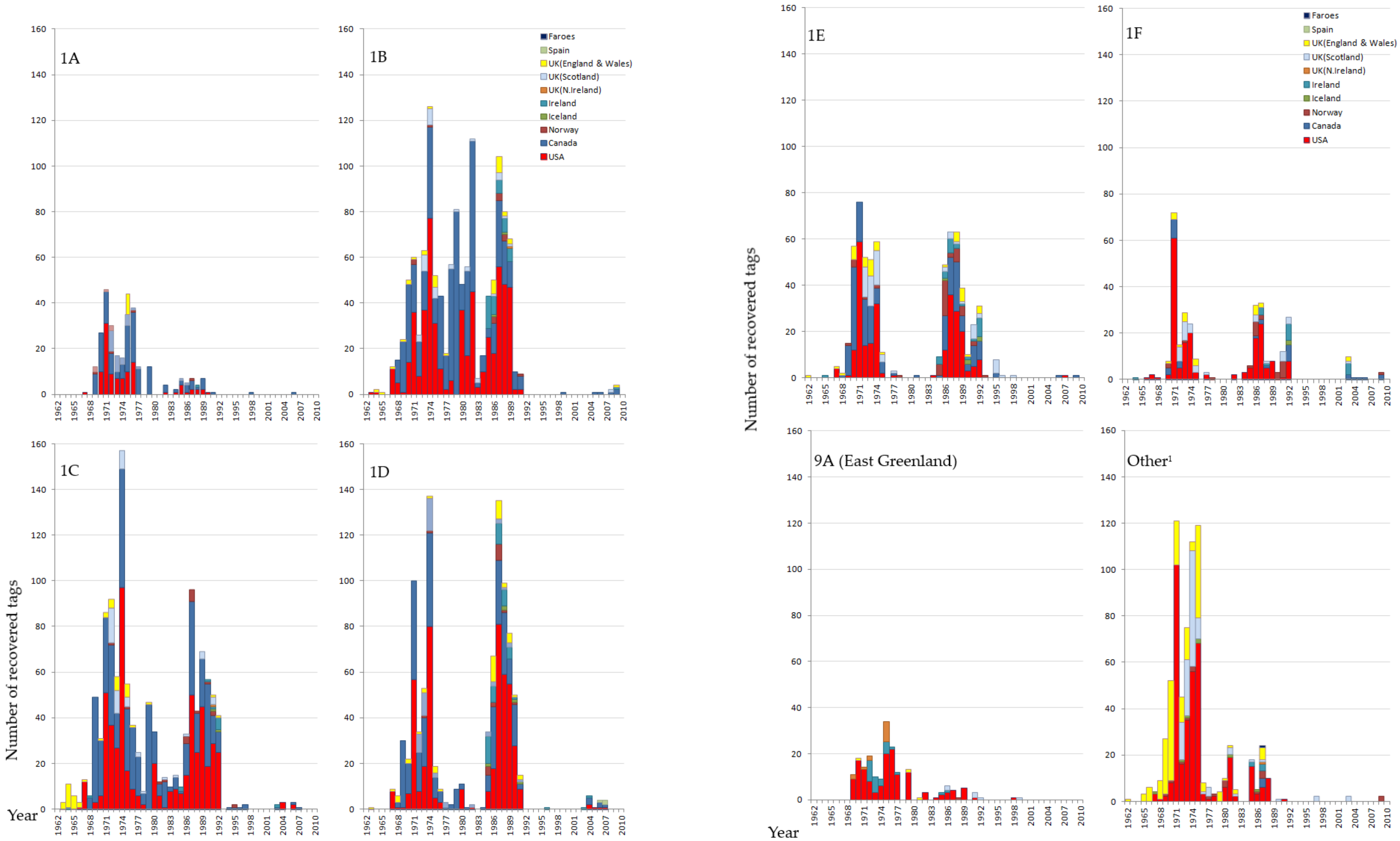


Figure 6.1. Stacked area plots of numbers of tag recoveries by NAFO area (1A, etc.), country of tagging, and year of recapture (see Figure 6.2 for map of NAFO areas and percentage recaptures).

The programme expanded over time with larger numbers of fish sampled at more locations, typically scanned between August and October. Although the recovery of CWTs through sampling programmes removes some reporting biases associated with external tags that rely on voluntary reporting, the scanning of selected catches was not consistent among years and fish processing plants, which may have caused a bias in sample collection (Miller *et al*., 2012a). Ideally, the annual recoveries should be scaled up according to the specifics of the annual sampling programmes.

6.1.3 Carlin tags

The NASTR database contains details of Carlin tag recoveries. Between 1961 and 2009, 4749 Carlin tags were recovered from the Greenland fisheries (Table 6.2). Of these, the majority were released from the USA (2218) between 1963 and 1988, and from Canada (1732) between 1970 and 2009. Most of the USA tags were released into the Machias and Penobscot rivers, with others released into the Union, Merrimack, Connecticut, Dennys, and Narragansett rivers. Release information for Canadian releases tend to be limited to fisheries locations or districts.

6.2 Summary descriptions of data

The West Greenland tag database comprises 13 separate country/jurisdiction/programme worksheets of tag-recovery data, together with three information worksheets (a sheet containing latitude and longitude values for locations at Greenland, a sheet providing descriptors of all the fields in the database, and a 'read me' sheet). These data were subject to earlier validation by national scientists and are understood to be as complete as possible. Summaries of the tagging and recovery information in the database are given in tables 6.3 and 6.4 and Figure 6.2.

Table 6.2. Greenland Carlin tag recoveries.

Country	No. tags	First year	Last year
USA	2 218	1963	1988
Canada	1 732	1970	2009
Norway	148	1969	2009
Iceland	4	1973	1981
Ireland	-	-	-
UK (NI)	-	-	-
UK (Sc)	384	1972	2003
UK (EW)	263	1961	1982
Spain	-	-	-
Faroe Islands	-	-	-
Total	4 749		

Table 6.3. Summary of tagging entries in the Greenland tag recovery database.

								Origin			Life stage when tagged					River age when tagged				
Country	**Tagging agency**	**No. of entries**	**Years**	**No. of years**	**No. with GIS locations**	**No. fork lengths**	**No. weights**	**Un-known**	**Wild**	**Hatchery**	**Un-known**	**Adult**	**Kelt**	**Parr**	**Smolt**	**Un-known**	**1+**	**1**	**2**	**3**
USA	NOAA	2 545	1962–2006	33	8	0	0	31	0	2 521	45	32	0	3	2 472	38	2	1 185	1 314	13
Canada (Sand Hill River)	DFO	86	1969–1973	5	1	80	12	0	86	0	0	0	0	0	86	81	0	0	0	5
Canada (Maritimes)	Canada	1 643	1967–1998	31	45	741	761	25	194	1 424	1 643	0	0	0	0	404	0	406	833	0
Canada (CWT and recent external)	Canada	118	2001–2008	7	18	0	0	9	23	86	95	8	0	0	15	118	0	0	0	0
Norway	NINA	148	1977–2008	29	3	145	70	0	25	123	0	0	0	0	148	148	0	0	0	0
Iceland	Directorate of Fisheries Iceland	24	1966–1985	7	13	1	0	0	1	23	16	1	0	0	7	23	0	0	1	0
Ireland	Ireland	146	1963–2008	6	37	4	2	37	4	105	136	0	1	1	8	146	0	0	0	0
UK (NI)	UK (NI)	3	1988–1990	2	1	0	0	1	1	1	1	0	0	0	2	3	0	0	0	0
UK (Scotland)	FRS	403	1968–2007	27	10	376	0	5	376	22	12	0	0	4	387	403	0	0	0	0
UK (EW)	UK (EW)	393	1960–2008	22	21	131	0	43	249	101	68	0	8	1	316	392	1	0	0	0
Spain	Spain	3	2003–2006	3	3	0	0	0	0	3	0	0	0	2	1	3	0	0	0	0
Faroe Islands	Faroe Islands	1	–	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0
Intl. West Greenland tagging experiment	DFO	236	1969–1972	3	0	18	0	236	0	0	18	218	0	0	0	221	0	1	8	6

Table 6.4. Summary of reporting entries in the Greenland tag recovery database.

									Sea age				Sex			
Country	**Tagging agency**	**Years**	**No. of years**	**Locations**	**NAFO divisions**	**No. fork lengths**	**No. round weights**	**No. gutted weights**	**Unknown**	**1SW**	**2SW**	**3SW**	**Unknown**	**Male**	**Female**	**GIS position**
USA	NOAA	1963–2007	32	84	7	488	160	1 234	109	2 361	75	7	2 038	254	260	2 546
Canada (Sand Hill River)	DFO	1970–1974	5	0	6	68	58	0	45	28	13	0	86	0	0	86
Canada (Maritimes)	Canada	1968–1999	31	11	6	640	985	0	1 643	0	0	0	1 643	0	0	1 643
Canada (CWT and recent external)	Canada	1986–2009	14	14	6	105	0	92	118	0	0	0	118	0	0	114
Norway	NINA	2009–2009	25	3	9	94	107	0	148	0	0	0	148	0	0	135
Iceland	Directorate of Fisheries Iceland	1967–1992	11	7	6	17	0	17	24	0	0	0	24	0	0	17
Ireland	Ireland	1964–2009	15	15	6	145	5	140	146	0	0	0	144	1	1	143
UK (NI)	UK (NI)	1987–1991	3	2	2	3	0	3	3	0	0	0	3	0	0	2
UK (Scotland)	FRS	1972–2008	27	6	8	14	0	12	403	0	0	0	390	5	8	273
UK (EW)	UK (EW)	1961–2009	30	41	7	186	14	184	393	0	0	0	366	7	20	201
Spain	Spain	2006–2007	2	1	1	2	0	0	3	0	0	0	3	0	0	3
Faroe Islands	Faroe Islands	1987–1987	1	0	0	1	0	1	1	0	0	0	1	0	0	0
Intl. West Greenland tagging experiment	DFO	1969–1974	6	0	13	162	123	1	236	0	0	0	154	21	61	212

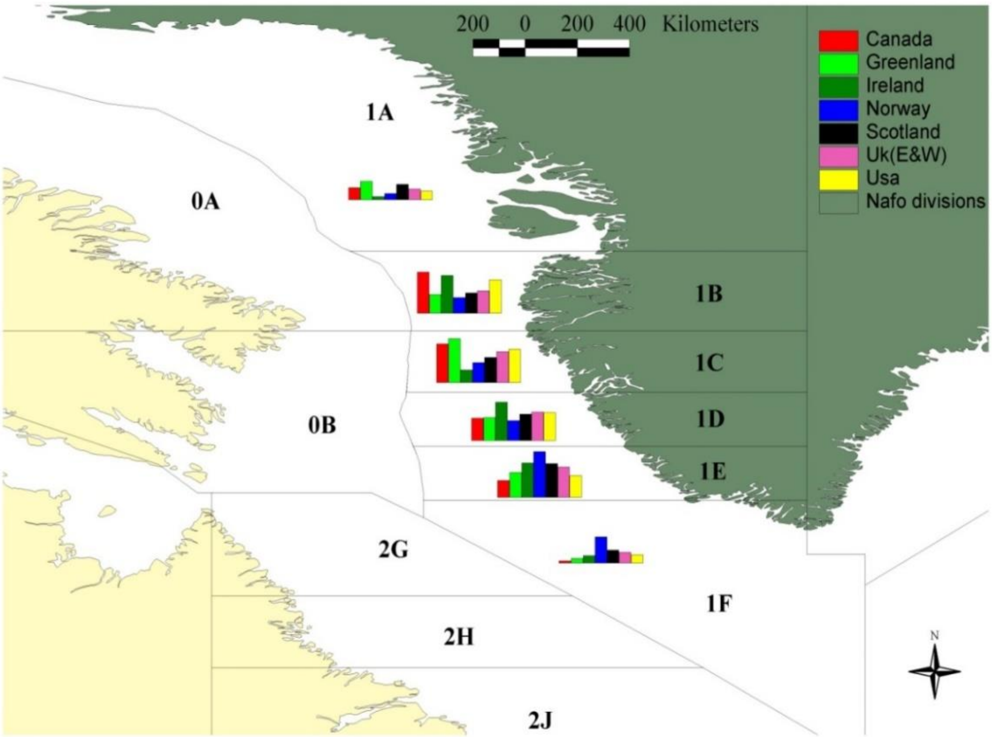


Figure 6.2. Map showing the percentage of recaptures by country from each NAFO division, West Greenland (Greenland recoveries indicate adult fish tagged and subsequently recaptured again in the West Greenland fishery).

6.2.1 Canada

Sand Hill River

This consists of 86 individual records all arising from external tagging of smolts between 1969 and 1973. Of the recoveries, 68 fork lengths and 58 round weights are recorded.

Maritimes

A total of 1643 tag recoveries are recorded, derived from external tagging primarily of smolts tagged between 1967 and 1998. Fork lengths of 741 salmon and weights of 761 salmon released were recorded. Fork lengths of 640 salmon and round weights of 985 recaptured fish are included. These come from 11 recovery locations over 6 NAFO divisions.

CWT and recent external

A total of 118 tag recoveries are recorded, mainly derived from CWT programmes between the 1980s and 1990s and external tags recovered until 2009. Tagging details (date and for some records location) are not currently provided in respect of the CWT recoveries. A total of 92 gutted weights of recovered fish are reported. A small number of Canadian-origin tags recovered from fish caught around West Greenland but imported into Ireland were added to the database during the validation exercise.

6.2.2 Faroes

A single tag derived from CWT tagging was recovered in 1987. The tag was recovered from a fish that was imported into Ireland from Greenland.

6.2.3 Iceland

Twenty-four tag recoveries are recorded, derived mainly from external and CWT tagging of hatchery smolts. 17 weights and 17 lengths of recovered fish were recorded.

6.2.4 Ireland

A total of 146 tag recoveries derived mainly from CWT tagging of smolts are recorded. Releases are recorded between 1963 and 2008 and recoveries between 1964 and 2009 across 15 locations. Of the recoveries, 145 fork lengths and 140 gutted weights are recorded. A small number of Irish-origin tags recovered from fish caught around West Greenland but imported into Ireland were added to the database during the validation exercise.

6.2.5 Norway

A total of 148 tag recoveries of externally tagged smolts between 1977 and 2008 are recorded. A total of 145 fork lengths and 70 weights were recorded at the time of tagging and 94 fork lengths and 107 round weights recorded at recovery.

6.2.6 Spain

Details of two tags from salmon released between 2003 and 2006 and recovered between 2006 and 2007 are provided.

6.2.7 UK (England and Wales)

This provides 393 tag recoveries, derived largely from external and CWT tagging of smolts released between 1960 and 2008. Releases took place across 21 locations. Fork lengths were measured for 131 of the released smolts. For these, 249 are recorded as wild and 101 as hatchery origin. Recoveries are recorded between 1961 and 2009 at 41 locations over 7 NAFO divisions. A total of 186 measurements of fork length are given, 14 round weights, and 184 gutted weights.

6.2.8 UK (Northern Ireland)

From UK (Northern Ireland), three tag recoveries are included. These come from CWT tagging of smolts on the River Bush. The data include a single tag recovered from a fish caught around West Greenland but imported into Ireland.

6.2.9 UK (Scotland)

A total of 403 tag recoveries were derived from both external and CWT tagging of smolts released between 1968 and 2007. Releases were made in 10 locations, and 376 fork lengths were recorded. Recoveries are recorded between 1972 and 2008 in six locations with 14 fork lengths and 12 gutted weights.

A small number of Scottish tags, recovered from fish caught around West Greenland but imported into Ireland, were added to the database during the validation exercise.

6.2.10 USA

A total of 2545 tag recoveries are recorded, mainly external Carlin tags and CWTs resulting from tagging programmes operated by NOAA. Tagging primarily took place in the state of Maine (2473 recoveries), but also in Connecticut (37 recoveries), Massachusetts (38 recoveries), New Hampshire (3 recoveries), and Rhode Island (one recovery) across 8 rivers. Tagging events took place between 1962 and 2008, though not in all sequential years. The life stages tagged were primarily smolts (2472), but recoveries were also recovered for 32 adults, 3 parr, and 45 undifferentiated smolt/parr releases.

Recoveries occurred between 1963 and 2007, though not in all concurrent years, across 84 locations in 7 NAFO divisions. Fork length was recorded for 488 of the recoveries, round weight for 160, and gutted weight for 1234. A small number of US-origin tags recovered from fish caught around West Greenland but imported into Ireland were added to the database during the validation exercise.

6.3 Origin of salmon sampled from West Greenland fishery

While conventional tagging provides information on the distribution of national or regional stocks within a fishery temporally and geographically, it may not provide an accurate reflection of the proportion of fish from each country or region of origin as the tag recoveries have not been scaled to the total tag output. Recent genetic stock identification efforts provide an opportunity to identify the origin of North American and European Atlantic salmon sampled from the West Greenland fishery (ICES, 2015; Bradbury *et al.,* 2016). Twelve regional groups in eastern North America and 14 in Europe can be reliably identified. Tissue samples from salmon sampled from the West Greenland fishery were genetically typed to continent of origin and the 2011–2014 North American-origin samples and the 2002 and 2004–2012 European-origin samples were assessed against regional baselines.

Three regional groups in North America contribute the majority (almost 90%) of the North American-origin salmon in the West Greenland fishery in these recent samples: Québec at 40%, Gulf of Saint Lawrence at 29%, and Labrador at 24%. Smaller contributions are from Newfoundland at 4.5%, Scotia-Fundy at 1%, and USA at 1%.

For the NEAC area, > 90% of the harvested European fish were assigned to three regions in these recent samples: (i) northern UK (Scotland) and northern and western Ireland; (ii) Irish Sea; and (iii) southern and eastern UK (Scotland). The regional categorization used in the analyses for southern and eastern UK (Scotland) also includes some of the east coast of England, and was by far the largest contributor to the West Greenland fishery, representing almost 40% of the European fish caught. Substantial numbers of fish were also assigned to the Irish Sea (26.6%), which are principally fish originating from the large rivers of Ireland's south and east coast, the English west coast, and Welsh, Scottish, and Solway rivers (the Solway estuary marks the border between England and Scotland on the west coast of the UK, therefore Solway rivers include rivers from northwest England and southwest Scotland). The region delineated on the basis of the west and north coasts of Ireland and UK (Scotland) represents an additional 25.2% of the total. Overall, UK (Scotland) appears to be a major contributor to the fishery, with possibly up to 70% of the fish being assigned.

6.4 East Greenland tag recaptures

In order to further explore the distribution of tag recoveries from both West (NAFO Divisions 1A–F) and East Greenland (NAFO Division 9A) for different countries, tag recovery data (external tags and CWTs) were extracted from the NASTR database. Over the entire time-series, 4739 tags were recovered at Greenland and also assigned to a recapture location (i.e. NAFO division). Of these, 4683 (98.8%) were recovered along the West Greenland coast and just 56 along the East Greenland coast. This is consistent with relatively low reported fishing effort and landings at East Greenland (ICES, 2015). The recaptures at East Greenland occurred on an intermittent basis between 1970 and 1999, with a period of above-average recaptures in the mid-1980s (Figure 6.1). With the exception of one CWT, all the recoveries consisted of external tags.

Table 6.5 summarizes the distribution of tag recoveries at both West and East Greenland, by country of origin. Recoveries from East Greenland comprised 1.2% of the records for which recapture location was available. The proportional distribution of recoveries was, however, significantly different between countries (χ^2 test, $p < 0.01$). The proportion of tags recovered from East Greenland was particularly low for fish originating in Canada and Ireland. In contrast, the proportion from East Greenland was well above average for Norwegian and Icelandic fish, although the sample size for Iceland was very small. The European-origin MSW salmon exploited from West Greenland mainly originate from southern Europe (Reddin and Friedland, 1999; ICES, 2009). The relatively large proportion of Norwegian fish from East Greenland suggests that MSW salmon from northern Europe have a more easterly distribution than those from southern Europe.

Table 6.5. Numbers of tags recovered at Greenland for which recapture location (NAFO division) was specified, by country of origin, and the percentage of all recoveries for each country reported from East Greenland.

Country of origin	West Greenland	(%)	East Greenland	(%)	Total
USA	2 128	98.6	30	1.4	2 158
Canada	1 814	99.9	2	0.1	1 816
Iceland	16	94.1	1	5.9	17
Norway	116	89.2	14	10.8	130
Ireland	139	100.0	0	0.0	139
UK (Scotland)	273	97.8	6	2.2	279
UK (E and W)	195	98.5	3	1.5	198
UK (N.I.)	2	100.0	0	0.0	2
Total	4 683	98.8	56	1.2	4 739

6.5 Greenlandic adult tagging programmes

A collaborative international tagging investigation involving ICES and ICNAF was conducted in the seas off West Greenland between 1969 and 1972. The adult fish released with tags contributed 236 tag recoveries, many of which were recaptured in the Greenland area. Others were recaptured in various home-water fisheries. The majority of tag-recovery data derive from a single year (1972), the main tagging year. In the NASTR database, fork lengths of 162 fish and round weights of 123 were recorded, although fork lengths of only 18 were recorded during both tagging and release. Full tagging and recovery details for earlier years could not be found, and only a few records based on fish tagged by Canadian scientists were included. The whereabouts of the other data are unclear, despite efforts to locate them. In the NASTR database, 18 fish were recaptured in North America (all in Canada) and 51 in Europe. The European tags were reported from the UK (Scotland, 25), Ireland (11), the UK (England and Wales, 11), Spain (2), and France (2). All others (167) were recaptured in Greenland. These values differ somewhat from the numbers reported by Jensen (1980b), which are shown in Table 6.6 for information.

Taking into account the higher production of salmon in northern European countries and Russia and the absence of any returns to these areas, the data indicated that the proportion of salmon from more southern areas of Europe present at Greenland is higher than the proportion of salmon from more northerly areas.

Table 6.6. Summary of adult salmon tagged around West Greenland as part of the ICES/ICNAF collaborative tagging programme and which were subsequently recaptured (summarized from Jensen, 1980b).

		Number of recaptures							Totals	
Year	Number of salmon tagged	Greenland	Canada	Ireland	UK (Sc)	UK	France	Spain	N. America	Europe
1965	227	3	1						1	0
1966	729	28	1		3				1	3
1967	375	6	1	2	1				1	3
1968	47	4	1						1	0
1969	444	18	7	2	1	3		1	7	7
1970	224	3	1	1	1				1	2
1971	247	6	4	3		2		1	4	6
1972	2 364	164	12	8	24	9	2	1	12	44
Total	4 657	232	28	16	30	14	2	3	28	65

Most of the fish recaptured within the West Greenland fishery were caught in the same year they were tagged (Jensen, 1980b). A small proportion were caught in subsequent years. Of the fish tagged in 1972, 164 were subsequently recaptured at West Greenland, 156 in 1972, 7 in 1973, and 1 in 1974. The data indicated that some fish spent two successive seasons in waters around West Greenland, possibly overwintering in the area.

No scale samples were available for the one fish recaptured in 1974, and so it is unclear whether this was a virgin fish or had returned to home waters to spawn in 1973.

The pattern of recovery of adult salmon recaptured within the Greenland fishery area indicated that fish moved both north and south from the tagging and release area (Jensen, 1980b). For fish tagged in 1972 and recaptured the same year, 71 (46%) were caught south of the tagging site, 45 (29%) north, with the remainder unknown (no recovery location available).

The 1972 entries in the NASTR database were re-examined with GIS software to derive fish swimming speeds from the latitude and longitude of the tagging and recovery locations and the number of days elapsed between release and recapture. This was completed only for the fish recovered within the West Greenland fishery in the same year in which they were tagged. The median speed for fish recovered south of the tagging location was estimated at 0.13 body lengths sec^{-1} (mean = 0.27 body lengths sec^{-1}, maximum = 2.4 body lengths sec^{-1}). The median speed for fish recovered north of the tagging location was 0.08 body lengths sec^{-1} (mean = 0.21 body lengths sec^{-1}, maximum = 1.3 body lengths sec^{-1}). Further information is provided in subsequent analyses in Section 7.

7 Distribution of salmon at sea: initial analyses of salmon tag recoveries

The natal rivers of Atlantic salmon range from as far south on the European seaboard as Spain and Portugal to the Pechora Sea off the northwest Russian coast, from the rivers of New England on the northern US coastline to Ungava Bay and Hudson Strait in northern Quebec, Canada. The distribution of Atlantic salmon at sea has been of interest for decades, with the introduction of tagging programmes revealing the ranges of their sea migrations. Tagging studies have reported recaptures from the Faroes, the northern Norwegian Sea, East and West Greenland, around the Labrador Sea, and into Davis Strait (Figure 2.1). Migrations from home rivers to feeding grounds north of the Faroes and Greenland coastal waters and the return to home waters are known to take from one to multiple years. However, the biological cues regulating the timing of seaward migrations, residence periods on feeding grounds, and onward or return migration timings are still not well understood. The tag-recovery databases offer the opportunity to investigate some of these unknowns.

7.1 Questions and hypotheses

The ocean distribution and migration of Atlantic salmon may be influenced by numerous factors including stock origin, life history, environment, and interception fisheries. Compilation of national tag-recovery datasets into a standard format provided a means by which various questions and hypotheses could be explored in the context of larger meta-analyses of available data. ICES WKSHINI workshop (ICES, 2008a) developed a set of hypotheses that could be tested against the compiled datasets. Elucidating the distribution and migration of salmon at sea in time and space and clarifying or updating beliefs regarding ocean migration routes improves current knowledge regarding the ocean life history of salmon. Analyses may also provide insight into how migration and subsequent distribution of salmon at sea could be influenced by changing biological and physical conditions in the North Atlantic. To this end, descriptive models that hindcast or predict the migration of salmon at sea could be formulated and tested using the tag-recovery observations.

