An overview of the East Greenland stock complex of Atlantic salmon

Summary

ICES notes that very little contemporary information on Atlantic salmon off the coast of East Greenland exists, although new studies are starting to provide some insights for this area. A series of marine surveys was conducted during the late 1960s through the early 1970s. There was likely lower density of Atlantic salmon in the Irminger Sea off the east coast of Greenland (Figure 1) than in West Greenland. The biological characteristics of salmon off East Greenland were similar to those at West Greenland, suggesting that the salmon were using these two feeding areas in similar ways. There was a higher proportion of European origin salmon in the Irminger Sea (about 80%) than in West Greenland (about 30%). Tagging studies have demonstrated that salmon from the following NASCO reporting areas contribute to the landings at East Greenland: Canada, Iceland, Ireland, Norway, UK (Scotland), UK (England and Wales), UK (Northern Ireland), and the United States. The fishery off the coast of East Greenland is small, with an annual quota of three tonnes (t) set for 2021–2025 fisheries and reported landings averaging only 0.7 t per year since 2008. The low landings are assumed to be a result of the low human population density, which contributes to low fishing effort coupled with low density of Atlantic salmon off the coast of East Greenland.

Introduction

At its 2021 Statutory Meeting, ICES resolved (C. Res. 2021/2/FRSG18) that the Working Group on North Atlantic Salmon (WGNAS) would meet in Copenhagen, Denmark, 28 March–7 April 2022 to consider questions posed to ICES by the North Atlantic Salmon Conservation Organization (NASCO). Due to the ICES suspension of meetings in March 2022, WGNAS was not able to meet to address the full terms of reference (ToRs) in 2022. Despite this, ICES was able to publish advice for North Atlantic salmon stocks on 6 May 2022. The later is based on the full ICES assessments that were conducted in 2021, and it is a suitable and a valid source of information for management actions scheduled in the relevant NASCO Salmon Commission areas.

WGNAS was able to meet via web conference to address ToRs 1.3 and 1.4 outside of ICES meeting suspension. As such, ICES is also able to provide advice on the 2022 WGNAS ToRs 1.3 (pink salmon) and 1.4 (salmon in East Greenland).

ToR	Question
1.3	Provide an update on the distribution and abundance of pink salmon across the North Atlantic and advise on potential threats to wild Atlantic salmon
1.4	Provide an overview of the East Greenland stock complex in terms of migration, stock composition, biological characteristics, historical landings, effort, etc.

This document provides the advice in response to ToR 1.4 (East Greenland).

Background

As part of an extensive marine migration, large numbers of North American and European origin Atlantic salmon congregate off the eastern and western coasts of Greenland each summer and autumn to feed (ICES, 2021a). Salmon off the west coast of Greenland are primarily North American in origin (1982–2019; mean = 69%), with the remainder European in origin and almost exclusively composed of southern European stocks (Ireland, UK [Scotland], UK [England & Wales], UK [Northern Ireland], France, and Spain). Salmon in the Irminger Sea (off East Greenland) originate from the same countries as those in West Greenland (Jensen, 1990). In the East Greenland catch there is a smaller proportion of salmon of North American origin than of European origin. The European origin fish in the East Greenland area also contain more northern origin (Norway, Russian Federation, Finland, Iceland, Sweden, and Denmark) fish than in the West Greenland area.

Greenland's human population lives exclusively along the coast in numerous towns and settlements (Figure 2; Government of Greenland, 2021). In 2021, Greenland's human population was approximately 56 000 with 6% (approximately 3000) living along the southeastern coast across seven settlements.

Fishery at East Greenland

The commercial fishery for Atlantic salmon started in the early 1960s (ICES 2021a; Figure 3). The first reported landings from East Greenland were in 1977 and amounted to 6 t (0.4% of the total Greenland landings; Table 1). Since then, landings for East Greenland have been reported in 31 of the 44 years, totalling 70 t and averaging 2.2 t per year; this equates to 1.4% of the total reported Greenland landings. Since 2008, a total of 9 t of landings have been reported, ranging from 0–1.7 t and averaging 0.7 t per year.