Examples of questions and hypotheses are provided (Table 7.1). They are divided into migratory, life history, physical, biological, and fisheries categories and are intended as a guide to initiate potential analyses of the data, to stimulate additional thought, and should not be considered exclusive.

The analyses which follow go some of the way in investigating these hypotheses. While they represent some detailed analysis, they are not intended as a complete synthesis of the listed hypotheses.

Table 7.1. Potential hypotheses and questions to investigate with the NASTR database.

Summary of testable hypotheses	Checked[1]
Migration and distribution	
The distribution of salmon at sea is not random. (Given the large number of river stocks from both sides of the Atlantic and the extent of the ocean area being investigated, some geographic clustering would be expected.)	Yes
The migration of salmon to marine feeding areas is not consistent over time (years, months) and space (route). (Changes in oceanic conditions over time have been recorded and would be expected to infuence these distributions.)	Yes
Life history	
The distribution and migration of salmon at sea depends on sea age. (Older fish stay at sea longer than younger fish, which mature earlier and return to home waters after their first winter at sea.)	Yes
The distribution and migration of salmon at sea is independent of rearing origin (hatchery vs. wild). (If behaviour of hatchery and wild fish is similar, migration behaviour can be inferred from either.)	–
The distribution and migration of salmon at sea depends on river (smolt) age. (Larger post-smolts may behave differently than smaller post-smolts, i.e. leave rivers at different times and under different conditions.)	–
The distribution and migration of salmon at sea depends on rate of growth. (Rate of growth may influence timing of maturity, avoidance of predators, and migratory distance.)	Yes
The distribution and migration of salmon at sea depends on spawning history (maiden vs. MSW vs. repeat and alternate spawning[2] salmon). (Previous migration to feeding grounds may influence return to those feeding grounds.)	–
The distribution and migration of salmon at sea depends on geographical origin of stocks (e.g. northern vs. southern stocks). (Northern or southern origin influences the timing of migration and entry to the ocean.)	Yes
The distribution and migration of salmon at sea depends on salmon run type (early vs. late spring vs. autumn runs). (These traits influence the oceanographic conditions encountered during migration.)	–
The distribution of European and North American salmon around West Greenland has changed over time. (There have been large recorded temporal changes in oceanic conditions which would be expected to influence these distributions.)	Yes
The distribution of North American salmon caught around West Greenland depends on stock origin (US, Quebec, Maritime, Newfoundland–Labrador, etc.). (Northern or southern origin would influence distribution in the ocean owing to timing and distance.)	Yes
The distribution of European salmon caught at the Faroe Islands depends on country of origin (Norway, Sweden, Finland, Denmark, Ireland, Iceland, UK, Russia, etc.). (Country origin would influence distribution in the ocean owing to timing and distance.)	Yes
Physical environment	
The distribution of salmon at sea depends on optimal temperature requirements. (Salmon are known to prefer a specifc temperature range during oceanic migrations.)	–
The distribution of salmon at sea depends on sea surface temperature. (Salmon are known to prefer a specifc temperature range during oceanic migrations.)	Yes
The distribution of salmon at sea depends on salinity. (Salmon are known to prefer a specifc salinity range during oceanic migrations.)	Yes
The distribution and migration of salmon at sea depends on the extent of pack ice in the Labrador Sea. (Ice melt influences oceanic conditions in this area, thus influencing salmon distribution.)	–
The distribution of salmon at sea depends on ocean current patterns and/or areas of potential upwelling. (These features are known to influence marine productivity.)	–

The distribution of salmon at sea depends on photoperiod. (Increased photoperiod during winter in Arctic and Subarctic areas may influence winter growth.)	–
Biological environment	
The distribution of salmon at sea depends on availability and abundance of prey species. (Distribution of prey species will not be random.)	–
The distribution of salmon at sea depends on predator abundance and distribution. (Distribution of predators will not be random.)	–
The distribution of salmon at sea is influenced by competition from other pelagic fish species. (There is overlap in food requirements of pelagic species including salmon.)	–
The distribution of salmon at sea is influenced by productivity of individual stocks. (Generally, salmon stocks are in low productivity, so this would not be expected.)	–
The distribution and migration of salmon at sea depends on local or distant-water salmonid aquaculture operations. (This may occur if aquaculture affects local stocks.)	–
The distribution and migration of salmon at sea depends on the abundance and distribution of escaped farmed salmon. (Distribution of locally escaped farmed salmon is probably not influencing oceanic migration and distribution of wild salmon on feeding grounds.)	–
Fisheries	
The distribution and migration of salmon at sea depends on local, home-water directed fisheries. (Only in the case of adult tagging at sea and subsequent recovery in home-water fisheries.)	–
The distribution and migration of salmon at sea depends on local, home-water bycatch fisheries. (Only in the case of adult tagging at sea and subsequent recovery in home-water fisheries.)	–
The distribution and migration of salmon at sea is influenced by distant-water interception fisheries. (This depends on the extent of the fishery and the prevailing stock size).	–
The distribution and migration of salmon at sea is independent of fishing season. (This depends on the extent of the fishery and the prevailing stock size).	–

[1] Hypotheses or questions that have been investigated to some degree within this report.
[2] A repeat spawning salmon spawns in more than one year, in either consecutive or alternate years.

7.2 Analyses of the Faroes tag-recovery database

The salmon fishery that began around the Faroe Islands in the 1960s, and extended farther north in the 1970s, indicated the distribution of salmon north of the islands.Following the establishment of NASCO in 1984, the commercial fishery was regulated and subsequently closed in 1991, after which only limited scientific fishing was continued in some subsequent years through to 2000. The database, covering the period 1968–2000 and comprising over 2000 tag recoveries from 13 countries or jurisdictions, was reviewed for spatial, temporal, and spatial distribution patterns in the recovery data.

Using ESRI ArcGIS software, potential ways of displaying and analysing positions of release and recapture were explored. The outputs were overlaid on a map of the North Atlantic incorporating ICES fishing areas, ICES statistical rectangles, and NAFO fishing areas.

7.2.1 Spatial distribution of Faroes tag recoveries

Data for salmon tagged in Norway and Ireland in the 1970s and 1980s as well as recaptures at known geographic locations in the fishery in the Northwest Atlantic between 1965 and 2003 were used to visualize the distribution of stocks in that period (Figure 7.1). These migration trajectories indicate considerable overlap in both time and space in the occurrence of Norwegian- and Irish-tagged fish from several rivers. There is also some indication that the more northerly Norwegian stocks were recaptured in the more northerly areas of the fishery. The number of recovered tags illustrates potential migration distances and distributions. However, the number of tags recovered is also affected by the number of tagged smolts (or other life stages) released, the fishing effort, and the effort extended in detecting tags in the catch. Therefore, any conclusions drawn need to be viewed in the context of these caveats. What is clear is that large numbers of tags from Norway and Ireland were recovered in the Faroes fishery, spanning an area generally between 60–70°N and 10–20°W. This area showed a high density of salmon over the autumn and winter fishing periods (October–December and January–April, respectively).

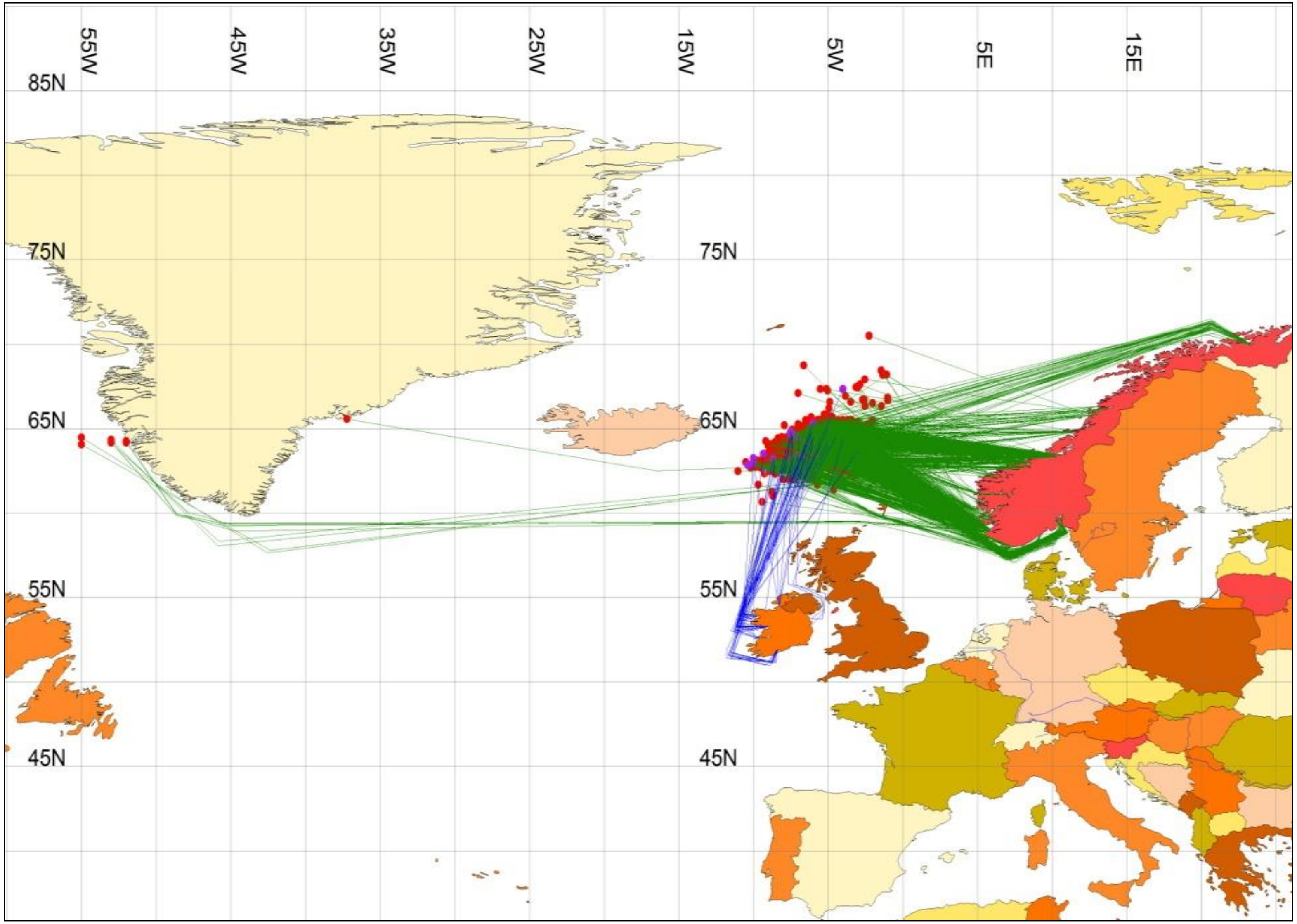


Figure 7.1. An example of geographical positions of salmon tagged in Norway (green) and Ireland (blue) during the 1970s and 1980s and recaptured around the Faroe Islands and Greenland (●) Lines are descriptive to link tag and recovery locations and do not represent known swim paths.

Where the position of recapture was known with less precision (only to ICES statistical rectangles), densities can be illustrated as categories with colours, shading, or patterns reflecting the number of tags recovered from within each area (Figure 7.2). This allows more data to be incorporated in a geographic framework, although with less overall precision. Figure 7.2 shows the high density of tag recoveries in the Faroes fishery, indicating two particularly high-density recapture areas. These two approaches can also be combined to show densities within defined spatial areas and indicate exact locations of recapture where known. This combined approach better discerns the two areas of higher density of recaptures and can also be used to visualize the spatial distribution of tags recovered by countries of origin (Figure 7.3). Investigating sea age in a similar way indicates that the majority of recaptures were 2SW, with the proportion varying from 94.2% for those fish tagged in the Faroes to 65–80% of those from Sweden, Iceland, Norway, UK (England and Wales), and UK (Scotland), to only 21% of the Irish recaptures (Figure 7.4 and Table 7.2).

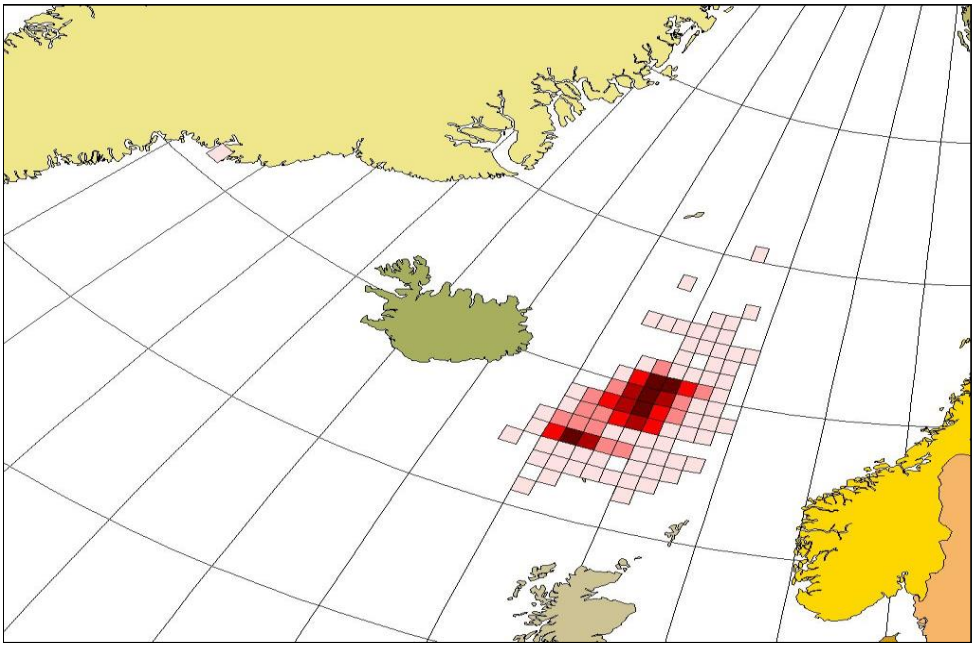


Figure 7.2. Number of tags recaptured inside ICES statistical rectangles. Darker colours indicate larger numbers of recaptures.

For Norwegian- and Irish-tagged salmon (Figure 7.1) as well as for records of all tagged salmon recovered in the Faroes fishery (Figure 7.2), the density of recaptures was displayed as density traces after spatial analysis with kernel polygons. The plots indicated a slightly more southern distribution pattern of salmon from Ireland than for those from Norway. The plots also revealed that catches of the tagged fish in certain months were very spatially concentrated (see Section 7.2.6).

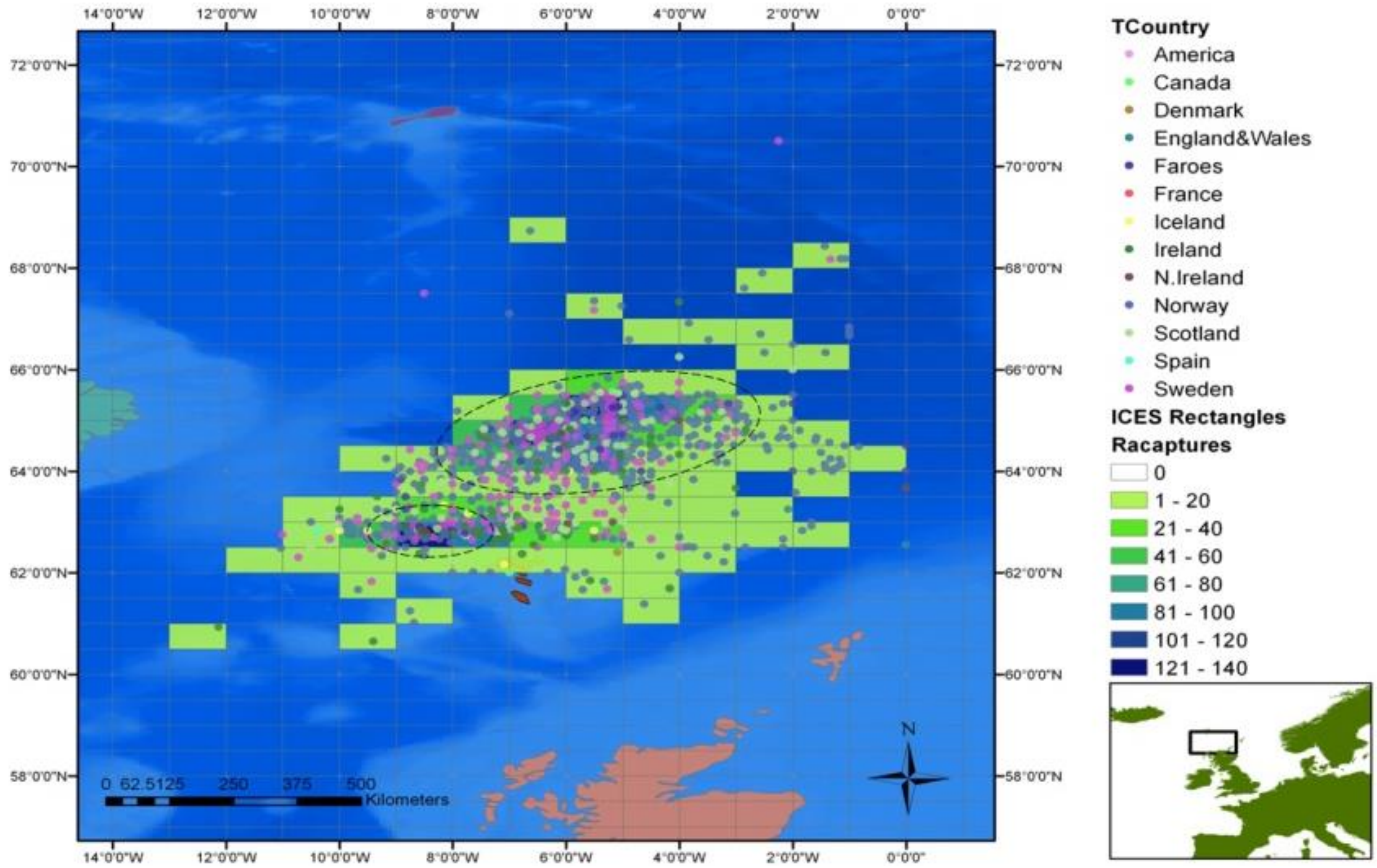


Figure 7.3. Spatial distribution of salmon recaptures around the Faroe Islands and associated densities per ICES rectangles, with hypothesized clusters indicated by dashed ovals.

Table 7.2. Summary of tag recoveries from the Faroes fishery by country of origin and sea age (percentages relate to subsequent totals).

Country	No. data points		Total				Autumn				Winter			
	All	Location	1SW	2SW	3SW	Total	1SW	2SW	3SW	Total	1SW	2SW	3SW	Total
United States	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Canada	6	–	–	–	–	–	–	–	–	–	–	–	–	–
Den-mark	10	–	–	–	–	–	–	–	–	–	–	–	–	–
France	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Spain	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Ireland	166	128	100 (78%)	27 (21%)	1 (< 1%)	128 (6%)	73 (79%)	18 (20%)	1 (1%)	92 (4%)	27 (75%)	9 (25%)	0 (0%)	36 (2%)
UK (Eng-land and Wales)	69	47	11 (23%)	32 (68%)	4 (9%)	47 (2%)	9 (31%)	18 (62%)	2 (7%)	29 (1%)	2 (11%)	14 (78%)	2 (11%)	18 (< 1%)
UK (Scot-land)	135	51	9 (18%)	33 (65%)	9 (18%)	51 (2%)	3 (14%)	13 (59%)	6 (27%)	22 (1%)	6 (21%)	20 (69%)	3 (10%)	29 (1%)
Iceland	27	18	2 (11%)	14 (78%)	2 (11%)	18 (< 1%)	1 (7%)	12 (80%)	2 (13%)	15 (< 1%)	1 (33%)	2 (667%)	0 (0%)	3 (< 1%)
Norway	1 760	1 183	147 (12%)	914 (77%)	122 (10%)	1 153 (57%)	33 (9%)	323 (87%)	15 (4%)	371 (18%)	114 (14%)	591 (73%)	107 (13%)	812 (39%)
Sweden	376	182	22 (12%)	145 (80%)	15 (8%)	182 (9%)	8 (13%)	55 (87%)	0 (0%)	63 (3%)	14 (12%)	90 (76%)	15 (13%)	119 (6%)
Faroes	99	69	1 (1%)	65 (94%)	3 (4%)	69 (3%)	0 (0%)	40 (95%)	2 (5%)	42 (2%)	1 (4%)	25 (93%)	1 (4%)	27 (1%)
Total	2 651	1 678	292 (17%)	1 230 (73%)	156 (9%)	1 678	127 (20%)	479 (76%)	28 (4%)	634 (38%)	165 (16%)	751 (72%)	128 (12%)	1 044 (62%)

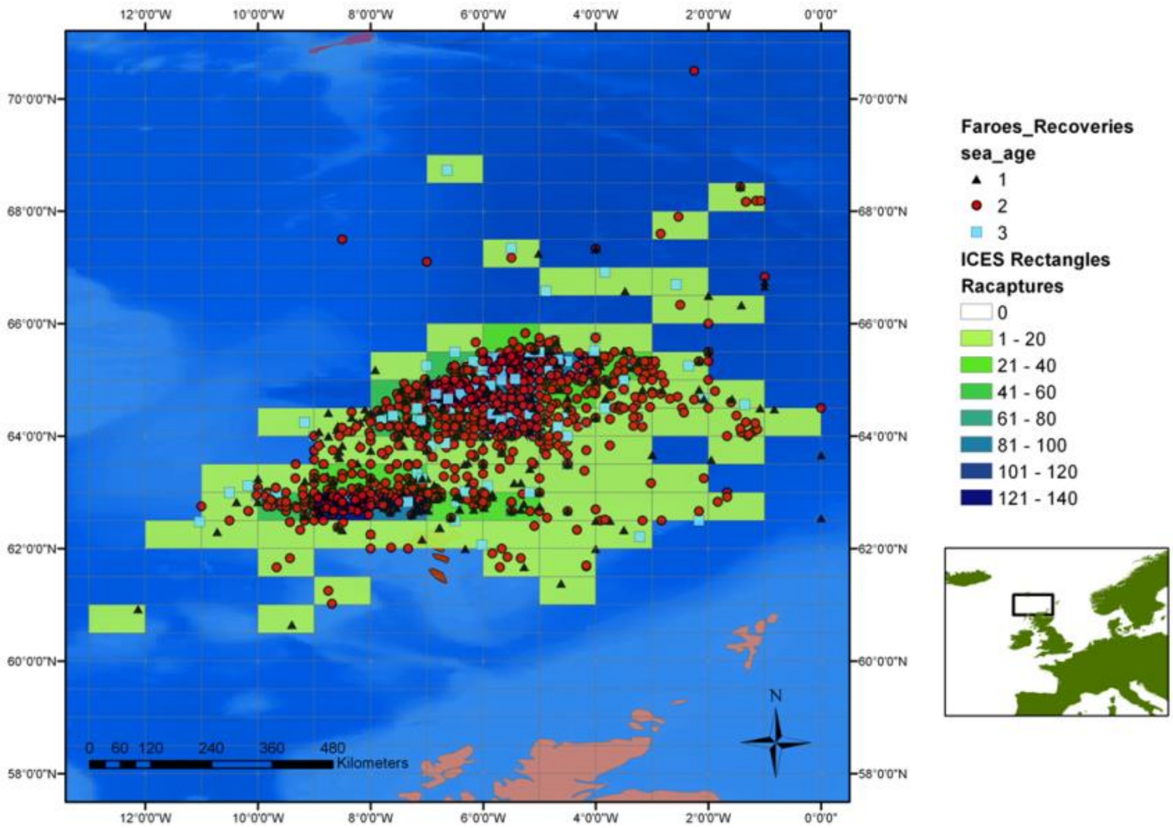


Figure 7.4. Spatial distribution and sea ages of salmon recaptures around the Faroes with associated densities per ICES rectangles.

7.2.2 Recaptures of salmon tagged as smolts

Fork length

Fork lengths of salmon in the Faroes tag-recovery database were extracted. In total, 1812 entries were recorded for 1966–1998. Of the fork lengths, 345 were for 1SW fish, 1305 for 2SW fish, and 162 for 3SW fish. Catches were divided by sea age and catch season, classified as autumn (October–December) and winter (January–April) and compared against catch year to examine variation with time.

Comparing recaptures from all countries together, autumn- and winter-caught 1SW and 2SW fish showed a very slight reduction in length over years. While only one of these correlations was significant (winter catch of 1SW fish), 1SW and 2SW age classes caught in autumn and winter showed significant differences in lengths over the years according to ANOVA tests of mean lengths (Figure 7.5, tables 7.3 and 7.4).

For 3SW autumn fish, a slightly positive trend was suggested by the data, although neither the correlation nor differences in length with years were significant. Winter-caught 3SW fish exhibited no apparent change in length over time.

A similar mix of results was shown when the data were split by country of origin. In many instances, there were too few data for meaningful analysis, and tests were not appropriate. Those tests where sufficient data existed are summarized in Table 7.4. In the majority of cases, fork length showed a reduction with time, with a number of instances where ANOVA results were found to be significant: winter-caught 2SW fish returning to Sweden, and winter-caught 1SW from Scotland. Norway showed several instances of strongly significant decreases in fish length over the time-series: 1SW fish caught in winter and 2SW fish caught in autumn and winter. 1SW fish from Ireland, caught in both autumn and winter, also showed strongly significant differences in length over time, as did autumn-caught 2SW fish returning to the Faroe Islands.

While most relationships are negative, with fish becoming shorter over the years, there are instances of positive relationships. Notable examples include Swedish winter-caught 2SW fish, Norwegian autumn-caught 3SW fish, and Irish autumn-caught 2SW fish.

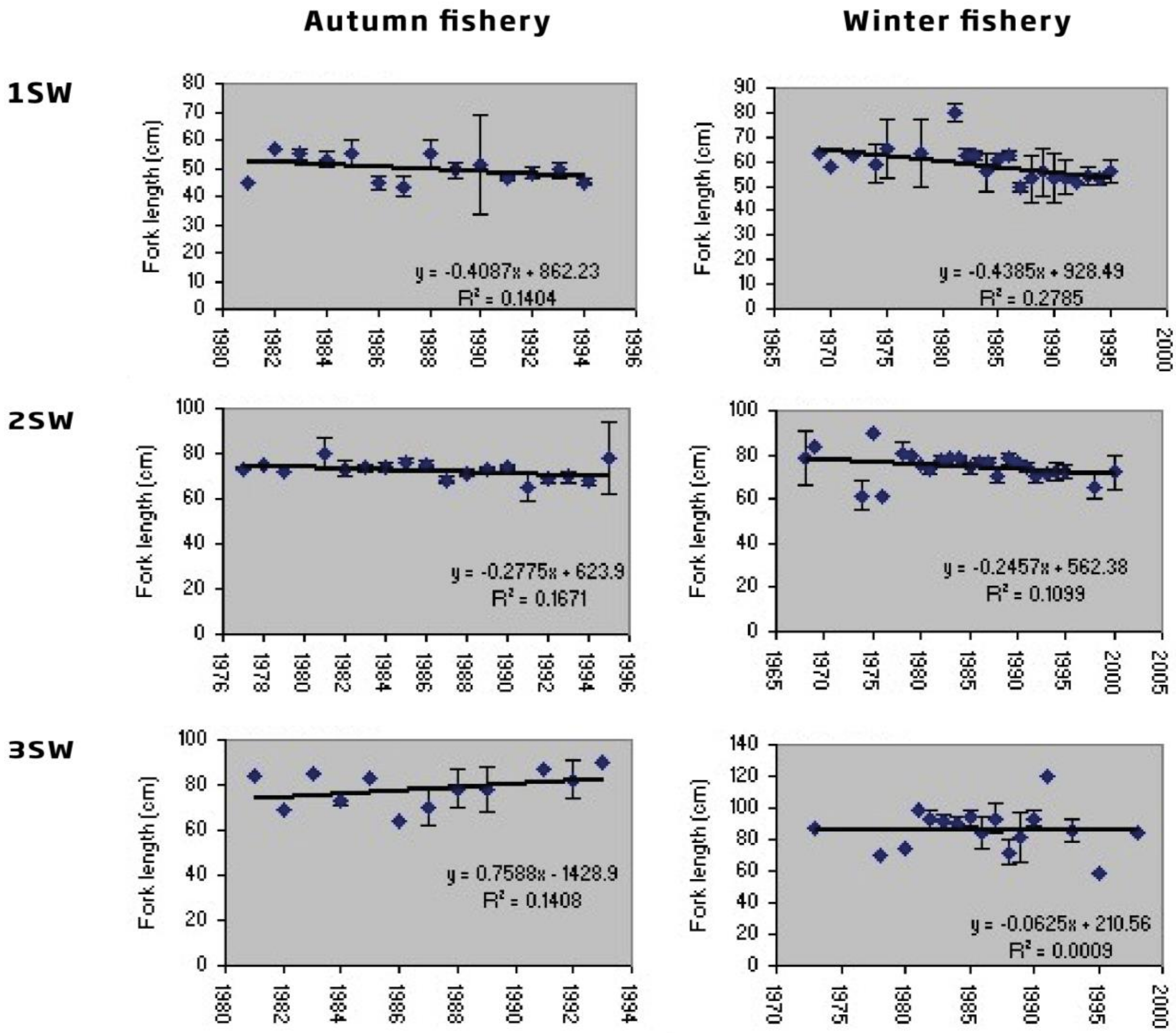


Figure 7.5. Variations in fork length of 1SW, 2SW, and 3SW salmon caught around the Faroes autumn (left) and winter (right) fisheries (significances shown in Table 7.4). (Note that axis scales vary between plots).

Table 7.3. Correlations and comparison of annual fork lengths over years (plots shown in Figure 7.5).

Fishery	Sea age (years)	Pearson correlation	ANOVA *F*	Number of years	Number of observa-tions
Autumn (Oct–Dec)	1	–0.375	3.818[2]	14	144
Autumn (Oct–Dec)	2	–0.409	7.72[2]	18	511
Autumn (Oct–Dec)	3	0.375	0.884	12	26
Winter (Jan–Apr)	1	–0.528[1]	4.144[2]	18	201
Winter (Jan–Apr)	2	–0.331	10.807[2]	18	794
Winter (Jan–Apr)	3	–0.030	1.572	17	136

Significance: [1] $p < 0.05$; [2] $p < 0.01$

Table 7.4. Summary correlation and ANOVA statistics comparing fork length with year by country of origin and sea age at recapture.

Country	Catch season	Sea age (years)	Correlation (Pearson's *r*)	ANOVA *F*	Number of years	Number of observations
Sweden	Autumn	1	–0.721	3.188	3	4
Sweden	Winter	1	–0.399	0.725	6	7
Sweden	Autumn	2	–0.876	2.738	5	21
Sweden	Winter	2	0.76[1]	3.415[1]	9	20
Scotland	Autumn	1	–0.871	12.167	3	4
Scotland	Winter	1	–0.896	70.472[1]	4	6
Scotland	Autumn	2	–0.358	3.905	5	10
Norway	Autumn	1	0.004	1.365	12	45
Norway	Winter	1	–0.503[1]	3.218[3]	18	153
Norway	Autumn	2	–0.593[1]	5.195[3]	17	384
Norway	Winter	2	–0.226	8.638[3]	18	717
Norway	Autumn	3	0.535	0.404	11	16
Norway	Winter	3	–0.027	1.49	17	129
Ireland	Autumn	1	–0.414	6.55[3]	11	77
Ireland	Winter	1	–0.395	7.152[3]	8	25
Ireland	Autumn	2	0.475	2.318	9	18
Ireland	Winter	2	–0.283	0.294	7	11
Iceland	Autumn	2	0.004	2.712	5	13
Iceland	Winter	2	–0.973	N/A	3	3
Faroes	Autumn	2	0.254	14.774[3]	4.0	40.0
Faroes	Winter	2	0.330	1.382	5.0	25.0
UK (EW)	Autumn	1	0.534	0.528	5	10
UK (EW)	Winter	1	–0.854	1.833	3	4
UK (EW)	Autumn	2	–0.585	2.493	9	21
UK (EW)	Winter	2	–0.501	0.684	8	14
UK (EW)	Autumn	3	0.923	N/A	3	3

Significance: [1] $p < 0.05$; [2] $p < 0.01$; [3] $p < 0.001$

Gutted weight

Gutted weights were extracted from the Faroes dataset. Of the 1502 data entries, 276 were from 1SW fish, 1089 from 2SW fish, and 137 from 3SW fish. Changes in weight were examined with time, based on sea age of fish and catch season classified as autumn (October–December) and winter (January–April).

The apparent trend across all countries, sea ages, and catch seasons was negative, with weight decreasing over time (Figure 7.6; Table 7.5), with the exception of autumn 3SW catch where a positive relationship was apparent. ANOVAs revealed significant differences ($p < 0.01$) in weight with time for three of six sea age/season groups (autumn-caught 1SW and 2SW and winter-caught 2SW salmon).

Data gaps prevent exploration of gutted weights for all tagging countries, catch seasons, and sea age classes. Instances where sufficient data were available are detailed in Table 7.6. Most trends and differences in gutted weights were not significant, although correlations were generally negative, with gutted weight declining over time. There are four instances where positive trends (increases in weight) were apparent: Norwegian autumn-caught 3SW fish, Irish autumn-caught 2SW fish, and Faroese autumn- and winter-caught 2SW fish. Significant differences in weight over time were apparent for Norwegian autumn- and winter-caught 2SW fish. Irish autumn- and winter-caught 1SW fish also showed significant differences, as did autumn-caught 2SW Icelandic and Faroese salmon and autumn-caught 1SW fish from the UK (England and Wales).

Table 7.5. Correlations and comparison of annual gutted weights over years (plots shown in Figure 7.6).

Fishery	Sea age (years)	Correlation (Pearson's *r*)	ANOVA *F*	Number of years	Number of observations
Autumn (Oct–Dec)	1	–0.784[2]	1.861[1]	13	122
Autumn (Oct–Dec)	2	–0.014	5.961[3]	16	438
Autumn (Oct–Dec)	3	0.741[2]	0.233	11	21
Winter (Jan–Apr)	1	–0.449	0.957	18	149
Winter (Jan–Apr)	2	–0.727[3]	4.874[3]	23	645
Winter (Jan–Apr)	3	–0.291	0.987	14	110

Significance: [1] $p < 0.05$; [2] $p < 0.01$; [3] $p < 0.001$

7.2.3 Faroes tag recoveries by countries of origin and ICES statistical rectangles – multivariate analyses

Multivariate analyses such as principal component analysis (PCA), which is an indirect ordination method (ter Braak and Smilauer, 2002), and Bray–Curtis cluster analysis (Beals, 1984) are mathematical tools for finding structures in large datasets and databases.

PCA and Bray–Curtis cluster analysis were applied to the Faroese tag returns, based on the abundance of recoveries in each ICES rectangle by country of origin. Bray–Curtis cluster analysis was performed using single linkage in the computer package BioDiversity Pro (McAleece *et al.*, 1997). PCA was performed in the statistical R "vegan" package.

Analyses were performed on log ($x + 1$) transformed abundance measures to better separate groupings (Figures 7.7 and 7.8). Norway and Sweden separated out most notably in the PCA analysis, indicating their large recoveries (1732 and 370, respectively) compared to other countries, and differences in the distributions of their recoveries among ICES rectangles compared to tag recaptures from other countries. Recoveries from other countries aggregated, with the UK (Scotland) and Ireland showing close proximity, as did Canada, Denmark, the Faroes, and the UK (England and Wales). It should be noted that these groupings might be confounded by the heterogeneous distribution in the catches (or fishing effort) between autumn and winter seasons. Results lend support to the hypothesis that salmon from different countries were not randomly distributed in the Faroes fishery area.

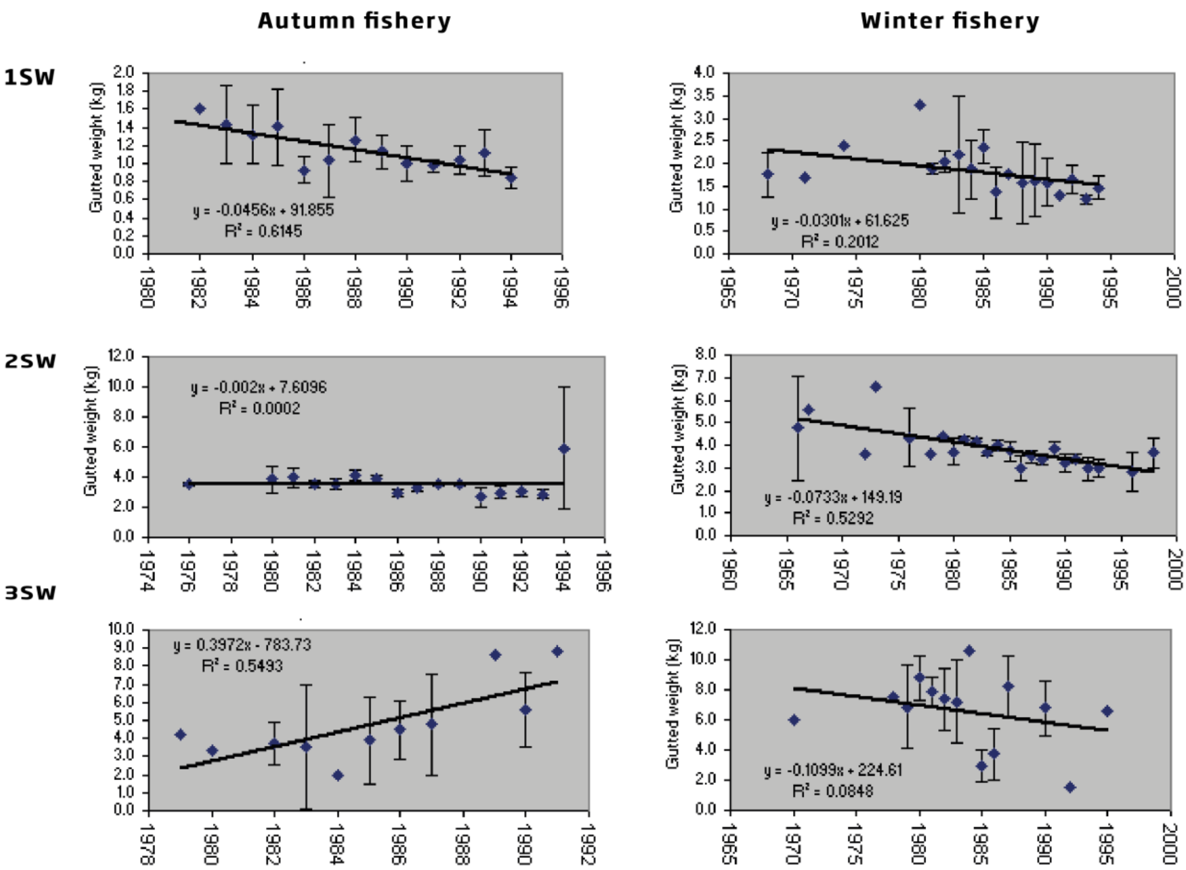


Figure 7.6. Variations in gutted weight over time of 1SW, 2SW, and 3SW salmon caught in the Faroes autumn (left) and winter (right) fisheries (significances shown in Table 7.6. (Note that axis scales vary between plots).

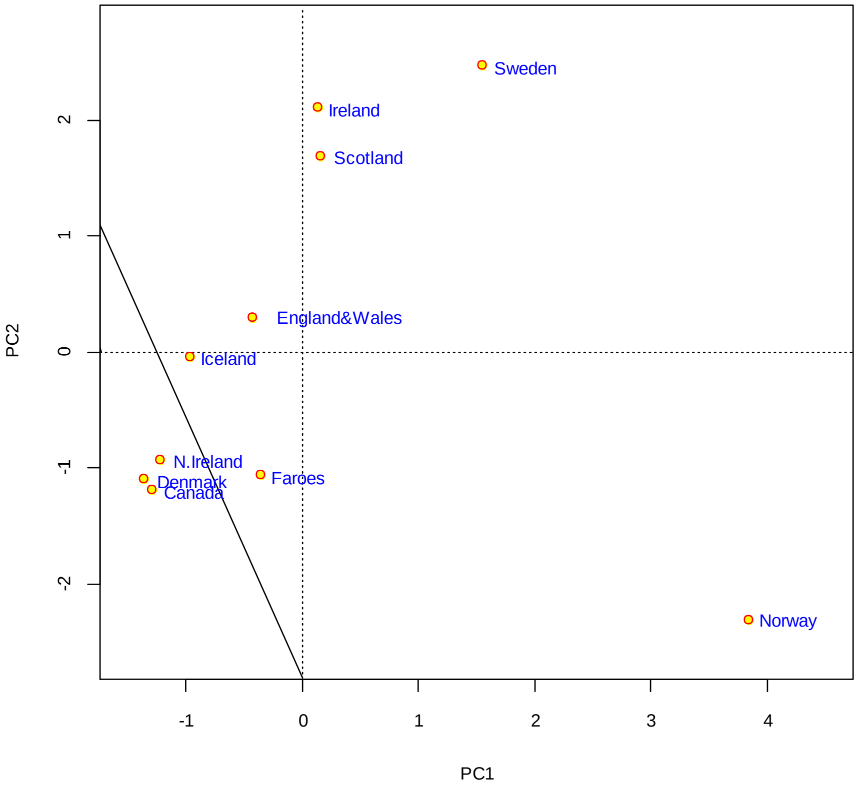


Figure 7.7. Principal component analysis of salmon recaptures in ICES statistical rectangles from tagging countries (as log (*x*+1) transformed abundance measures).

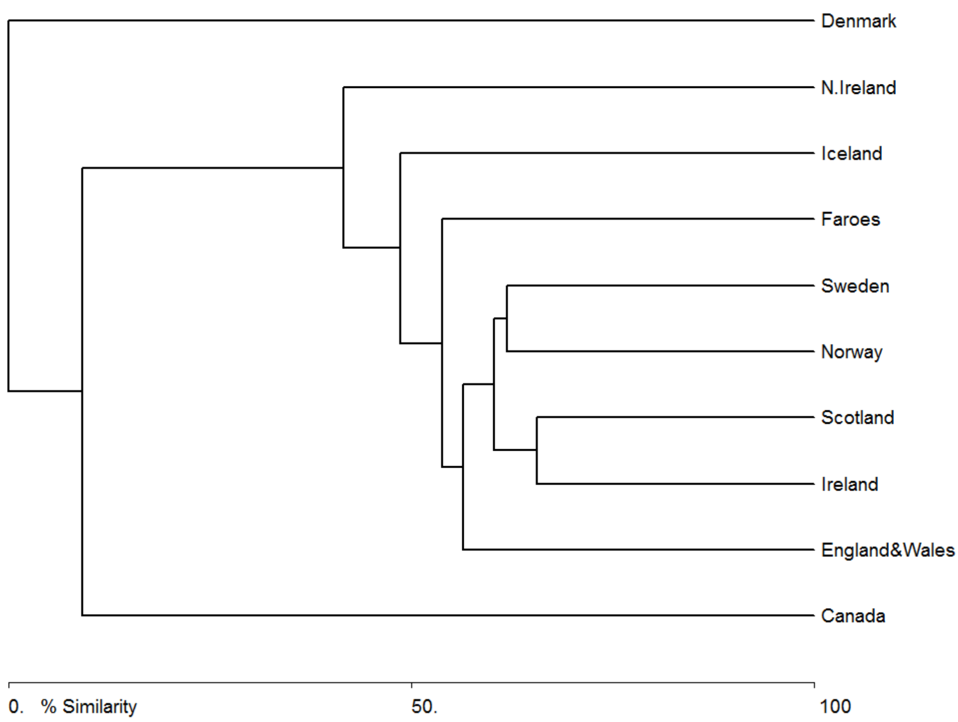


Figure 7.8. Bray–Curtis cluster analysis of salmon recaptures in ICES statistical rectangles from tagging countries (as log (*x*+1) transformed abundance measures).

Table 7.6. Summary correlation and ANOVA statistics comparing gutted weight with year, by country of origin and sea age at recapture.

Country	Catch season	Sea age (years)	Correlation (Pearson's *r*)	ANOVA *F*	Number of years	Number of observations
Sweden	Autumn	1	0.500	4.500	3	4
Sweden	Autumn	2	–0.616	2.265	5	20
Sweden	Winter	2	–0.235	0.359	7	15
UK (Sc)	Winter	1	–0.910	N/A	4	4
UK (Sc)	Autumn	2	–0.142	2.654	5	8
Norway	Autumn	1	–0.290	0.209	11	30
Norway	Winter	1	–0.199	0.729	17	109
Norway	Autumn	2	–0.460	3.692[3]	15	319
Norway	Winter	2	–0.700[3]	4.619[3]	23	576
Norway	Autumn	3	0.873[3]	0.364	10	13
Norway	Winter	3	–0.289	0.868	14	104
Ireland	Autumn	1	–0.529	5.972[3]	11	69
Ireland	Winter	1	–0.442	6.967[3]	8	24
Ireland	Autumn	2	0.501	2.328	8	15
Ireland	Winter	2	–0.375	0.128	6	9
Iceland	Autumn	2	–0.058	6.955[1]	5	11
Faroes	Autumn	2	0.346	6.991[3]	4	38
Faroes	Winter	2	0.49	1.475	5	24
UK (EW)	Autumn	1	–0.418	12.434[1]	5	9
UK (EW)	Autumn	2	–0.382	1.707	7	18
UK (EW)	Winter	2	0.023	1.213	7	13

7.2.4 Faroes tag recoveries in association with location, weight, sea age, season, and year of recapture

Faroes recoveries were used for this analysis, classed by the country of origin as "dummy variables" and consisting of recapture latitude and longitude, gutted weight (kg), sea age, season (autumn: October–December, winter: January–April), and year. The original dataset, consisting of 2646 recaptures, was reduced to 1650 owing to poor or missing values for some variables.

Redundancy analysis (RDA) was performed in the statistical package R using the vegan library and based on the algorithm of Legendre and Legendre (1998). A permutation test showed the analysis to be significant ($F = 22.449$; $p < 0.001$; d.f. = 6).

The first RDA axis accounted for 79.1% of the observed variance and the second axis accounted for 15.6% (Figure 7.9). The variables "recovery year" and "recovery season autumn" gave high negative loadings along the RDA axis 1, while the other variables showed positive correlation with this axis (length of vectors indicates correlation strength to the axis). The vectors of "sea age" and "gutted weight" point in the same direction indicating, as may be expected, that age and size are intercorrelated. Tagging countries with similar RDA scores indicate that their recovery details were closely related, specifically the UK (England and Wales), the UK (Northern Ireland), the Faroes, Iceland, and Sweden. Recoveries of fish tagged in the UK (Scotland) and in Norway differed mostly from each other and the other recoveries. Permutation tests showed that RDA axes 1–3 were significant (Table 7.7) as were all of the terms included in the analysis (Table 7.8).

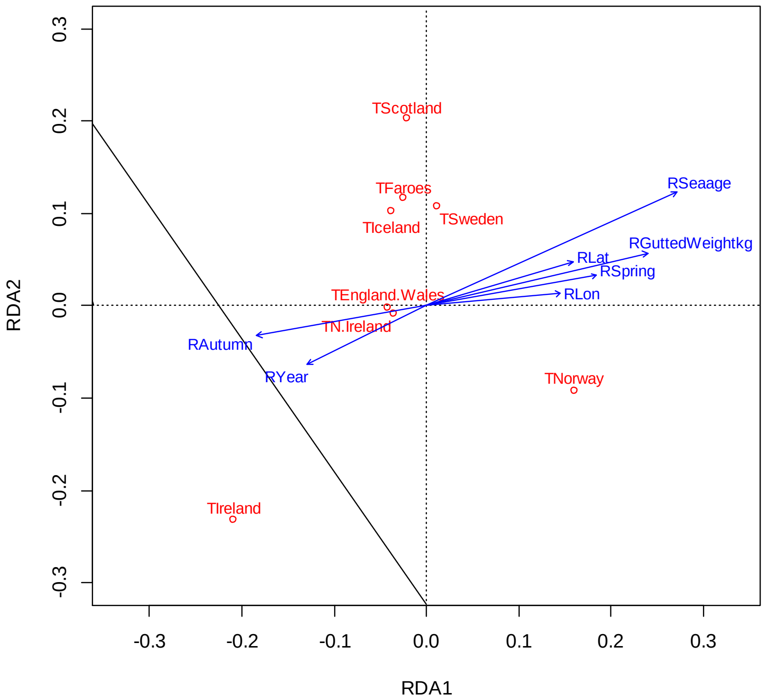


Figure 7.9. Faroes tag-recovery RDA, axes 1 and 2 biplot of tagging (prefixed by T) countries: UK (Scotland), Faroes, Sweden, Iceland, UK (England and Wales), UK (Northern Ireland), Norway, and Ireland (red) and vectors for constraining variables of recapture (prefixed by R) year, latitude, longitude, gutted weight (kg), sea age, and capture season: autumn and spring (blue).

Table 7.7. Permutation test: significance of RDA axes 1–6. Number of permutations: 999.

Axis	d.f.	Variance	F
RDA1	1	0.0294	106.605[1]
RDA2	1	0.0058	20.998[1]
RDA3	1	0.0014	5.057[2]
RDA4	1	0.0004	1.411
RDA5	1	0.0002	0.599
RDA6	1	0.0001	0.023
Residual	1 640	0.4527	

Significance:[1] p <0.001; [2] p <0.01

Table 7.8. Permutation test: significance of individual terms. Number of permutations: 999.

Term	d.f.	Variance	F
RYear	1	0.0044	15.8571
RLat	1	0.0055	19.7401
RLon	1	0.0031	11.3181
RGuttedWeightkg	1	0.0153	55.4621
RSea age	1	0.0063	22.6341
RAutumn	1	0.0027	9.6821
RSpring	0	0.0000	
Residual	1 640	0.4527	

Significance:[1] p <0.001

The vectors for recoveries in autumn (October–December) and winter (January–April) point in opposite directions, along RDA axis 1, indicating an inverse relationship. The spring recovery vector points in the same general direction, increasing along axis 1, as sea age, weight, longitude, and latitude, indicating that larger individuals with higher sea ages are more commonly recovered during spring, and that these recoveries tended to occur at higher latitudes and longitudes (to the northeast), while the opposite situation occurs in autumn.