The number of Atlantic salmon fishing licences issued by the Government of Greenland and the number of fishers who reported landings on an annual basis since 1987 are provided by ICES annually (ICES, 2021a; Table 2). The total number of licences issued is provided since 1999 and has ranged from 150 to 786. The number of fishers reporting from West Greenland has ranged from 41 to 614 and from one to 24 for East Greenland, which is 1–7% of the total number of fishers reporting. Given the low population abundance and the limited freezer capacity and transport facilities available, landings of Atlantic salmon at East Greenland have always remained well below that at West Greenland (Jensen, 1990).

Historical survey efforts at East Greenland

Given the increasing Atlantic salmon fishery at West Greenland in the mid-1960s and subsequent investigations into the impacts of that fishery on the contributing stocks, there was a recognized lack of knowledge of salmon at other feeding areas throughout the North Atlantic. As a result, research surveys conducted by the Danish research vessel Dana were organized in the Irminger Sea in 1966, 1973, 1974, and 1975. Results from these early survey efforts were summarized and reported by Jensen and Lear (1980).

Survey activities occurred over a total of 21 days (Figure 1) during June 1966 (five days), August 1973 (five), July 1974 (four) August 1974 (four) and August 1975 (three) and involved polyfilament nylon nets in 1966 and monofilament nets of varying lengths, depths, and mesh sizes in the other years. A total of 80 salmon were captured with 21.3% assigned as North American in origin and 78.7% European in origin based on scale pattern analysis. Samples collected from the eastern side of the survey area contained a higher proportion of European-assigned individuals consistent with the proximity to that continent (88.5% for eastern Irminger Sea samples versus 73.5% for western Irminger Sea samples), although the differences were not statistically significant. One-sea-winter (1SW) salmon were the dominant sea age group (96%), mean smolt age was 3.4 years old for North American origin fish and 1.9 years for European origin fish, and the average fork length for 1SW salmon was 65.5 cm; all of these are similar to salmon sampled at West Greenland (Sheehan *et al*., 2019, 2021a, 2021b; ICES, 2021a).

Standardized catch per unit effort (CPUE) estimates from these surveys and from commercial salmon fishing activity in the Irminger Sea in September through October 1972 were compared with those from the fishery at West Greenland from the 1970s. Irminger sea CPUE estimates ranged from 1.5 salmon captured per 100 commercial nets in July 1966 to 11.9 in August 1975. These estimates are appreciably lower than the West Greenland estimates, which ranged from 41 salmon captured per 100 commercial nets in August 1973 to 111 in August 1975. Based on these data, Jensen and Lear (1980) suggested that the density of salmon in the Irminger Sea was much lower than that off the coast of West Greenland.

A joint Icelandic–Greenlandic exploratory fish survey aboard the Icelandic FRV *Dröfin* was conducted along the East Greenland coast within Angmagssalik Fjord (near Tasiilaq) and Skjöldungen Sound (~300 km southwest of Tasiilaq; Thorsteinsson and Gudjónsson, 1986; Figure 2) in 1985. Numerous fishing techniques and gears were deployed to survey for demersal fish and shrimp to characterize fishing opportunities for potential future settlement planning. The Greenlandic authorities did not consider experimental salmon fishing to be of great importance and therefore little effort was made to capture salmon. A series of floating/surface gillnets of varying lengths and mesh sizes were set in Skjöldungen Sound with one end of the net secured to shore, a practice compatible to contemporary fishing techniques at West Greenland. Within the Angmagssalik Fjord region, driftnets were deployed. No salmon were caught within Angmagssalik Fjord, but three were captured outside of it. No salmon were captured within the northern part of Skjöldungen Sound, while 398 were captured in its southern part. Insufficient details are provided for calculating CPUEs. The salmon's biological characteristics were similar to those reported from the earlier Danish East Greenland survey activities (Jensen and Lear, 1980) and from the fishery at West Greenland (ICES, 2021a).