The pattern of Norwegian fish recovery was the most distinct from those originating in other countries, in alignment along axis 1 to the spring vector. This indicated that a larger proportion of Norwegian fish were recovered in spring, at higher latitudes and longitudes, that they weighed more, and had spent a longer time at sea. This conclusion may also have been influenced by the relatively large number of Norwegian recaptures relative to other countries of origin.

Irish recoveries, located to the lower end of axis 1, aligned more with autumn recoveries and the vector of recovery year, indicating greater recoveries in the later years of the time-series. Vectors suggest that the Irish recoveries tended to be smaller, having spent less time at sea, and were mainly caught at lower latitudes and longitudes (to the southwest) and in autumn. Other countries tended towards the middle of the RDA, thus showing less clear trends. Norwegian and Irish fish showed the most dissimilar patterns, although this conclusion will have been influenced by the sample sizes of both these and other countries of origin.

7.2.5 Faroes tag recoveries and climate

It should be expected that observed changes in the environment from around the 1990s may have influenced the distribution of salmon north of the Faroes. Sea surface temperatures (SSTs) were interpolated (temporally and spatially) for each salmon recapture location. Figure 7.10 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, although this may well be a result of the different recovery locations.

Figure 7.11 shows the distribution of fish for autumn (November–December), winter (February–March), and spring (May–June), along with the long-term mean SST for the same period. In February and March, fish were caught over a greater north–south range and generally in colder water than in the other two periods (Figure 7.10).

At each location with recaptured fish, an SST anomaly was calculated as the difference between the ambient SST and the long-term mean SST for that month and location. In 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 7.12. Salmon recaptures were found in relatively colder waters in 1981–1984 and 1993–1996, and in relatively warmer water in 1985–1988. There is similar SST variability found north of the Faroes (Figure 7.13).

Figure 7.14 shows recaptured fish locations for autumn (November–December) and winter (February–March) over three periods (1981–1984, 1985–1988, and 1993–1996). In the 1981–1984 winter fishery, a few fish were recaptured farther north of the central catch grouping, thus in colder waters, compared to autumn. Over the winters of 1985–1988, all fish were found in water with average temperatures >4°C. During 1993–1996, salmon were not recaptured farther to the north but were found in colder water closer to the Faroes. This may have been a result of increased southwesterly winds (associated with a high North Atlantic Oscillation index) over several years, which increased transport of Arctic waters to the area. A more southerly recapture location was also found in autumn (1993–1996) compared to the other two periods.

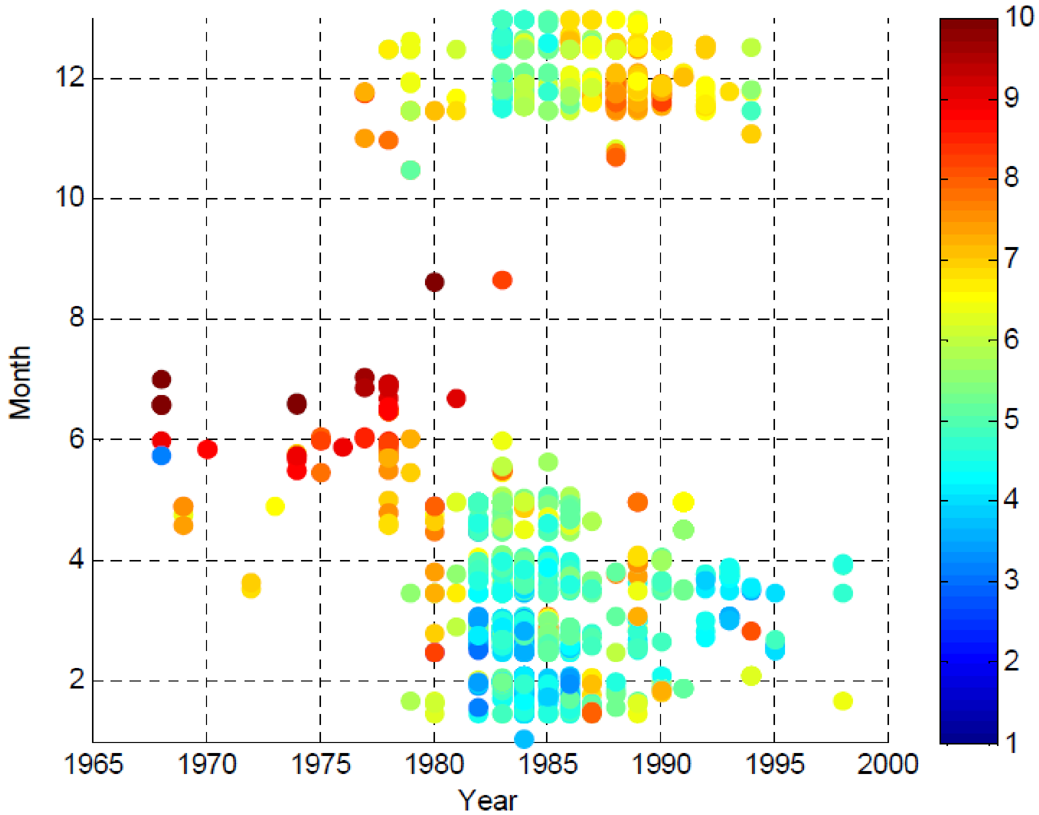


Figure 7.10. SST at locations where fish were recaptured as a function of year and month.

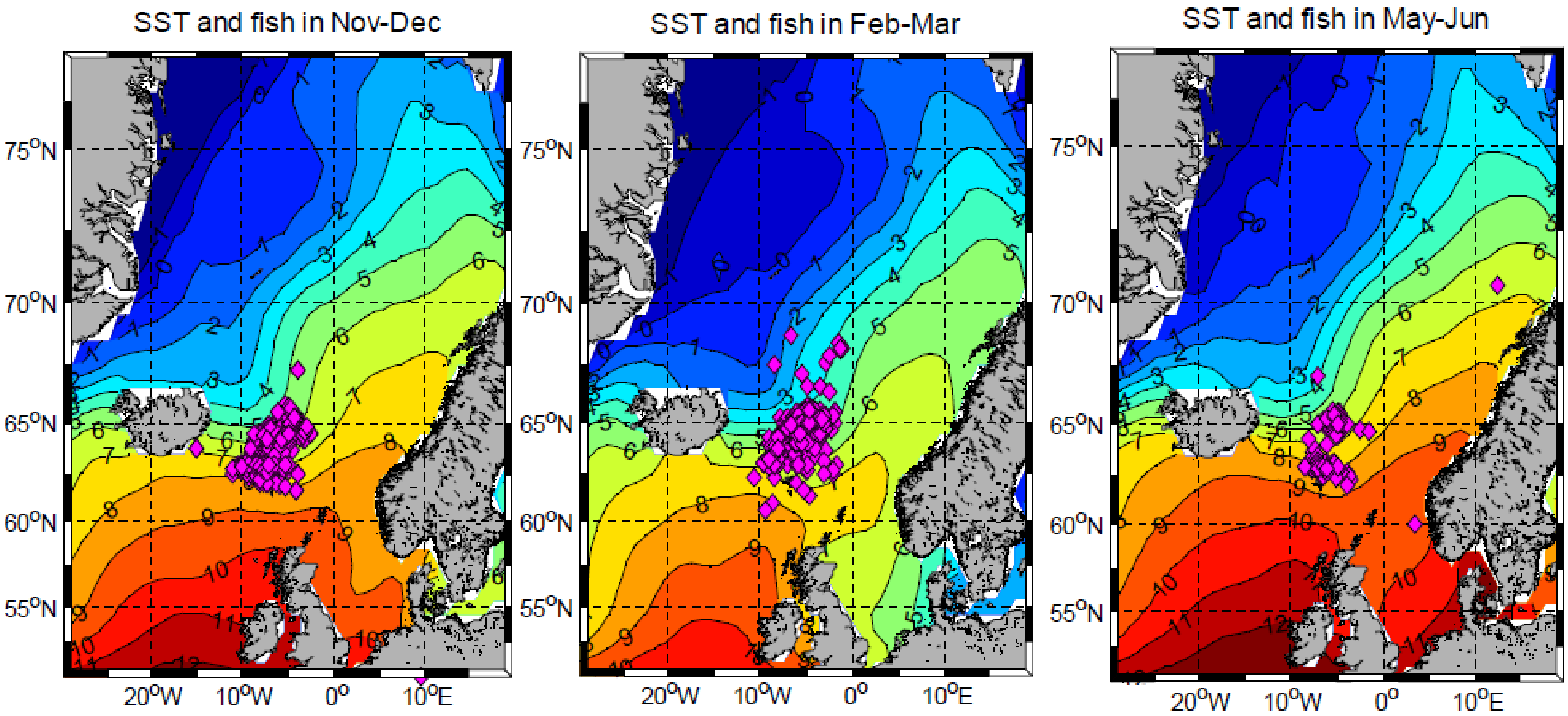


Figure 7.11. Averaged SST together with all recaptured fish for autumn (November–December, left), winter (February–March, middle), and spring (May–June, right) fishing seasons.

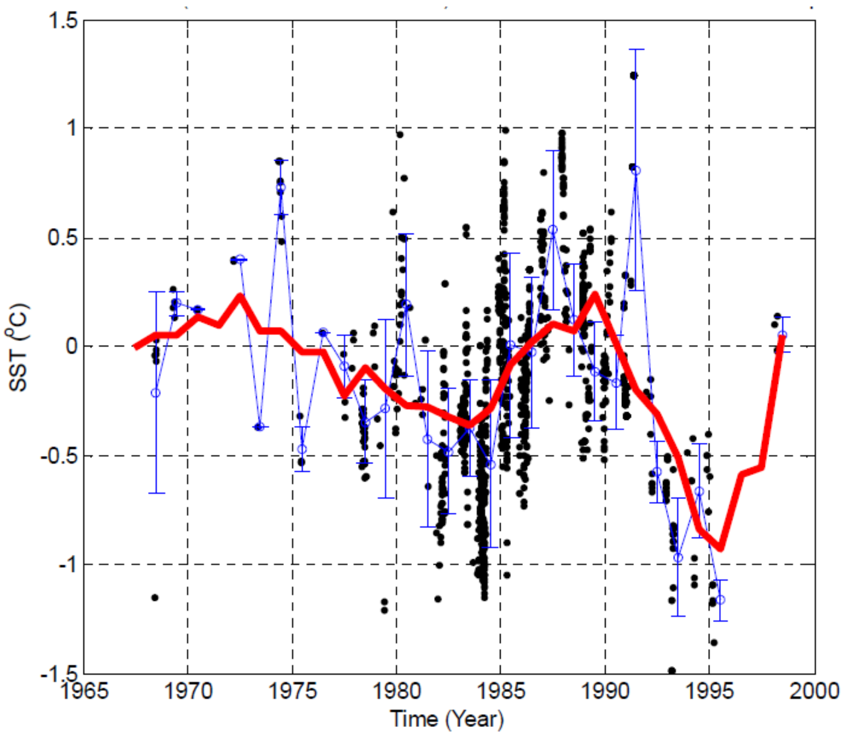


Figure 7.12. SST anomalies (black dots) calculated as the difference between the ambient SST (at the time and location of recapture) and the long-term mean SST for the month at the location of recapture. Yearly average SSTs (blue lines) with error ranges (standard deviations) and five-year running means (blue lines) are shown for comparison.

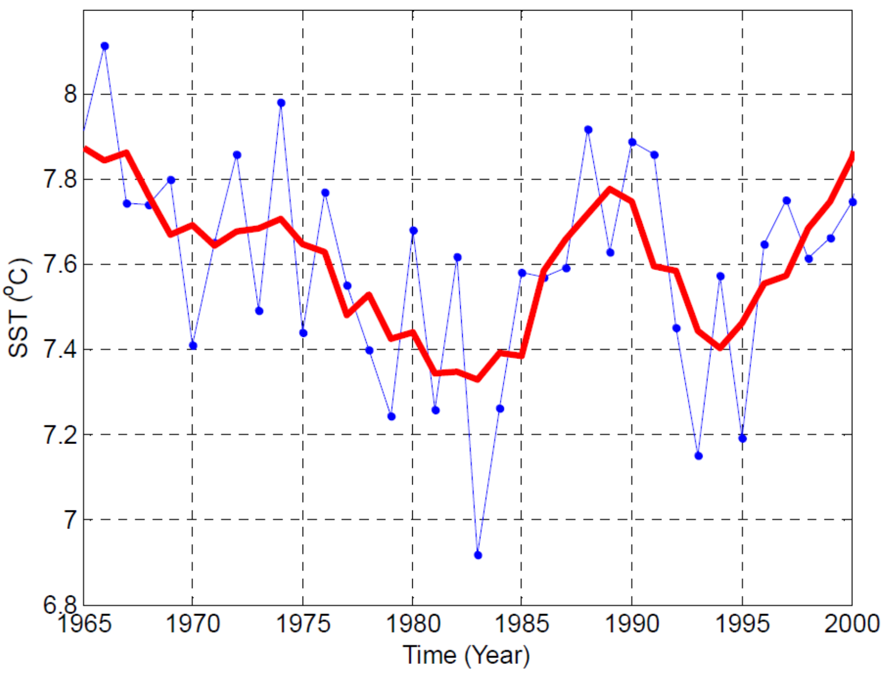


Figure 7.13. Mean SST May–December at 64°N 007°W (north of the Faroes). The red line is the five-year running mean. Data from Jensen *et al.* (2008b) are based on the monthly NOAA extended re-constructed SST (http://www.esrl.noaa.gov/psd/map/clim/sst.shtml).

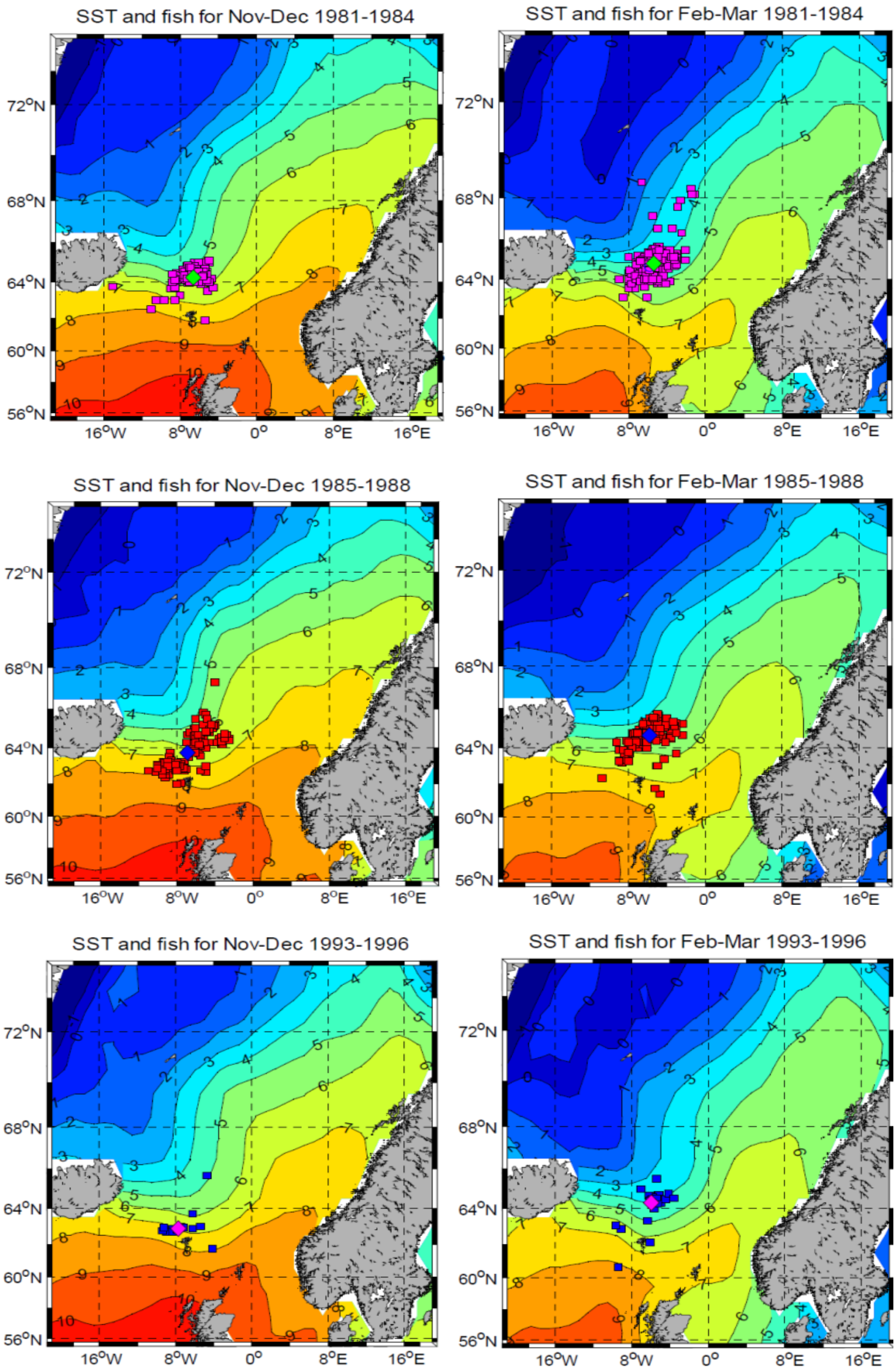


Figure 7.14. Averaged SST and location of recaptured fish for autumn (November–December, left) and winter (February–March, right) in 1981–1984 (upper panels), 1985–1988 (middle panels), and 1993–1996 (lower panels). Diamonds in each figure represent the centroid of catch locations.

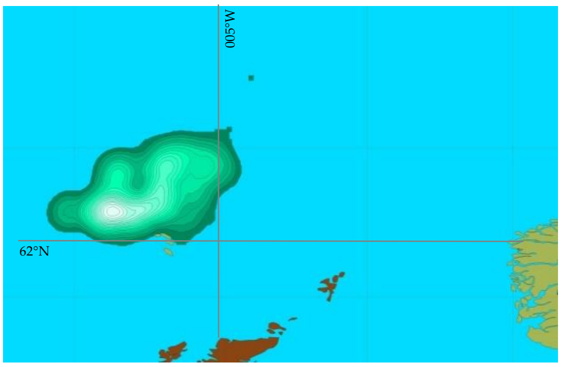
The hypothesis that distribution and migration of salmon at sea is independent of (fishing) season was not tested in the present report, as tag recovery data are fisheries dependent. Previous studies however, have revealed that the country of origin of the salmon caught in autumn differs from the composition in winter (Jacobsen *et al.*, 2001), supporting a rejection of this hypothesis.

Preliminary analysis indicates that there are discernible patterns in the compiled dataset pertaining to spatial and temporal salmon distributions around the Faroes although fishing and tagging efforts may also influence any observed patterns. It should also be noted that in the analyses of a single parameter, for instance sea age or country of origin, it is possible that any result may be confounded by heterogeneous distribution in the catches (or fishing effort) over time as effort is probably not randomly distributed during the autumn and winter season fisheries. This requires further analyses to include a time parameter such as season or month in the tests.

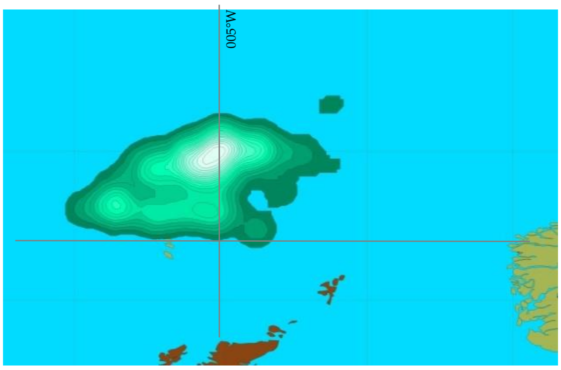
7.2.6 Spatial densities of recoveries in the Faroes fishery

Combined tag recoveries in catches from the Faroes salmon fishery are presented as the autumn (November–December) fishery and late season (winter: February–March) fishery recovery densities (kernel plots) of tagged salmon by 1SW and 2SW age groups (Figure 7.15). Tag recoveries in the fishery were distributed more to the west and south during the autumn season than in the winter season. Recoveries of 2SW tagged fish appeared to have been more prevalent in the northeast in winter (Figure 7.15). Although sea age distributions may be confounded by differences in the spatial distribution of the fishery in each period, results suggest rejecting the hypothesis that distribution is independent of sea age and that different sea ages are not randomly distributed, but clustered.

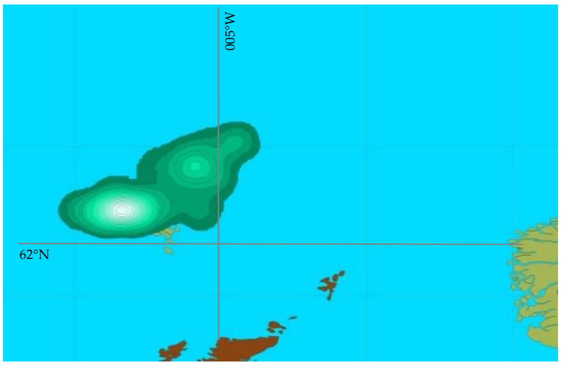
Figures 7.16–7.22 show kernel plots of the recovery distributions around the Faroes for fish tagged as smolts by country. Plots show the autumn fishery and winter fishery recovery densities of tagged salmon by nation of tagging and sea age (with the exception of the Faroes and Iceland, where this breakdown is not possible). Although densities and distributions of the different national sea ages overlapped, distinct differences were noted for recoveries from each country of origin and between autumn and winter fishing season catches for each sea age.



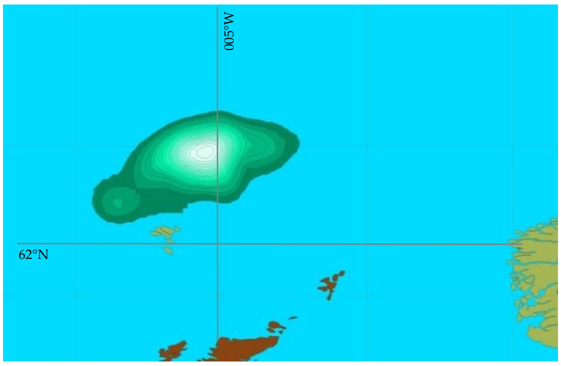
1SW, autumn



1SW, winter



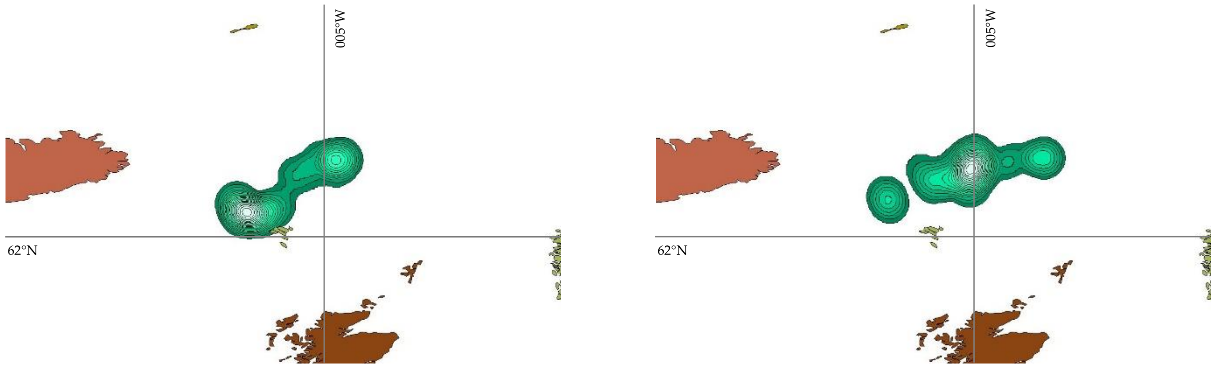
2SW, autumn



2SW, winter

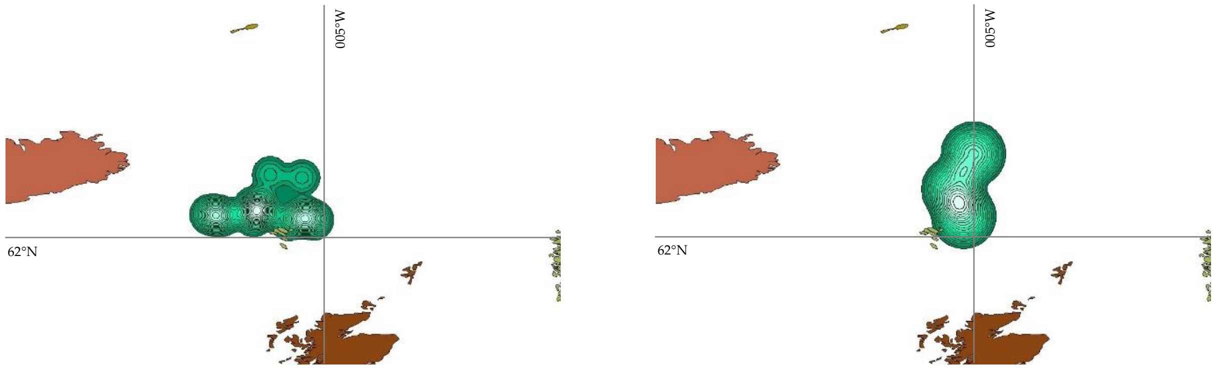
Figure 7.15. Kernel plots of salmon recaptures (numbers) north of the Faroes grouped by sea ages (1SW and 2SW) and by season (autumn: November–December and winter: February–March).

Salmon tagged and released from the Faroes were caught in the autumn and winter fishing seasons, with winter catches extending farther east and slightly farther north. Icelandic recaptures had a more northerly and westerly distribution in the winter fishery. While the distribution by sea-age appears similar, this could also be affected by fishery season. Recaptures of Irish 1SW salmon were more widely distributed around the Faroes Islands in the winter fishery than in autumn, and there was a distinct shift in the distribution from more easterly recoveries in autumn to more westerly recoveries in winter. Recaptures of 2SW tagged salmon did not show as distinct a shift in distribution from east to west with changing fishing seasons. As with Irish 1SW salmon, tagged Norwegian 1SW salmon were recaptured over a wider geographical area during the winter fishery. The older sea-ages appeared to be less widely dispersed, except for the wide distribution of 3SW recaptures in the autumn season. Recaptures of the older Swedish salmon also appeared to be less widely dispersed than the 1SW fish, with autumn recaptures of 2SW and 3SW salmon extending slightly farther east than winter recaptures. Autumn fishery recoveries of UK (England and Wales) 1SW and 2SW fish had the most southerly distribution of all the countries examined. Winter recoveries of 1SW fish were generally distributed north of the Faroes, with 2SW winter fishery recoveries distributed to the north and east. Winter recoveries of UK (Scotland) 1SW and 2SW salmon occurred farther east and north of the Faroes than in autumn. In winter, 3SW recoveries were clustered farther north of the Faroes than in autumn.

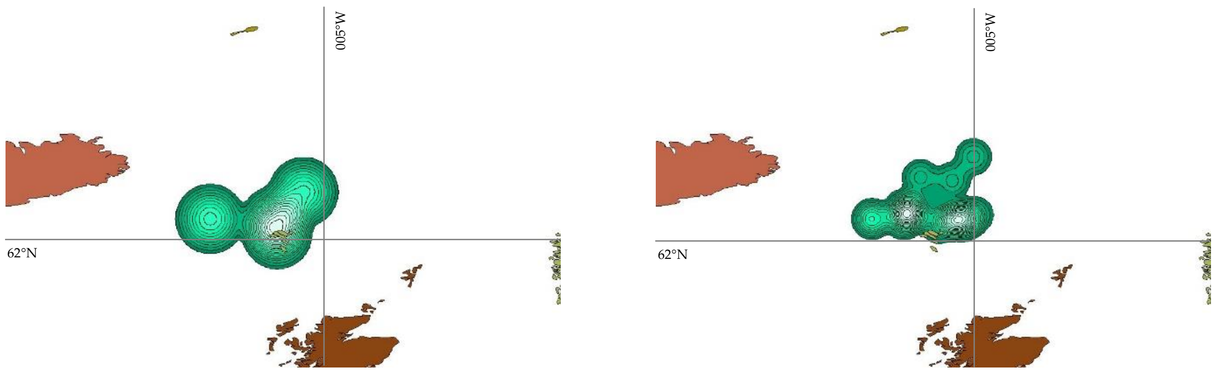


2SW, autumn **2SW, autumn**

Figure 7.16. Kernel plots of Faroese-origin salmon recaptures (numbers) north of the Faroes. These recaptures are from a small number of releases in Faroese rivers.



Autumn **Winter**



Sea age 1 **Sea age 2**

Figure 7.17. Kernel plots of Icelandic-origin salmon recaptures (numbers) north of the Faroes.

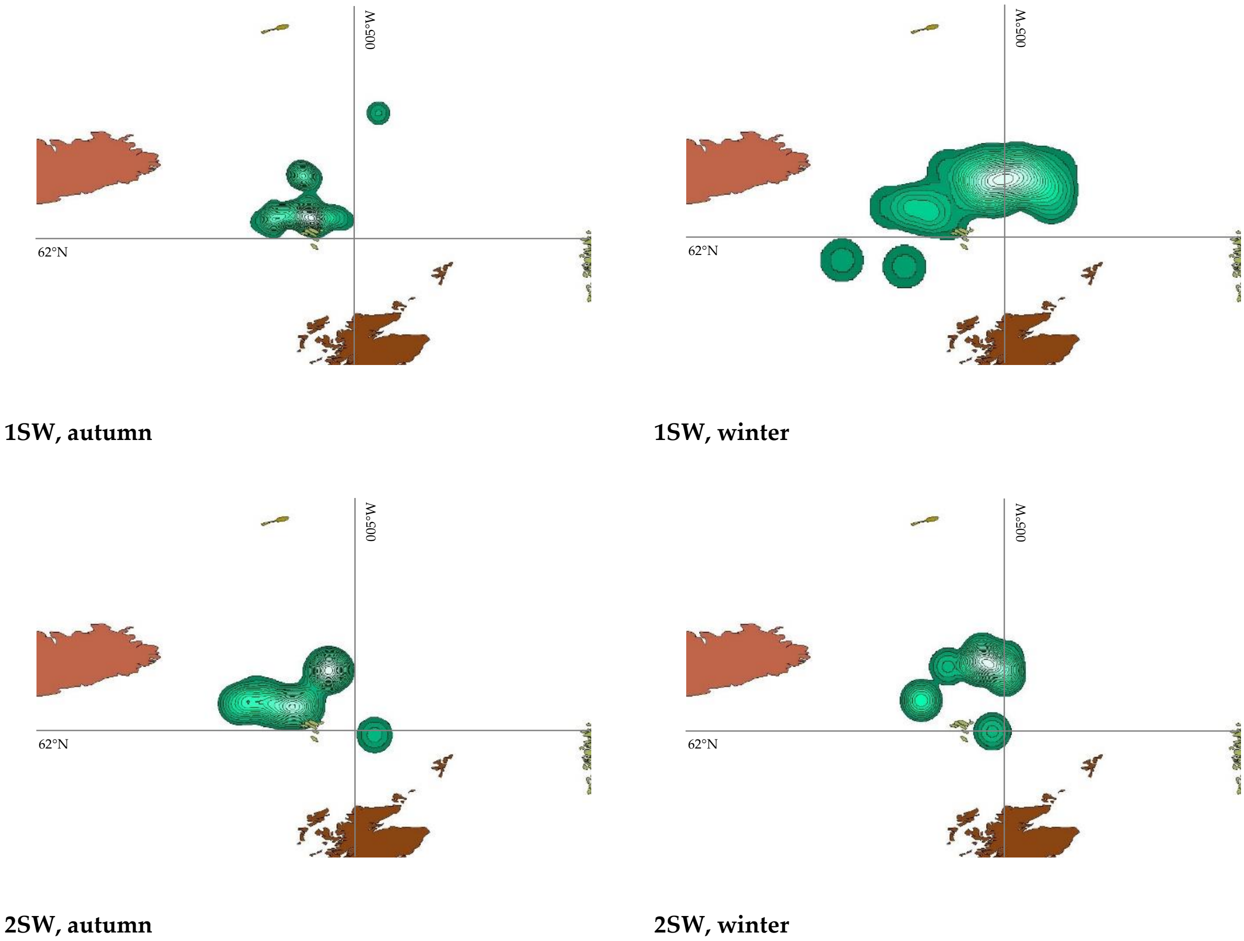


Figure 7.18. Kernel plots of Irish-origin salmon recaptures (numbers) north of the Faroes.

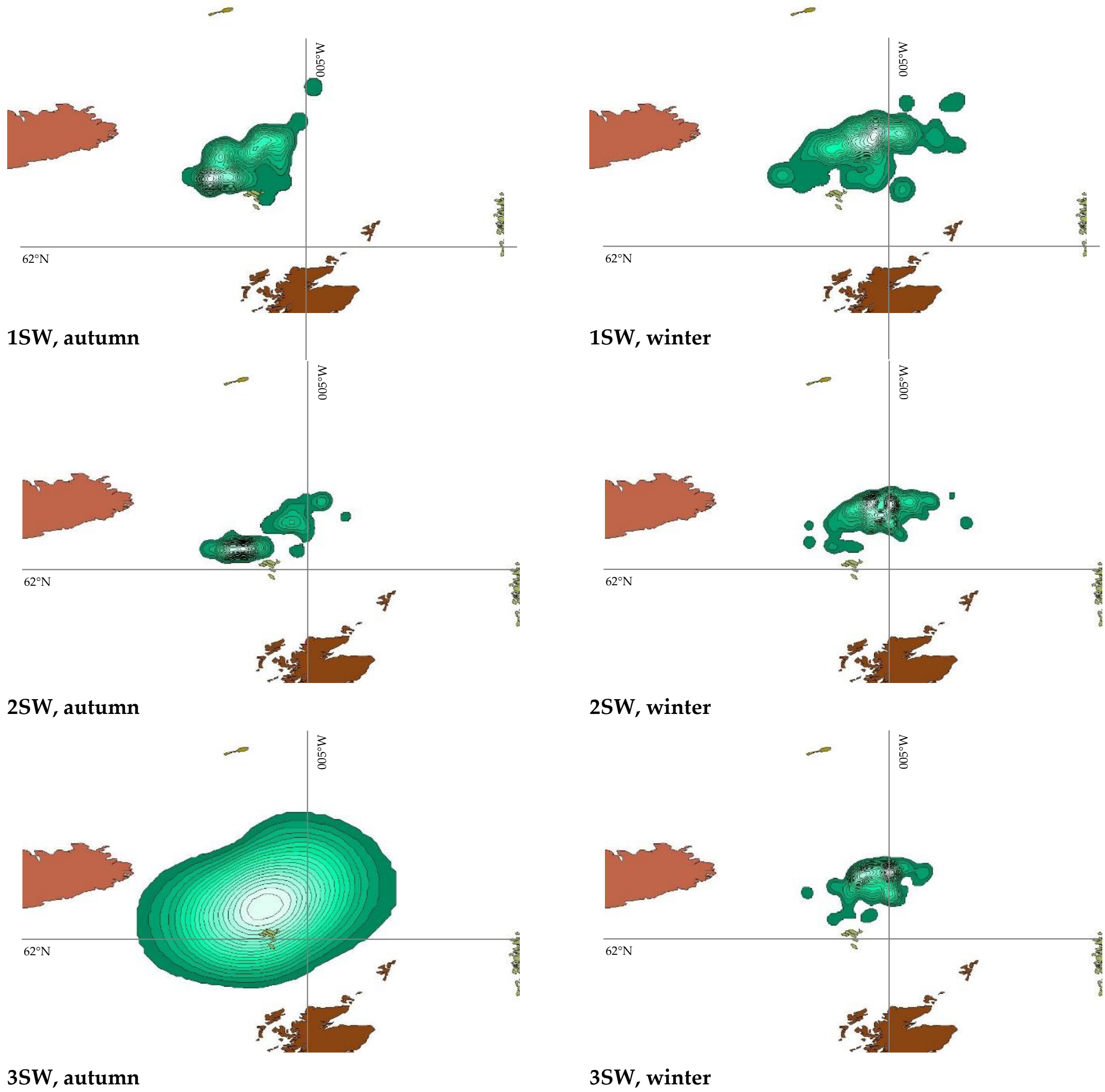


Figure 7.19. Kernel plots of Norwegian-origin salmon recaptures (numbers) north of the Faroes.

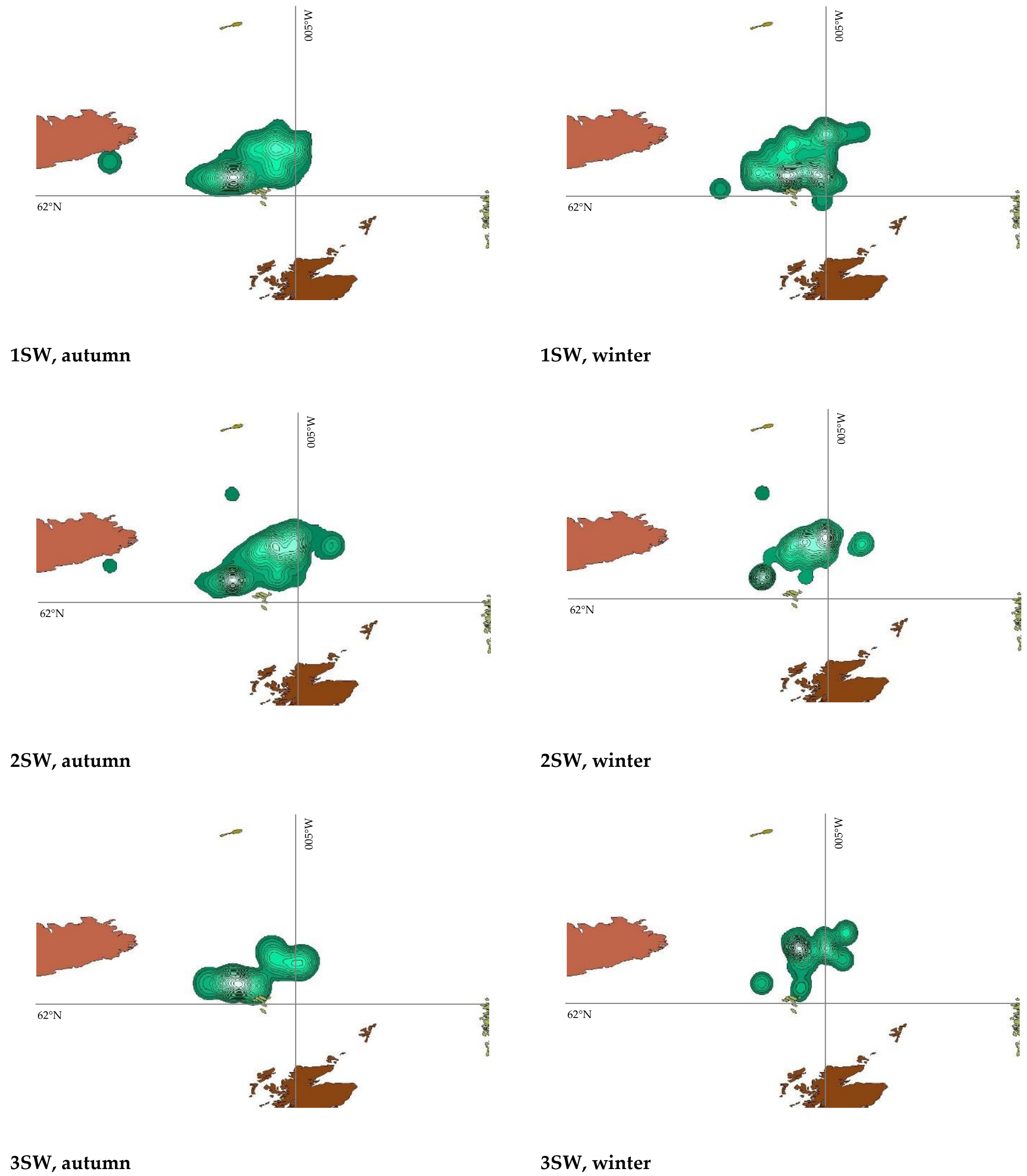
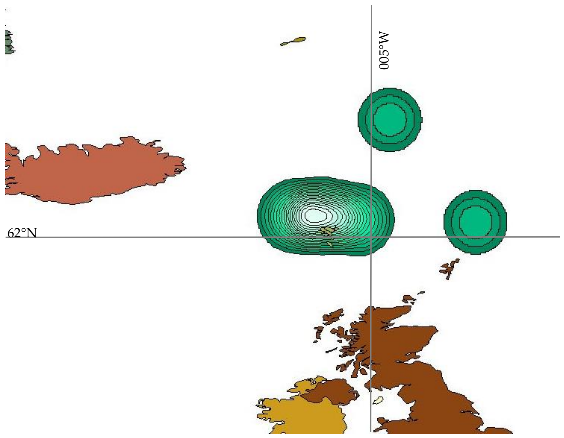


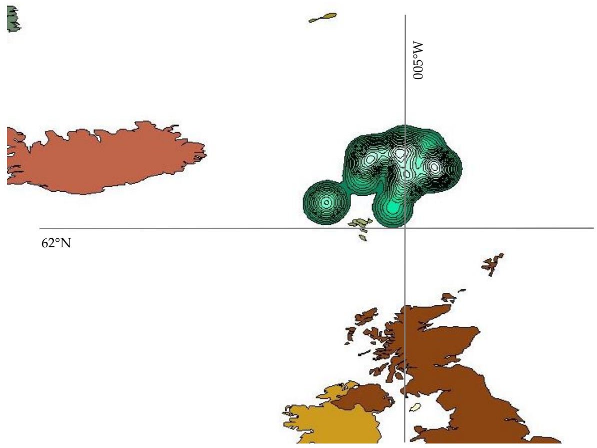
Figure 7.20. Kernel plots of Swedish-origin salmon recaptures (numbers) north of the Faroes.



1SW, autumn

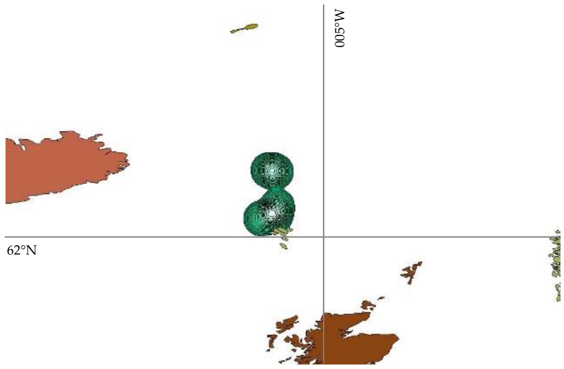
1SW, winter

2SW, autumn

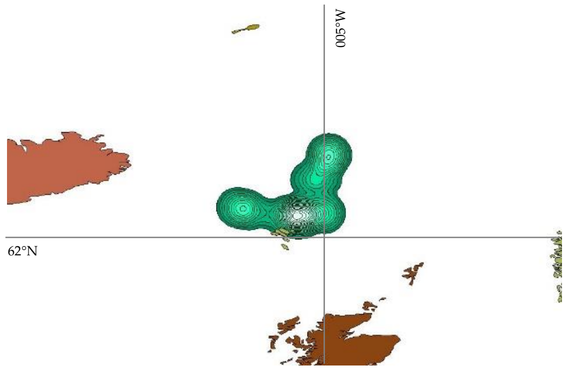


2SW, winter

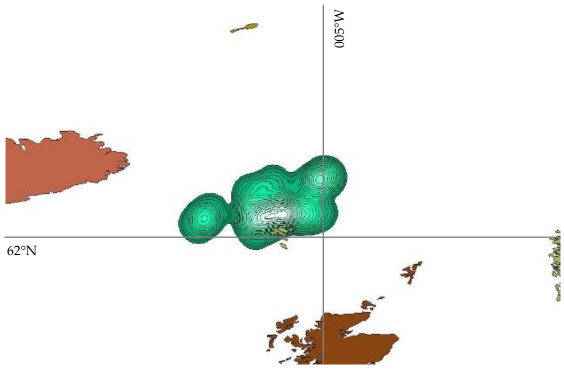
Figure 7.21. Kernel plots of UK-origin (England and Wales) salmon recaptures (numbers) north of the Faroes.



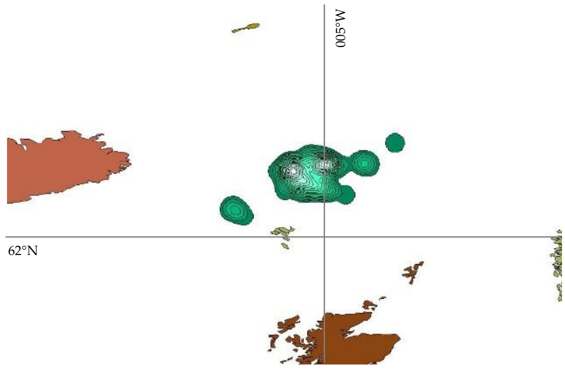
1SW, autumn



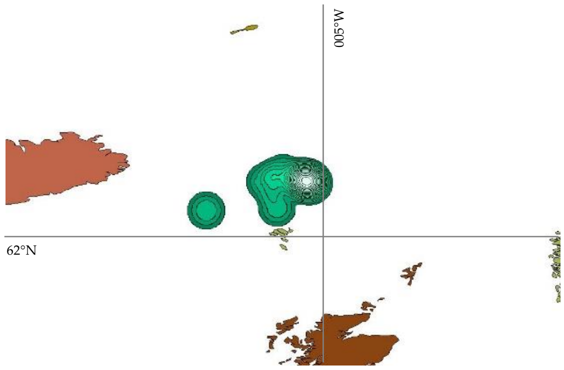
1SW, winter



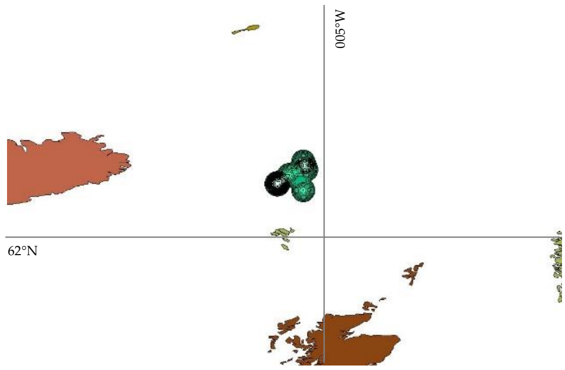
2SW, autumn



2SW, winter



3SW, autumn



3SW, winter

Figure 7.22. Kernel plots of UK-origin (Scotland) salmon recaptures (numbers) north of the Faroes.

7.3 Analyses of the Greenland tag-recovery database

The West Greenland fishery operates in late summer and early autumn (August–October) and primarily catches potential MSW salmon (Idler *et al.*, 1979). Younger salmon (i.e. post-smolts) may be present in the Greenland area but are rarely caught there, perhaps owing to the size of the mesh used in this fishery, which is generally too large to retain post-smolts.

7.3.1 Spatial distribution of Greenland recaptures

Information from the entire West Greenland tag recoveries (external tags and CWTs) time-series was initially examined to determine whether the distribution of tag recoveries was equal among three different regions: Northwest Greenland (NAFO divisions 1A–C), Southwest Greenland (NAFO divisions 1D–F), and East Greenland. Results for Canada, USA, Norway, the UK (Scotland), and the UK (England and Wales) were consistent in that tag recoveries for all countries were not uniformly distributed (all X^2 tests, $p < 0.0001$). However, given that these results are likely related to the varying distribution of fishing effort among these regions (there is very little salmon fishing at East Greenland), a reanalysis of the data was carried out for West Greenland only to test whether tag recoveries were uniformly distributed among the NAFO divisions.

Reanalysis of tag recoveries from West Greenland demonstrated similar results. For all countries of origin, salmon tag recoveries were not uniformly distributed across the respective NAFO divisions (all X^2 tests, $p < 0.0001$). Canadian and US tagged salmon were more commonly captured in northern locations (NAFO divisions 1B and C), while European-origin salmon tended to be caught farther south in NAFO Divisions 1E and F. As expected, the recovery of North American-origin salmon differed significantly from that of European salmon around West Greenland (likelihood ratio G-test = 1044.88, $p < 0.0001$). Collectively, 35% of North American tag recoveries occurred in NAFO divisions 1A and B compared with only 17% of European tag recoveries. In contrast, 56% of the European-origin tag recoveries were from NAFO divisions 1E and F compared with only 17% of North American recoveries (Figure 6.2).

7.3.2 Greenland tag recoveries by countries of origin and NAFO areas – multivariate analyses

PCA and Bray–Curtis cluster analysis were applied to the Greenland tag recaptures, based on abundance of tags by country of tagging and by NAFO area. Bray–Curtis cluster analysis was performed using single linkage in the computer package BioDiversity Pro (McAleece *et al.*, 1997). PCA was performed in the statistical package R using the vegan library.

Analyses were performed on log(x+1) transformed abundance measures to better separate groupings and reduce the influence in the data of very high abundance measures from Canada and the USA (Figure 7.23). In the resulting cluster, the USA, Canada, and Ireland clustered separately from other countries. Norway and Iceland clustered closest to each other, with the UK (England and Wales), the UK (Scotland), and the UK (Northern Ireland) also close, showing similarity in abundance and recovery in NAFO areas.

The PCA positioned the UK (Scotland) and the UK (England and Wales) in close proximity, and this was reflected in the Bray–Curtis clustering (Figure 7.24) showing them to have had the highest percentage similarity, followed by the USA–Canada cluster. Norway separated from the UK (England and Wales) and UK (Scotland) grouping, and Ireland separated from these and the USA–Canada group. While PCA clustered Norway, the UK (Northern Ireland), Iceland, and Scotland in proximity, Bray–Curtis separated UK (Northern Ireland) and Iceland early, indicating their dissimilarity in abundance and in NAFO recapture areas shown by salmon from other countries.

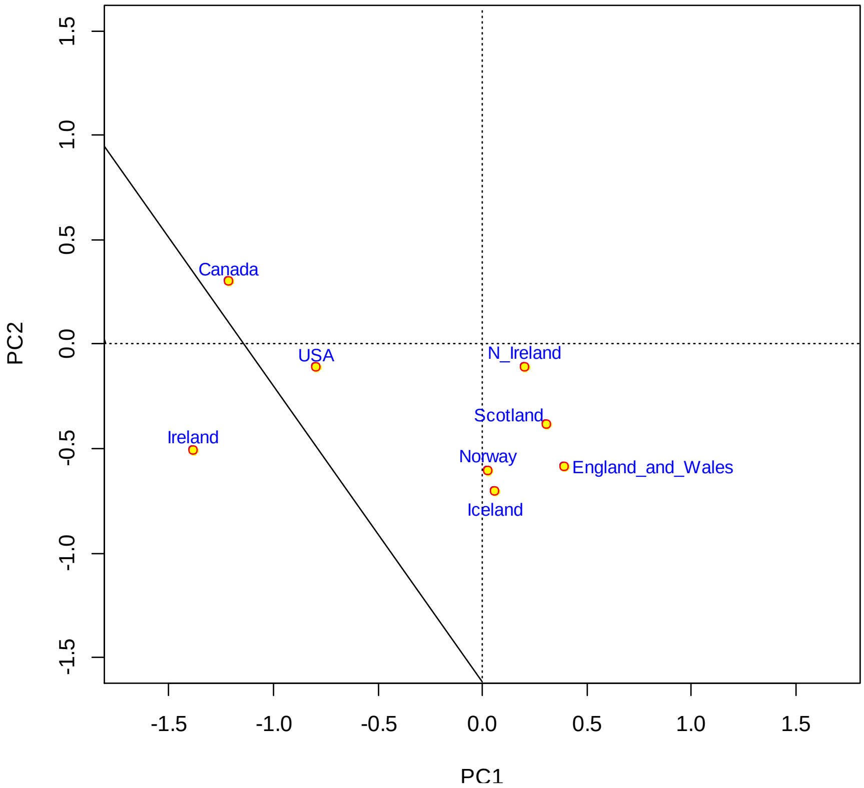


Figure 7.23. Principal component analysis of salmon recaptures in NAFO areas from tagging countries (as log (*x*+1) transformed abundance measures).

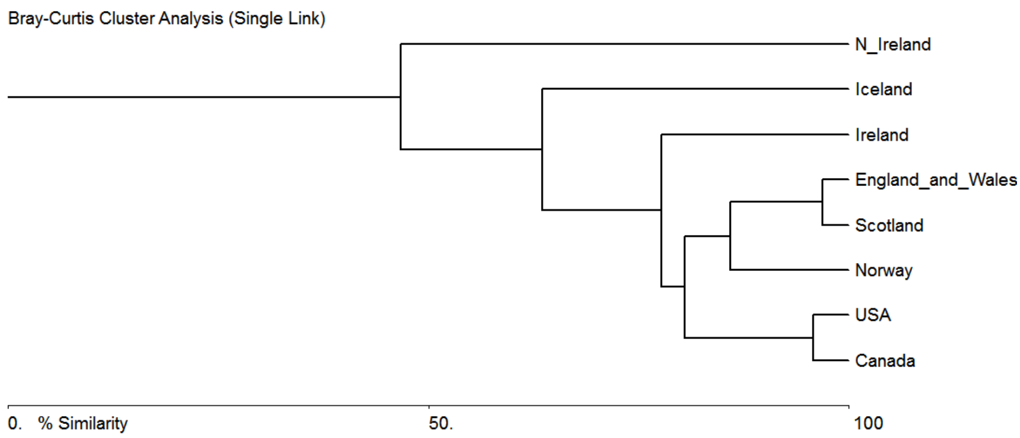


Figure 7.24. Bray–Curtis cluster analysis of salmon recaptures in NAFO areas from tagging countries (as log (*x*+1) transformed abundance measures).

Within North America, the distribution of Canadian and USA tag recaptures around West Greenland was also found to differ (likelihood ratio G-test = 81.61, $p < 0.001$). Canadian salmon were recaptured further north more often than US fish. A comparison of European salmon from Norway, Ireland, the UK (Scotland), and the UK (England and Wales) also showed differences (likelihood ratio G-test = 53.51, $p < 0.001$): salmon from Norway and UK (Scotland) were recovered more in northern areas, while salmon from Ireland and UK (England and Wales) were likely to be recaptured in southwest Greenland.

7.3.3 Greenland tag recoveries and climate

Time-series of SST averaged over the different NAFO areas (near the coast) are shown in Figure 7.25. The data are 5-year averages using only the month of August. Several cold periods can be seen in the time-series for all areas, especially around 1970 and 1983. Around the mid-1990s, a drop in temperature was also observed for nearly all areas, except the southern area. The most significant cold period around 1970 occurred at a similar time to the Great Salinity Anomaly (Dickson *et al.*, 1988), which was a result of increased ice transport flowing out of Fram Strait southward with the East Greenland Current. Figure 7.26 shows the averaged August SST for 1965–1985 and 1986–2006, with the difference between the two periods shown in Figure 7.27. The latter period was warmer than the former over the whole region (typically 0.5–1.5°C warmer, depending on the area). These differences in SST may have influenced salmon distribution, and hence the recaptures in different areas shown in Sections 7.3.2 and 7.3.4. Associations between changes in SST and tag recoveries require further investigation.

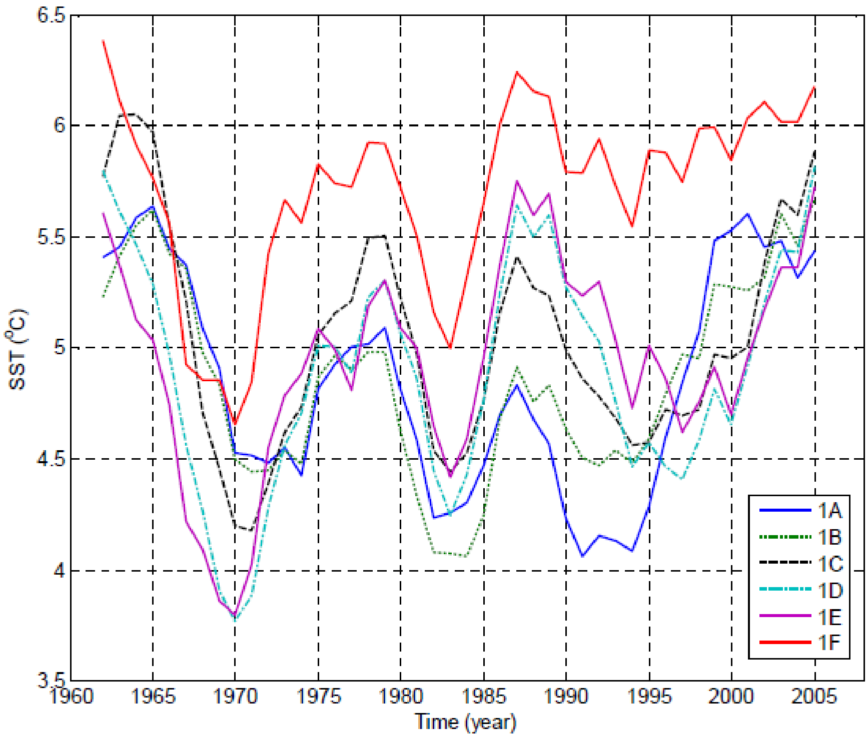


Figure 7.25. August SST averaged over the different NAFO areas along and close to the West Greenland coast. The data are 5-year averages. The different areas where the SSTs are averaged over are shown in Figures 7.26 and 7.27.

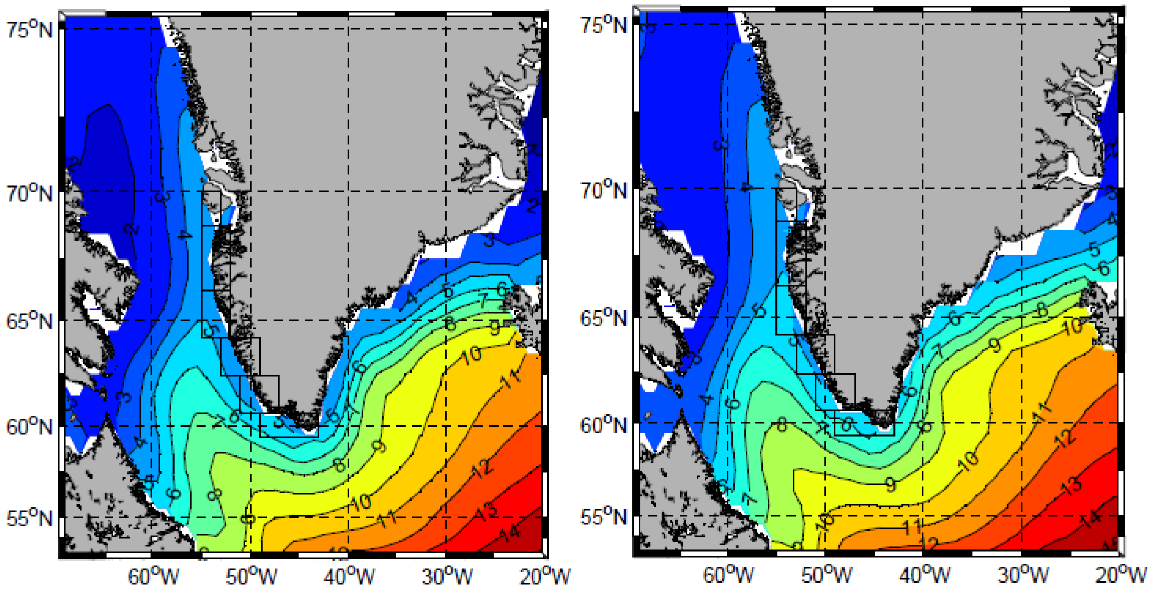


Figure 7.26. SST for August averaged over 1965–1985 (left) and 1986–2006 (right).

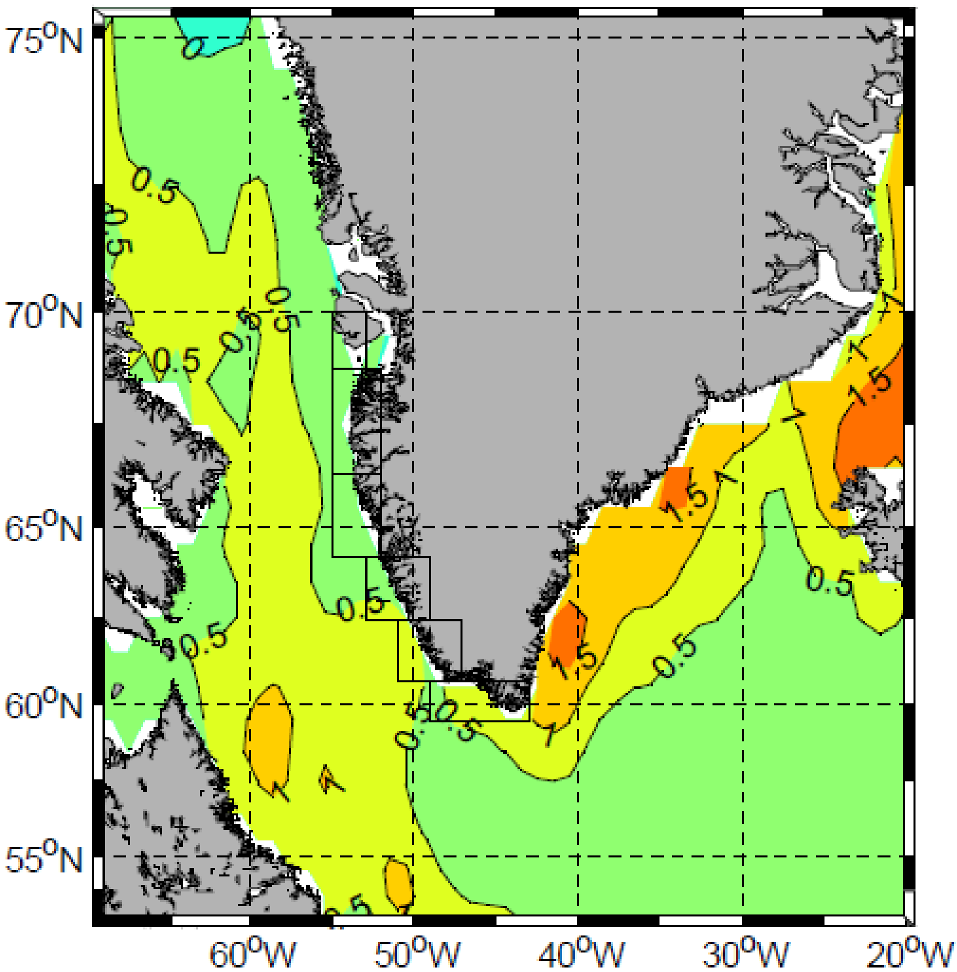


Figure 7.27. SST difference between the two periods (1965–1985 and 1986–2006) for August.

7.3.4 Greenland tag recoveries – temporal variation

Studies have demonstrated that environmental changes around the late 1980s have had a significant influence on the productivity of Atlantic salmon in the Northwest Atlantic (Chaput *et al.*, 2005; Mills *et al.*, 2013). Analysis of the annual midpoint estimates of "pre-fisheries abundance" (the estimated salmon abundance prior to any fisheries taking place) relative to the "lagged spawners" (the number of spawners lagged forward on the basis of expected smolt age distributions and recruitment; Rago, 2001), indicated a temporal split in the time-series of productivity: a high productivity period in 1979–1989 and a low productivity period from 1990 to the end of the time-series (2006; ICES, 2008b).

It was hypothesized that these environmental and abrupt productivity changes indicated non-stationarity, which may have also influenced the distribution of North American and European salmon at Greenland. Thus, 1989 was used to establish two 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, $p < 0.001$) and European salmon (likelihood ratio G-test = 88.33, $p < 0.001$), the distributions between periods were found to differ among NAFO divisions. In both cases, North American and European salmon were found farther south at Greenland in the latter period than in the former. This may have been temperature-related as Period 2 was cooler than Period 1. It may also be related to changes over time in fishery management measures or the distribution of fishing effort (e.g. fishing times may have been more extensive in earlier years, or fishing effort different in different NAFO divisions).

The Greenland database includes information relating to locations of tag release and recovery, fork length, and gutted weight of recaptured fish. These data allow investigation of temporal trends in putative maximum mean swimming speeds (based on time elapsed and distance travelled between tagging and recovery locations), mean length, and mean weight over the period 1960–2000.

The time-series covers 50 years, and during this time, there have been management changes in both the timing of the fishery and the timing of salmon-tagging programmes. Such changes will affect release and capture dates of North American- and European-origin salmon and calculated swimming speeds.

Release and recapture dates of European-origin salmon

Release dates ranged from March to June, with annual 95th percentiles generally overlapping. Capture dates in the 1960s were later in the year than for the rest of the dataseries, taking place between September and November. Catch dates from the 1970s onward generally occurred in September, though they ranged from June to November (95th percentiles overlap). There was a notable reduction in the number of salmon being recaptured in the late 1970s to mid-1980s and from the mid-1990s to 2010, reflecting, in part at least, reduced levels of tagging. In general, among-year variations were not notably different from within-year variations, with the exception of the 1960s capture dates (Figure 7.28). An ANOVA comparing dates of release in each year by decade showed that significant differences did occur ($F_{4,351} = 10.398$, $p < 0.0001$), and a *post hoc* least significant difference (LSD) test indicated that this difference was specific to release dates in the 2000s (Table 7.9), with no significant differences between other decades. Similar comparisons for decadal recaptures also showed that significant differences occurred ($F_{4,351} = 22.568$, $p < 0.0001$) and that they were specific to dates in the 1960s (Table 7.10).

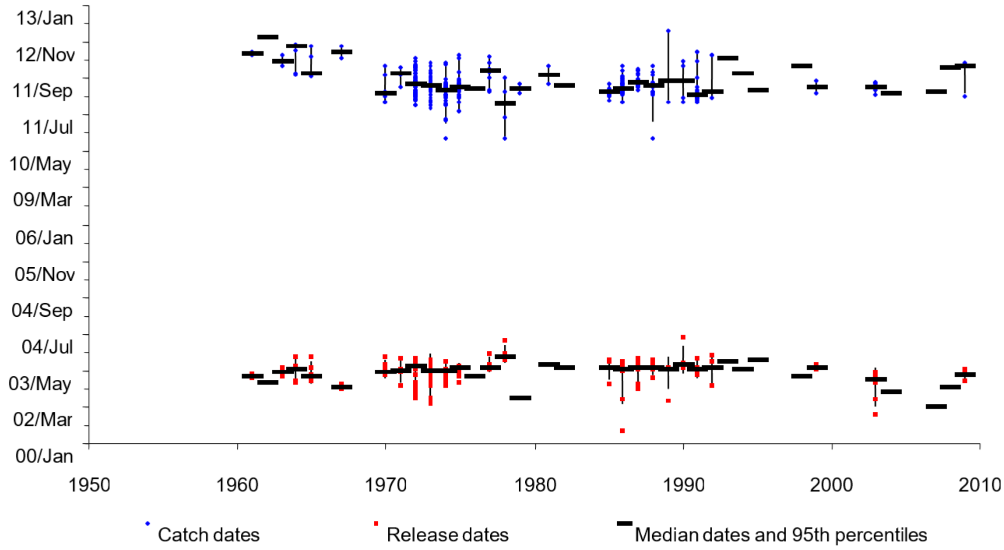


Figure 7.28. Release dates of European-origin tagged salmon (red) and capture dates (blue).

Table 7.9. ***Post hoc*** **LSD test results detailing decadal differences in the release dates of European tagged salmon.**

Decadal comparison	Difference (days)	s.e.	*p*
1970–1960	4.22	4.00	0.892
1980–1960	10.19	4.21	0.212
1980–1970	5.97	2.15	0.105
1990–1960	14.13	4.93	0.086
1990–1970	9.91	3.34	0.069
1990–1980	3.94	3.59	0.877
2000–1960	−15.97	5.83	0.114
2000–1970	−20.19	4.57	0.001[1]
2000–1980	−26.16	4.75	< 0.001[2]
2000–1990	−30.10	5.40	< 0.001[2]

[1] $p < 0.01$; [2] $p < 0.001$

Release and recapture dates of North American-origin salmon

Release dates for North American hatchery-origin salmon were more varied than European release dates, tending to occur between April and August. A period in the early 1970s had a large range in release dates, and releases were recorded as late as November throughout the 1970s. In the first half of the 1980s, releases were focused around May and June, becoming wider ranging (March–July) into the early-1990s, at which time numbers of recaptured tagged fish declined markedly. From the mid-2000s, small numbers of tag recoveries were recorded, and this was associated with the wide range of release dates (April–September). Generally, median release dates from 1970 to 2000 were between March and April, with comparable inter 95th percentile ranges overlapping (Figure 7.29). Statistical comparison of decadal release dates using ANOVA did, however, show significant differences ($F_{4,3209} = 82.249$, $p < 0.0001$), with almost all decades differing significantly from each other (*post hoc* LSD test, Table 7.11).

Table 7.10. *Post hoc* LSD test results detailing decadal differences in the recapture dates of European tagged salmon.

Decadal comparison	Difference (days)	s.e.	p
1970–1960	−48.50	5.14	< 0.001[1]
1980–1960	−46.00	5.41	< 0.001[1]
1990–1960	−41.73	6.33	< 0.001[1]
2000–1960	−41.37	7.48	< 0.001[1]
1990–1970	6.76	4.29	0.116
1980–1970	2.49	2.76	0.367
1990–1980	4.27	4.61	0.355
2000–1970	7.13	5.87	0.225
2000–1980	4.63	6.10	0.448
2000–1990	0.37	6.93	0.958

[1] $p < 0.001$

Differences were also apparent in recapture dates of North American-tagged salmon, which showed a broad range across the years 1966–1991, at which time the numbers of tag recoveries fell (Figure 7.29). Inter 95th percentile ranges generally overlapped among years; however, ANOVA analysis of recapture day by decade did indicate significant differences ($F_{4,3209} = 67.505$, $p < 0.0001$), with most decades differing from each other (Table 7.13).

Table 7.11. *Post hoc* LSD decadal differences of release dates of North American-tagged salmon.

Decadal comparison	Difference (days)	s.e.	p
1970–1960	1.154	1.586	0.467
1980–1960	−8.551	1.626	< 0.001[1]
1980–1970	−9.705	0.758	< 0.001[1]
1990–1960	−18.501	1.996	< 0.001[1]
1990–1970	−19.655	1.385	< 0.001[1]
1990–1980	−9.950	1.430	< 0.001[1]
2000–1960	18.206	4.271	< 0.001[1]
2000–1970	17.051	4.022	< 0.001[1]
2000–1980	26.757	4.037	< 0.001[1]
2000–1990	36.707	4.200	< 0.001[1]

[1] $p < 0.001$

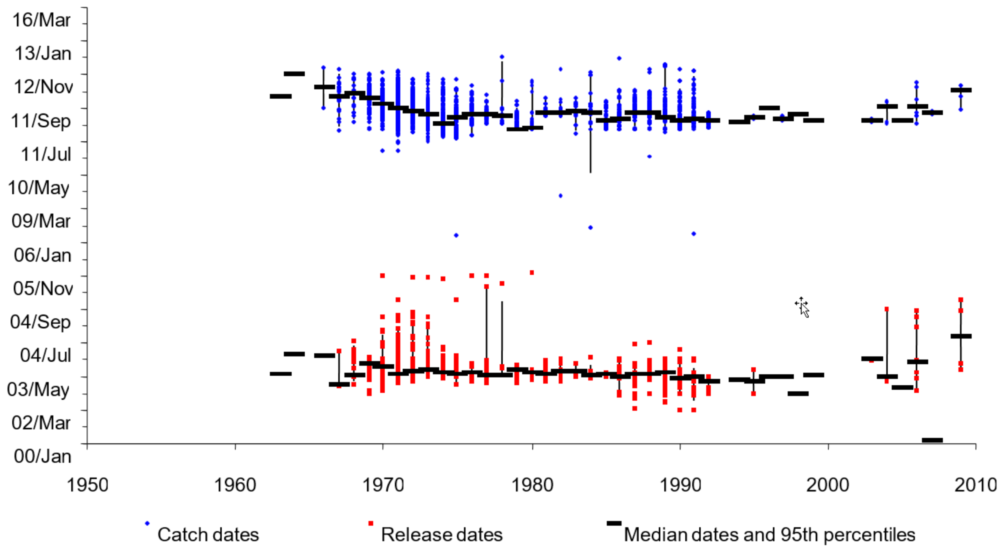


Figure 7.29. Release dates of North American-origin tagged salmon (red) and capture dates (blue).

Table 7.12. ***Post hoc*** **LSD decadal differences of recapture dates of North American-tagged salmon.**

Decadal comparison	Difference (days)	s.e.	p
1970–1960	−28.932	1.88	< 0.001[1]
1980–1960	−29.200	1.926	< 0.001[1]
1980–1970	−0.268	0.899	0.765
1990–1960	−34.093	2.366	< 0.001[1]
1990–1970	−5.161	1.641	0.002[2]
1990–1980	−4.893	1.694	0.004[2]
2000–1960	−16.995	5.061	< 0.001[1]
2000–1970	11.936	4.766	0.012[3]
2000–1980	12.205	4.784	0.011[3]
2000–1990	17.098	4.977	< 0.001[1]

[1] $p < 0.001$, [2] $p < 0.01$, [3] $p < 0.05$

Weights, lengths, and swim speeds of Greenland-caught, European-origin, and North American-origin salmon

Recorded gutted weights and lengths of tagged salmon captured in the Greenland fishery provide an opportunity to examine how these changed between 1960 and 2010. The mean gutted weight of European salmon showed a slight decline from 3.3 kg in 1961 to 2.8 kg in 2010 ($p > 0.05$, $n = 79$, Figure 7.30). This was similar for North American-origin salmon, which fell from 2.6 kg in 1967 to 2.4 kg in 2007 ($p > 0.05$, $n = 508$, Figure 7.31). Neither decline was statistically significant.

Fork lengths did not show the same pattern in European- and North American-origin 1SW salmon. Those from Europe showed an apparent reduction in average length (Figure 7.32, $n = 152$), while North American-origin 1SW fish showed an apparent increase in length at capture (Figure 7.33, $n = 154$). The regression of fork length over year was significant at $p < 0.05$ for both European- and North American-origin 1SW salmon. It should be noted that the data were not corrected for changes in the spatial and temporal distribution of the sampling of the fishery, which has been shown to influence annual estimates of length and weight of sampled salmon (ICES, 2015) and could influence tag recoveries.

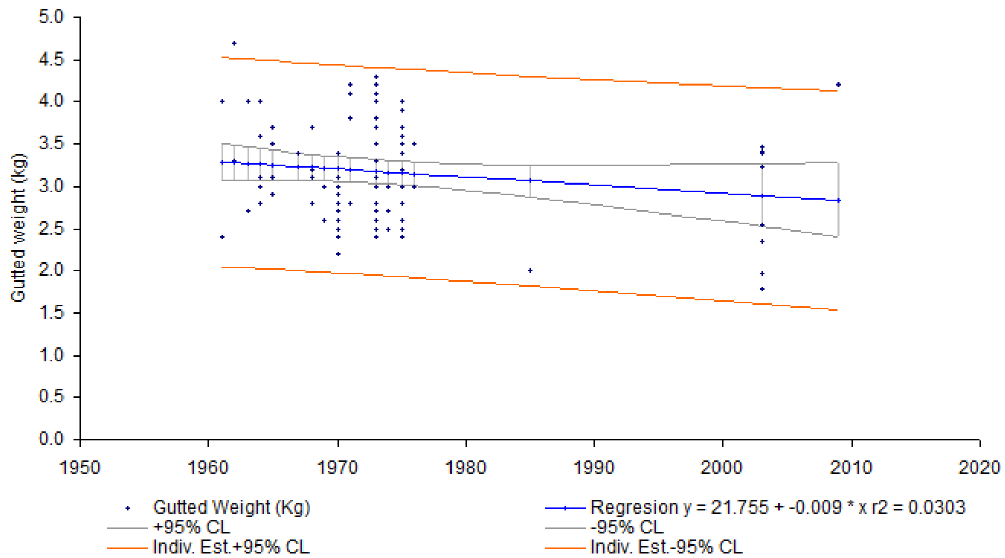


Figure 7.30. Gutted weights of tagged 1SW European-origin salmon captured off Greenland 1960–2010 (*n* = 79).

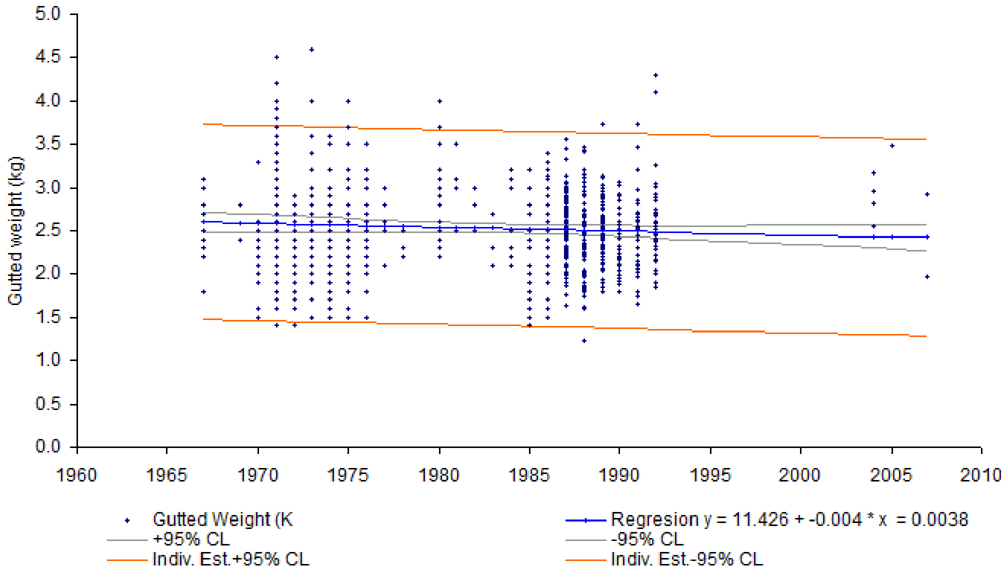


Figure 7.31. Gutted weights of tagged 1SW North American-origin salmon captured off Greenland 1960–2010 (*n* = 508).

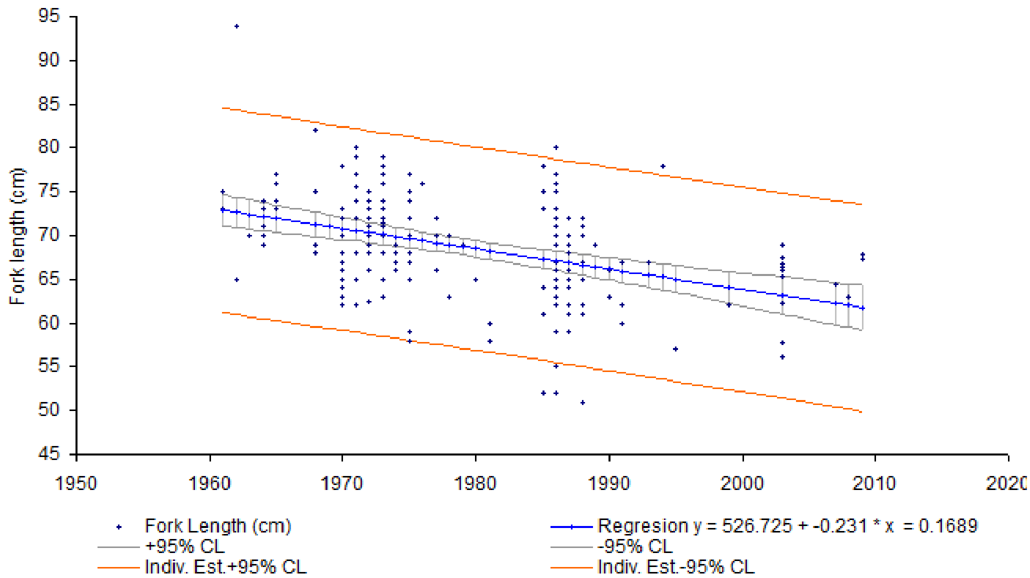


Figure 7.32. Lengths of tagged 1SW European-origin salmon captured off Greenland 1960–2010 ($n = 152$).

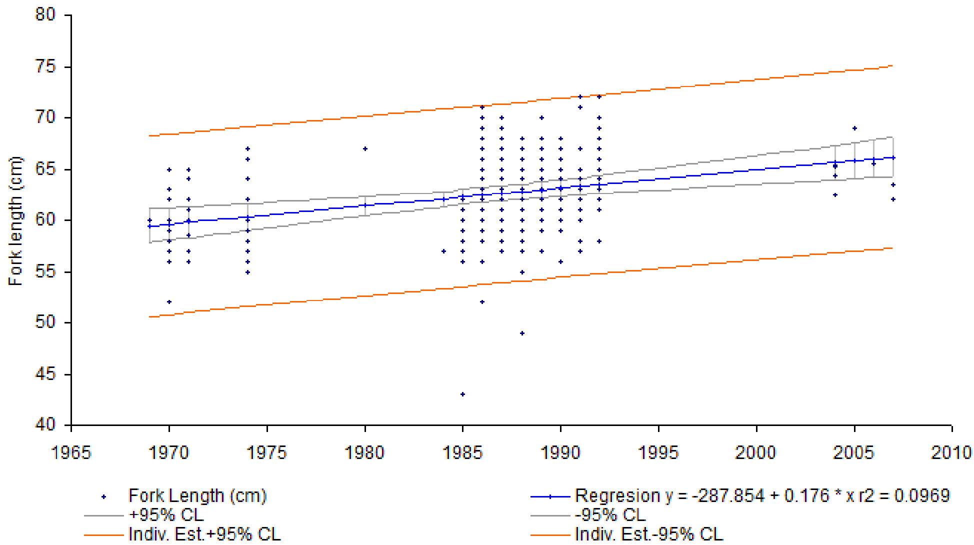


Figure 7.33. Lengths of tagged 1SW North American-origin salmon captured off Greenland 1960–2010 ($n = 154$).

Using the compiled tagging database, swim speed can be calculated from the latitude and longitude of release and recovery locations and dates. While distances can only be calculated based on direct paths and travel time is rounded to the day, the calculated migratory speeds over the sample period are informative. Swim speeds, as metres per second (m s^{-1}), appear to have decreased for European-origin 1SW salmon from 0.32 m s^{-1} in 1961 to 0.29 m s^{-1} in 2009 (Figure 7.34, $n = 356$), while there is no apparent change for North American-origin salmon, i.e. 0.43 m s^{-1} in 1967 and 2007 (Figure 7.35, $n = 1401$). Neither of the regressions were statistically significant ($p > 0.05$). Changes in release and recapture dates over the 50-year period may influence calculated swim speeds; however, the averages of these swim speeds tend to be similar.

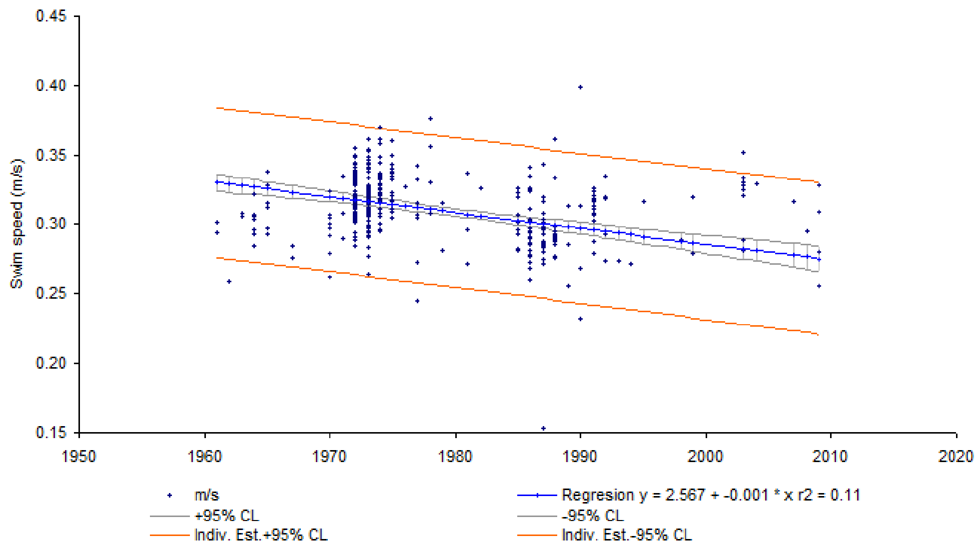


Figure 7.34. Swim speeds of tagged 1SW European-origin salmon captured off Greenland 1960–2010 (*n* = 356).

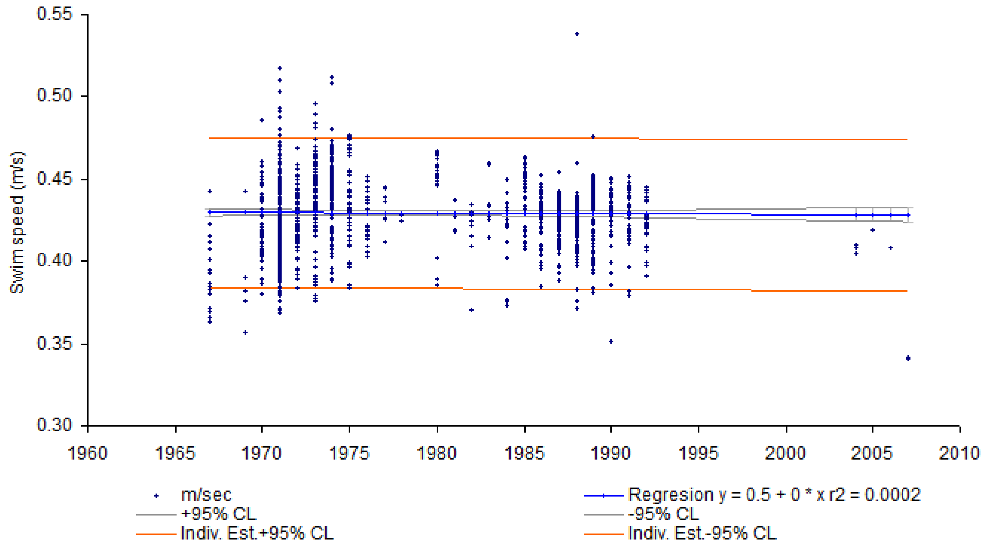


Figure 7.35. Swim speeds of tagged 1SW North American-origin salmon captured off Greenland in 1960–2010 (*n* = 1401).

7.4 Adult tagging in the Norwegian Sea

Several programmes involving tagging of adults in the Norwegian Sea and off the Norwegian coast were carried out in 1970. Figure 7.36 illustrates the returns of salmon tagged in different months and in different areas. A few of the fish tagged early (April) in the northern Norwegian Sea were recovered later in rivers in Russia, while fish subsequently tagged through May and June were recovered mainly in mid- and southern Norway.

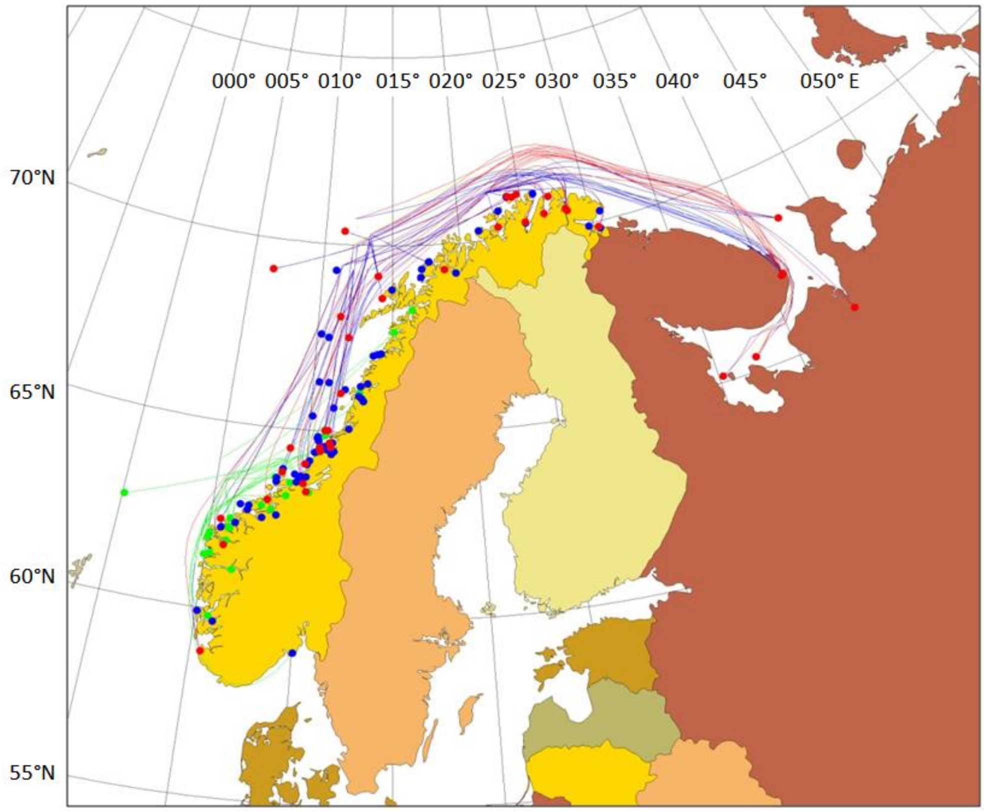


Figure 7.36. Recaptures of adult Atlantic salmon tagged and released in the Norwegian Sea in spring 1970. Red lines and dots represent fish tagged in April, blue are May, and green are June. Dots represent recovery locations. Lines are descriptive to link tag and recovery locations and do not represent putative swim paths.

7.4.1 Multivariate analyses of the Norwegian adult tagging dataset

The PCA of the adult tagging dataset from Norway, performed on 280 *z*-score transformed variables (Figure 7.37, reduced from 513 owing to missing values), showed that adult fish with longer residence times (the time between tagging and release, and recovery) generally showed more growth (seen as an increase in length) and higher recovery weight (round weight). Fish released below 69°N were generally released later in the year and displayed faster swim speeds (as calculated through straight lines between mark and recapture locations). Fish released above 69°N tended to have longer residence times, were larger, and weighed more at recapture, and those that were released later in the time-series (in years) tended to weigh more at release and moved south.

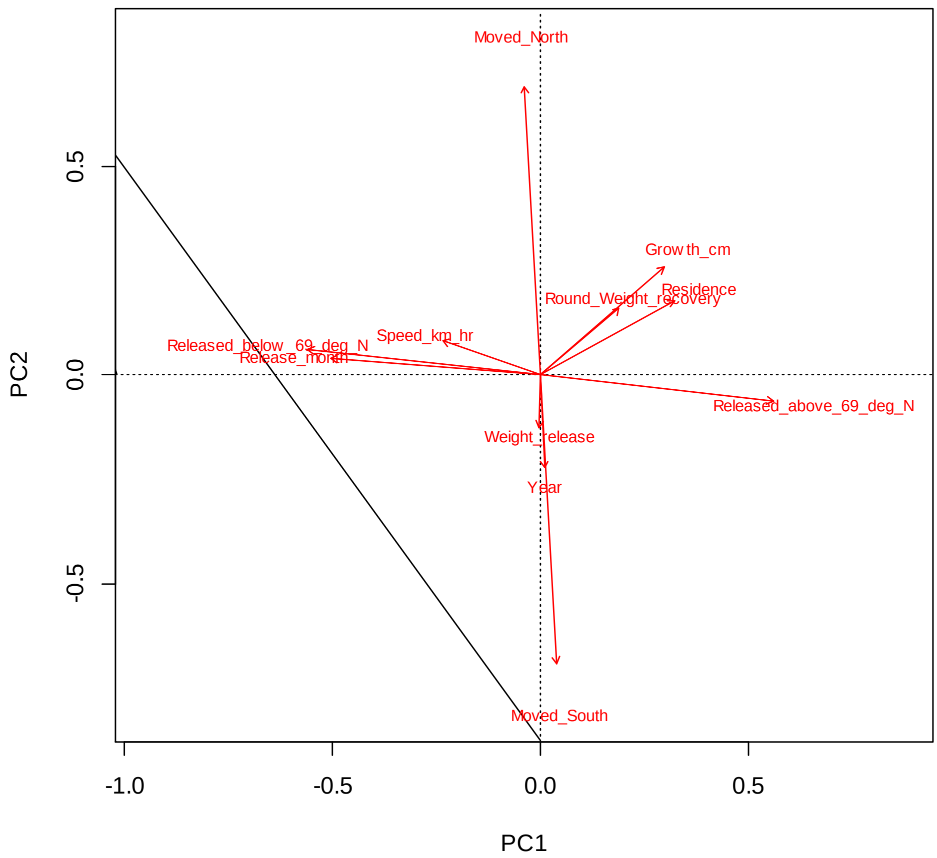


Figure 7.37. PCA variable loadings of recovered salmon tagged as adults in the Norwegian Sea (performed on *z*-score transformed variables).

7.5 Adult tagging at Greenland

Adult salmon were tagged with Carlin tags between 1969 and 1972 around Greenland (in Davis Strait and Labrador Sea, Figure 3.1). Figure 7.38 shows that while these were predominantly recaptured along the west coast of Greenland (167 of 236 recoveries), there were also recoveries around the UK (England and Wales) (11), UK (Scotland) (25), Ireland (11), France (2), Spain (2), and Canada (18). Using the latitudes and longitudes of fish tagging and recovery locations to calculate direct distances between the two gives minimum distances travelled. Pairing these with the number of days between tagging and recapture dates allowed estimation of salmon swim speeds by country of recapture (Figure 7.39). ANOVA on log-transformed values (not including recaptures in France and Spain, for which only two recaptures in each country were made) indicated that significant differences existed between swim speeds by country of recapture ($F_{4,165} = 3.43$, $p < 0.05$). The largest differences in estimated swim speeds (Table 7.13) were between recaptures in Ireland and Greenland ($p < 0.05$), followed by Ireland and Canada, the UK (England and Wales) and Greenland ($p < 0.05$), the UK (England and Wales) and Canada, and Scotland and Greenland ($p < 0.05$).

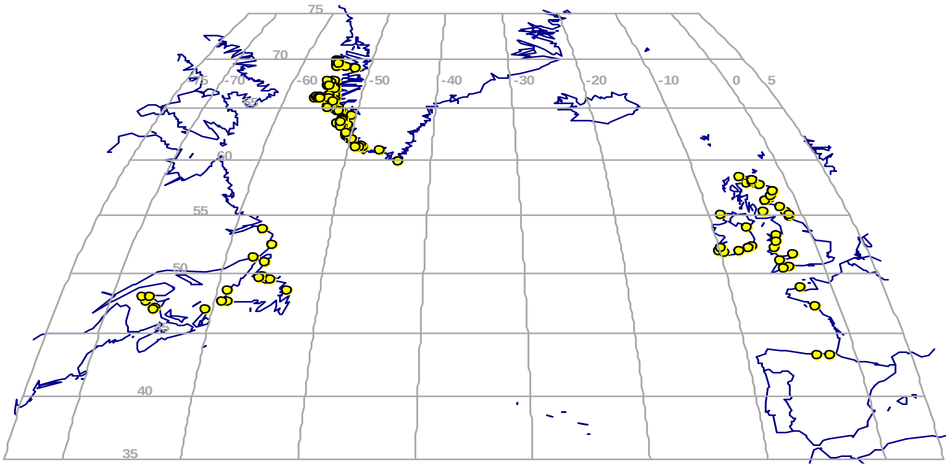


Figure 7.38. Recovery locations of adult salmon tagged in Davis Strait and the Labrador Sea.

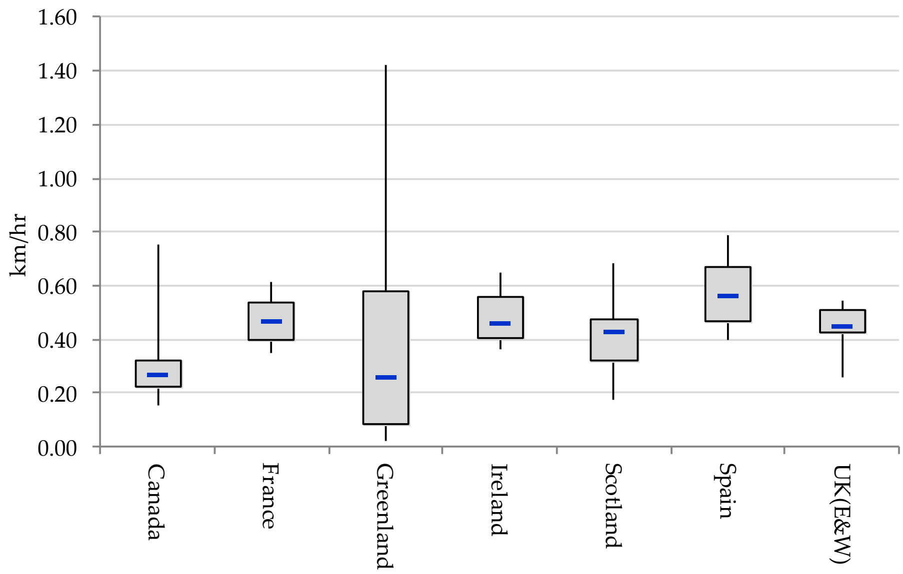


Figure 7.39. Box and whiskers plot of the estimated swim speeds of adult salmon marked in West Greenland by country of recapture.

Table 7.13. Differences in median swim speeds (and rank order) of salmon tagged in West Greenland and subsequently recaptured, and significant differences (*post hoc* least squared difference test, performed on *Ln* transformed values) by recapture country.

		Differences in median swim speeds (km h^{-1} and rank order[1])						
	Recapture country	**Canada**	**France**	**Greenland**	**Ireland**	**UK (Sc)**	**Spain**	**UK (EW)**
Significant differences in *Ln* transformed swim speeds (*p*)	**Canada**		0.20	−0.01 (10)	0.19 (2)	0.16 (6)	0.29	0.18 (4)
	France	NA		0.21	−0.01	−0.04	0.10	−0.02
	Greenland	0.324	NA		0.2 (1)	0.17 (5)	0.30	0.19 (3)
	Ireland	0.179	NA	0.019[2]		−0.03 (7)	0.10	−0.01 (9)
	UK (Sc)	0.325	NA	0.014[2]	0.552		0.13	0.02 (8)
	Spain	NA	NA	NA	NA	NA		−0.11
	UK (EW)	0.234	NA	0.026	0.863	0.683	NA	

[1] With only two recaptures in France and Spain, values were not incorporated into either rank ordering or significance testing.
[2] $p < 0.05$.

7.6 Overview of the Salmon at Sea: Scientific Advances and their Implications for Management symposium

Organized by NASCO and ICES, the Salmon at Sea: Scientific Advances and their Implications for Management symposium was held in La Rochelle, France 11–13 October 2011. Three of the papers presented at the symposium detailed investigations based on the national and international salmon tagging and recovery programmes detailed in the databases covered in this report.

Miller *et al.* (2012b) reported on a US tagging programme that began in 1962 following the development of an Atlantic salmon fishery off West Greenland, with over 1.5 million smolts tagged with Carlin tags by 1996. A recovery rate of around 0.55% was achieved: 23.2% of these in Canada, 26% in Greenland, and 50.8% in the US (Figure 7.40). Marine survival, based on returns of tagged salmon to the Penobscot River, was analysed using a generalized additive model to investigate the possible effects of month and year of release, sea age, smolt age, North Atlantic Oscillation (NAO), Atlantic Multidecadal Oscillation (AMO) indices, and local sea surface temperatures. Findings showed that AMO and NAO indices, SST, sea age, and date affected survival.

US-origin salmon are believed to overwinter in the Labrador Sea and are expected to arrive along the West Greenland coast after spending a full winter at sea. The earliest tag recoveries indicate that US-origin salmon had spent 14 months at sea before their capture in the West Greenland fishery. Because of the timing of the Greenland fishery and the fact that recaptures of tagged salmon are dependent on the fishery, it is possible that 1SW salmon arrived in Greenlandic waters before the fishery commenced and were thus undetected. Monthly patterns of tag recoveries at Greenland are also likely to reflect the dynamics of the fishery and/or the response of fishers to the arrival of salmon (Figure 7.41).

Salmon arriving in Greenlandic waters become susceptible to fishing in the south one or two months earlier than in the north. The Canadian and Greenland fisheries probably harvested mainly 1SW salmon (as indicated by the high percentage of 1SW tags recovered in the fisheries, Figure 7.40) that would otherwise have returned to home rivers the following spring as 2SW adults. 2SW salmon in the Gulf of Maine accounted for > 50% of tag recoveries in that area (Figure 7.40). Post-smolts were the second largest source of tag recoveries in the Gulf of Maine. Tags were recovered from post-smolts as late as July, many from the Bay of Fundy (NAFO Division 4X), indicating a different migration pattern from that seen in post-smolts from other areas which are believed to be heading directly for Greenland. Miller *et al*. (2012b) stated that the results provide information to support fisheries management of Atlantic salmon stocks spatially and temporally in US rivers and the West Greenland fishery.

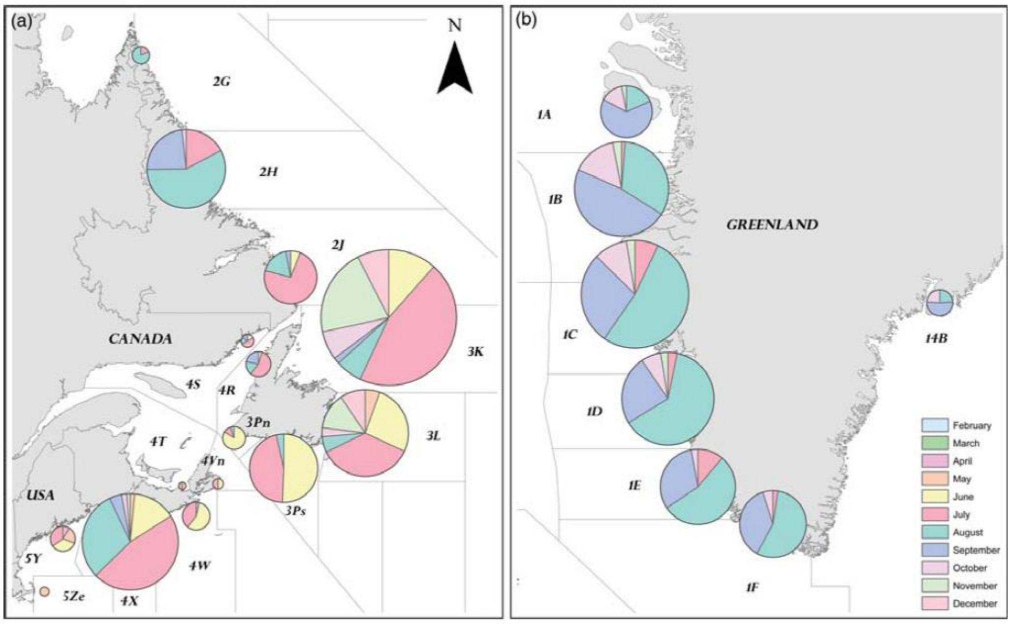


Figure 7.40. Geographic distribution of Carlin tag recoveries of US-origin salmon by sea age (a) in US and Canadian waters and (b) at Greenland. Areas shown are NAFO divisions and ICES Statistical Area XIV east of Greenland. Circle size indicates the number of tags recovered. For scale, the smallest sample size (*n* = 2) came from NAFO Division 4T in the Gulf of St Lawrence and the largest sample size (*n* = 712) from NAFO Division 3K off Newfoundland (Figure 2 in Miller *et al*., 2012b).

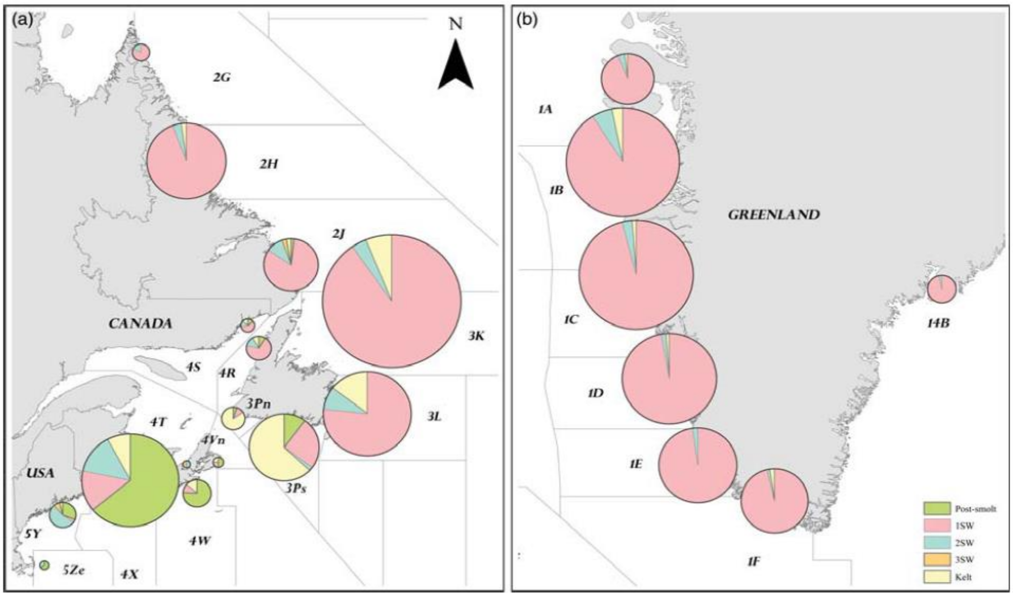


Figure 7.41. Geographic distribution of Carlin tag recoveries of US-origin Atlantic salmon by month of the year (a) in US and Canadian waters and (b) at Greenland. Areas shown are NAFO divisions and ICES Statistical Area 14 east of Greenland. For scale, the smallest sample size (*n* = 2) came from NAFO Division 4T in the Gulf of St Lawrence and the largest sample size (*n* = 712) from NAFO Division 3K off Newfoundland (Figure 3 in Miller *et al.*, 2012b).

Jacobsen *et al*. (2012) investigated tag recoveries from international releases recovered in the Faroes high seas longline fisheries between 1968 and 2000. A total of 2651 tags were recovered from tagging programmes in 13 countries or jurisdictions. Geographic distribution and origin of the salmon captured with respect to differences in sea age, fishery season, and hydrographic features in the Faroes area were examined in both the autumn and winter fisheries approximating the position of the Iceland–Faroe Front

(Figure 7.42). Results indicated that salmon were not distributed randomly in the Faroes area by fishing season, sea age, or country of origin (Figure 7.43). Distributions were found to be partially dependent on their geographic origin. Salmon from countries in the northern European stock complex were distributed significantly farther northeast than those from countries in the southern European stock complex. Additionally, the proportion of tag recoveries from southern European countries was higher in autumn, and the proportion recovered from northern European countries was higher in winter.

The median recapture distance from a dividing line splitting the southwest fishery from the northeast fishery (Figure 7.42) was positive (i.e. indicating a distribution northeast of the dividing line) for the UK (Scotland), Norway, Sweden, and the Faroes, and negative for Ireland, the UK (England and Wales), and Iceland (indicating a distribution southwest of the dividing line). For Norway and Sweden, the majority of data (above the 25th percentile) were greater than zero, being located exclusively northeast of the dividing line. The median distance was also positive for all sea ages. For 3SW salmon and salmon recovered during winter, the location was almost exclusively northeast of the dividing line (Figure 7.43). Jacobsen *et al*. (2012) hypothesized that the apparent temporal and spatial segregation of stocks of different origin indicates differential exploitation, and that this could inform fisheries management with regard to temporal and spatial fishing options for the Faroes commercial salmon fishery should it recommence in future. Reddin *et al.* (2012) examined 5481 tags recovered at Greenland from salmon released in Canada, France, the Faroes, Greenland, Iceland, Ireland, Norway, Spain, the UK (Northern Ireland), the UK (Scotland), the UK (England and Wales), and the US from the early 1960s to 2009. For 4806 tags, recovery latitude and longitude information were available, describing, to varying degrees of accuracy, the location of recovery of tagged fish. Release and recovery dates were variable, though no significant differences over time were apparent.

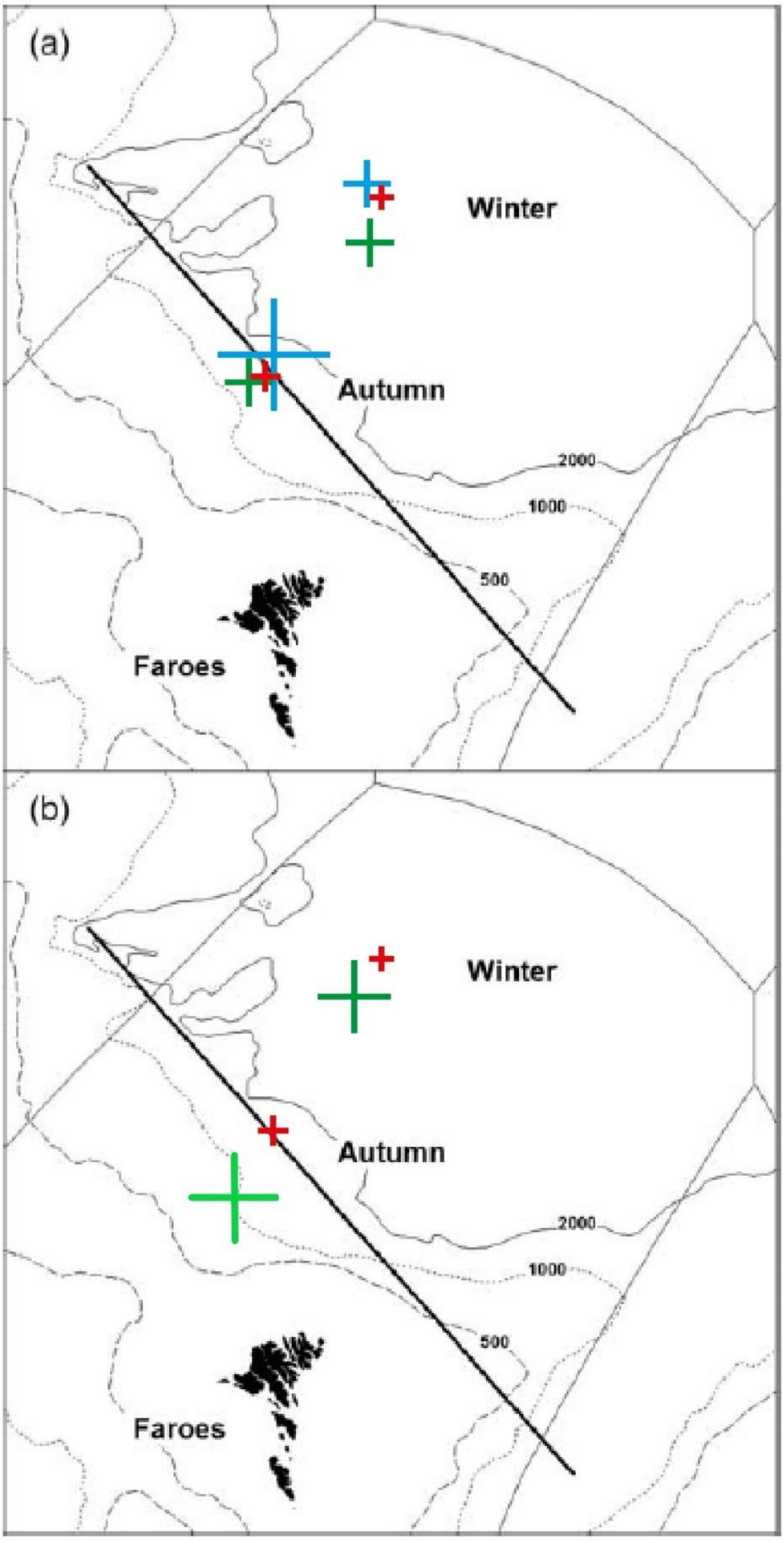


Figure 7.42. Average geographic locations of recapture of salmon during the Faroese longline fishery indicated by crosses representing 95% confidence intervals for latitude and longitude directions by (a) sea age (1SW green, 2SW red, and 3SW blue crosses) during autumn (November–December) and winter (January–April), and (b) from the southern (green crosses) and northern (red crosses) European stock complexes during autumn and winter for 2SW salmon. The 500-m (dashed line), 1000-m (broken line), and 2000-m (solid line) depth contours and national EEZs (solid thin lines) and the dividing line is also shown (Modified from Figure 4 in Jacobsen et al., 2012).

The distribution and growth of salmon of different origins was investigated, with the proportion of recoveries from East Greenland suggesting that potential MSW salmon from northern Europe had a more easterly distribution than those from southern Europe. The location of recovery of salmon from North America differed from that of European salmon along the west coast of Greenland. Tag recoveries by country were not uniformly distributed across the respective NAFO divisions (Figure 6.1). Tags from salmon originating in Canada and the US were more commonly recovered in more northerly locations than tags from European-origin salmon.

The straight-line migration speed of both North American and European salmon changed very little over the time-series, but was 40% greater for North American salmon (0.43 m s^{-1}) than for European salmon (0.29–0.32 m s^{-1}).

Additional analyses were conducted to evaluate the influence of the NASCO Tag Return Incentive Scheme on the recovery rates external tags at Greenland. The NASCO Tag Return Incentive Scheme was introduced in 1989 to increase the return rate of externally applied tags through a monetary lottery scheme. The return rates per tonne of salmon harvest pre and post 1989 were similar (ANOVA; $F = 0.003$, $p = 0.957$). Although there was an initial increase in recoveries when the programme started, return rates quickly decreased to levels commensurate with those prior to 1998. Further, recoveries that had been applied to juvenile salmon in the US indicated that the recovery rate per tag applied had in fact declined significantly between 1983–1988 and 1989–1996, also suggesting that the reward scheme had no apparent influence on tag recoveries at Greenland.

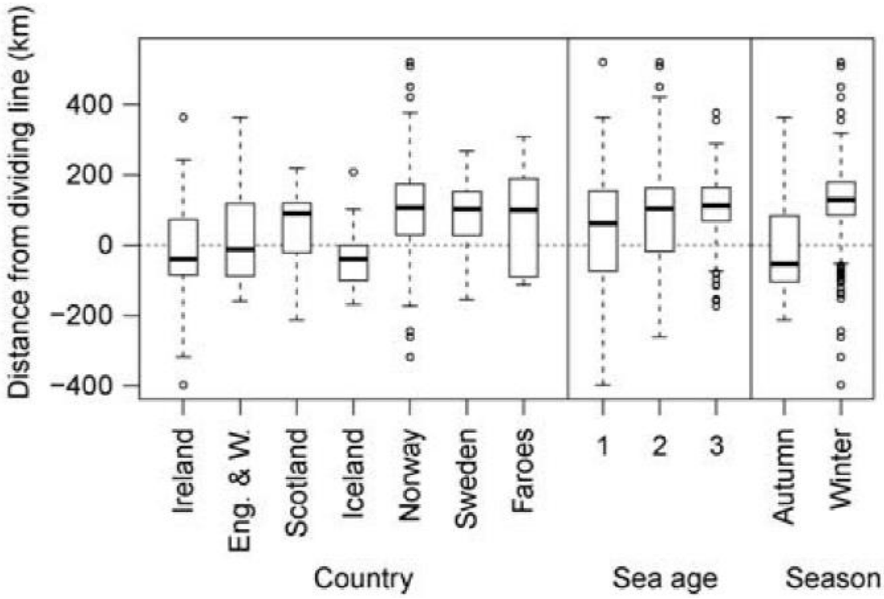


Figure 7.43. Boxplots of the distance of recaptures from the dividing line between autumn and winter fisheries following the Iceland–Faroe Front (IFF), by country of origin, sea age, and season. Distance is zero at the artificial dividing line, positive in a northeasterly direction, and negative in a southwesterly direction. Median values, interquartile ranges, and minimum-to-maximum values are indicated; open circles indicate outlier values > 1.5-fold the IQR from the IQR limits (Jacobsen *et al.*, (2012).

8 Conclusions

The efforts and resources expended across the North Atlantic over the last 50 years in tagging migrating juvenile and adult salmon and recovering tagged fish have been immense. International tagging operations have tagged and released millions of salmon over the period. Recoveries totalling 5508 tags from the seas around Greenland between 1963 and 2009, and 2646 tags from Faroes waters between 1966 and 1998 have been recorded in the North Atlantic Salmon Tag Recovery databases (NASTR) to date and the number of records continues to rise with additional catches and tag detections in Greenland. The NASTR database, therefore, contains the most comprehensive collection of data on tagging and recovery locations available and is the only such compilation of international tagging and recovery programmes for Atlantic salmon. It represents an historic advance in the compilation of tag-recapture data and for the first time allows international tag recoveries to be analysed jointly.

The analyses presented here are based on preliminary investigations undertaken during the ICES workshops WKDUHSTI (ICES, 2007), WKSHINI (ICES, 2008a), WKLUSTRE (ICES, 2009), and WKSTAR (ICES, 2012) as well as a series of research articles published on the recent analyses of the data. These give a comprehensive overview of salmon migration to the recognized feeding grounds around Greenland and the Faroes and information on the time and distances of migrations and changes in biological characteristics over time.

Through review of catch densities and locations around the Faroes, patterns of total, national, and age-specific recovery hot spots suggested significant differences in distributions of fish between the autumn and winter fisheries, with a general shifting of the distribution of recovery east and north of the Faroe Islands. Associations between catch areas and countries of origin have shown an eastern Atlantic/western Atlantic country-of-origin split, generally followed by splits of countries within these large regional groupings. This may represent differences in the migration destinies of salmon from different locations and differences in the timings of migrations of salmon from different locations along migration routes, although such conclusions need to be tempered against possible differences in the timing of fishing at different locations. Multivariate analyses of the Faroes tag-recovery data showed similar temporal relationships between weight, length, age, and season of catch over the time-series. Greater recovery weights, sea ages, higher latitudes and longitudes, and spring catches were primarily exhibited by Norwegian-origin salmon compared to salmon originating in Ireland, UK (England and Wales) and UK (Northern Ireland), while salmon from UK (Scotland), Sweden, the Faroes, and Iceland overlapped these characteristics with the other countries.

Sea surface temperature associations with catches suggest a change in location relative to a 4°C cut-off, possibly owing to prevailing winds and a high North Atlantic Oscillation index.

Similar conclusions can be drawn from analysis of the Greenland tag-recovery database, with catches on the west coast of Greenland showing different proportions of country of origin with progression northwards, and countries of origin with close proximity showing generally similar tag-recapture distributions in different areas. Investigations into temperature influences indicate notable differences over the earlier and latter parts of the time-series. With reported temperature effects upon salinity, it may be hypothesized that such changes would influence temporal shifts in distribution/catch, migration timings, and weights and lengths of Greenland-caught salmon.

While these findings are interesting and valuable in dissecting the historic and more recent sea migrations of Atlantic salmon, they should be seen as initial investigations. The compiled NASTR database represents the combined, extensive efforts of sixteen nations, initially collected and subsequently collated through collaborative activities at considerable cost. All parties are encouraged to explore these data and use them to further our understanding of salmon migrations, with the aim of discerning changes that may have coincided with population declines over the same period.

Researchers who further explore these data are encouraged to take into account the various caveats detailed throughout this report that affect the conclusions drawn from reanalysis of these data. As an example, including the number of tagged fish released and/or more detailed fishery dynamics would enhance conclusions drawn here about temporal or spatial trends in the recapture data. These data are available in some agencies, and researchers are encouraged to contact them for specific information. In addition, researchers using the data are requested to acknowledge ICES, this report, the NASTR database, and all the data providers in any subsequent papers or reports.

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Annex 6: Glossary of acronyms used in this report

1SW *(one-sea-winter).* Maiden adult salmon that has spent one winter at sea.

2SW *(two-sea-winter).* Maiden adult salmon that has spent two winters at sea.

3SW *(three-sea-winter).* Maiden adult salmon that has spent two winters at sea.

AMO (*Atlantic Multidecadal Oscillation*). A mode of natural variability occurring in the North Atlantic which has its principle expression in the sea surface temperature (SST) field.

ANOVA (*analysis of variance*). Statistical models used to analyse the differences among group means.

CPUE *(catch per unit of effort).* A derived quantity obtained from the independent values of catch and effort.

CRR (*Cooperative Research Report*)

CWT *(coded wire tag).* The CWT is a length of magnetized stainless steel wire 0.25 mm in diameter. The tag is marked with rows of numbers denoting specific batch or individual codes. Tags are cut from rolls of wire by an injector that hypodermically implants them into suitable tissue. The standard length of a tag is 1.1 mm.

DFO *(Department of Fisheries and Oceans).* DFO and its Special Operating Agency, the Canadian Coast Guard, deliver programs and services that support sustainable use and development of Canada's waterways and aquatic resources.

Distant-water fisheries. Fisheries which take place away from the home coastal waters of the fishing fleet, usually classed as waters outside their home country 200nm zone.

DNA *(deoxyribonucleic acid).* DNA is a nucleic acid that contains the genetic instructions used in the development and functioning of all known living organisms (with the exception of RNA- ribonucleic acid viruses). The main role of DNA molecules is the long-term storage of information. DNA is often compared to a set of blueprints, like a recipe or a code, since it contains the instructions needed to construct other components of cells, such as proteins and RNA molecules.

EEZ (*exclusive economic zone*). An area of sea designated under the United Nations Convention on the Law of the Sea which a state has rights regarding the exploration and use of marine resources, stretching out 200 nautical miles from the coastal baseline.

ICNAF (*International Commission for the Northwest Atlantic Fisheries*). An international fisheries organization established in 1949 that was the precursor of the Northwest Atlantic Fisheries Organization (NAFO) which succeeded it in 1979.

IDF (*Icelandic Directorate of Fisheries*). An agency of the Ministry of Industries and Innovation, Iceland. The Directorate's task is monitoring fisheries and the daily administration of the fisheries management system in Iceland.

LSD (*least significant difference*). Fishers LSD test is a *post hoc* analysis applied following a one-way or two-way ANOVA to compare mean values of test groups.

MSW (*multisea-winter*). A MSW salmon is an adult salmon which has spent two or more winters at sea and may be a repeat spawner.

NAFO (*Northwest Atlantic Fisheries Organization*). NAFO is an intergovernmental fisheries science and management organization that ensures the long-term conservation and sustainable use of the fishery resources in the Northwest Atlantic.

NAO (*North Atlantic Oscillation*). A weather phenomenon of fluctuating sea surface atmospheric pressure between the Icelandic Low and the Azores High defined as seasonal average air pressure difference between meteographic stations.

NASCO (*North Atlantic Salmon Conservation Organization*).

NASTR (*North Atlantic Salmon Tag Recovery database*). Database developed by the ICES Working Group on Effectiveness of Recovery Actions for Atlantic Salmon (WGERAAS).

NEAC (*North East Atlantic Commission*). A commission of NASCO. Members include Denmark (in respect of the Faroe Islands and Greenland), the European Union, Norway, and the Russian Federation. Canada and the United States of America may also submit and vote on proposals for regulatory measures for salmon stocks originating in their rivers and occurring off East Greenland.

NINA (*Norwegian Institute for Nature Research*). **Norway's institution for applied ecological research.**

NOAA (*National Oceanic and Atmospheric Administration*). An American scientific agency within the United States Department of Commerce focused on the conditions of the oceans and the atmosphere.

PCA (*principal components analysis*). A multivariate statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components.

RDA (*redundancy analysis*). A multivariate statistical procedure that examines how much variation in one set of variables explains the variation in another set of variables. A multivariate analogue of simple linear regression.

SALSEA-Merge (*Salmon at Sea Merge*). SALSEA-Merge is an international programme of cooperative research designed to improve understanding of the migration and distribution of salmon at sea in relation to feeding opportunities and predation. It differentiates between tasks which can be achieved through enhanced coordination of existing ongoing research and those involving new research for which funding is required.

SST (*sea surface temperature*). SST is the water temperature close to the surface. In practical terms, the exact meaning of surface varies according to the measurement method used. A satellite infrared radiometer indirectly measures the temperature of a very thin layer of about 10 micrometres thick of the ocean which leads to the phrase "skin temperature". A microwave instrument measures subskin temperature at about 1 mm. A thermometer attached to a moored or drifting buoy in the ocean would measure the temperature at a specific depth, (e.g. at one meter below the sea surface). The measurements routinely made from ships are often from the engine water in-takes and may be at various depths in the upper 20 m of the ocean. In fact, this temperature is often called sea surface temperature, or foundation temperature.

UK (Sc) (*United Kingdom – Scotland).* A jurisdiction in the UK.

UK (EW) (*United Kingdom – England and Wales*). A jurisdiction in the UK.

UK (NI) (*United Kingdom – Northern Ireland*). A jurisdiction in the UK**.**

USSR (*Union of Soviet Socialist Republics*). The USSR was a socialist state on the Eurasian continent existing between 1922 and 1991 as a union of multiple subnational Soviet republics.

VIE (*Visible implant Elastomer*). VIE is a coloured elastomer that can be injected as a liquid under the skin of a fish. It the cures to a pliable solid, marking the fish. Colours are bright and can be fluorescent, lighting up under ultra violet light.

WGERAAS (*Working Group on the Effectiveness of Recovery Actions for Atlantic salmon*). An ICES expert group that last met in 2015.

WKDUHSTI (*Workshop on the Development and Use of Historical Tagging Information from Oceanic Areas*). An ICES workshop held in 2007.

WKSHINI (*Workshop on Salmon Historical Information – New Investigations from Old Tagging Data*). An ICES workshop held in 2008.

WKLUSTRE (*Workshop on Learning from Salmon Tagging Records*). An ICES workshop held in 2009.

WKSTAR (*Workshop on Salmon Tagging Archive*). An ICES workshop held in ICES 2012.