Contemporary survey efforts at East Greenland

The International Ecosystem Summer Survey in the Nordic Seas (IESSNS) has been conducted annually since 2007 (ICES, 2015, 2016, 2017, 2018, 2019, 2020b, 2021b) and involves a number of research vessels from Norway, Iceland,

Faroe Islands, and Denmark. The survey runs from June through August and covers a large area of the Northeast Atlantic, including parts of the Irminger Sea (Figure 4). It employs a standardized pelagic swept area trawl method, which is capable of catching both post-smolt and adult Atlantic salmon, although the survey's main objective is to provide an annual age-disaggregated abundance index for northeast Atlantic mackerel. A few hundred Atlantic salmon have been collected over the time-series. Although the survey covers part of the Irminger Sea (Figure 4), almost all of the salmon captured (except three) have been taken east of Iceland. These results support the hypothesis that the salmon in the Irminger Sea is of much lower density thanin the Norwegian Sea and off the coast of West Greenland.

As part of the EU funded SMOLTRACK project, researchers of the Technical University of Denmark's (DTU) National Institute of Aquatic Resources travelled to Kummit, Greenland, about three hours north (by boat) of Tasiilaq (Figure 2) in September 2021 to investigate the feasibility of catching and tagging Atlantic salmon at East Greenland. A number of capture methods were used including longlines, gillnets, and trolling with rods and lures. A total of 40 salmon were captured. No fish were captured with longline and most fish were captured with gillnets. A few salmon were captured through trolling, which was attempted at the end of the trip and concluded to be a well suited method for future efforts. Lengths and weights, scale samples for age determination, and tissue samples for continent and region of origin analysis were collected. The results are not yet available, but further field efforts are planned for 2022, and a full accounting of the results will be presented in 2023.

Sampling the landings at West Greenland has occurred almost every year since 1968 (ICES, 2021a). In 2020, due to the travel restrictions brought about by the COVID-19 pandemic, the international sampling programme did not operate. A contingency sampling plan was thus initiated to collect biological characteristics data and samples from the Greenland landings. One aspect of this plan involved a citizen science programme where individual fishers, including those from East Greenland, were asked to provide length, weight, tissue, and scale samples from their landings. Very few samples were collected in 2020 (ICES, 2021a) and therefore a modified citizen science approach was implemented in 2021. A total of 252 samples were collected this time around, but only 14 were from East Greenland. At time of writing, these samples are being analysed, and the data will be available in 2023. Although the number of samples collected from East Greenland was low in 2021, this effort represents a potential targeted opportunity for collecting samples in the future to better understand the biological characteristics and regional contributions of the East Greenland landings.

Stock composition of the East Greenland complex

Since the early 1960s, a total of 5481 tag recoveries have been reported from Greenland, of which only 59 were from East Greenland (Reddin *et al*., 2012; Table 3). The low number of recoveries from East Greenland is consistent with relatively low fishing effort and landings in that region. East Greenland tag recoveries originated from fish released in Canada, UK (Scotland), UK (England and Wales), UK (Northern Ireland), Iceland, Ireland, Norway, and United States. There is a great deal of variability in the distribution of tag recoveries by country of origin at both West and East Greenland with the proportion of tags recovered at East Greenland being particularly low for fish originating from Ireland and Canada, but relatively high for US-origin fish compared to Canadian fish (1.4% versus 0.1% respectively) suggesting a more easterly distribution of US-origin fish. The proportion of recoveries from East Greenland also suggested that potential multi-sea-winter salmon from northern Europe have a more easterly distribution than those from southern Europe. It should be noted that inconsistencies were identified in the number of Canadian tag recoveries reported by Jensen and Lear (1980) and Reddin *et al*. (2012), but these minor inconsistencies would not alter the interpretations provided.

The conclusions from the historical tagging efforts are supported by more recent investigations involving tagging post-spawned Atlantic salmon from Norway, Denmark, Ireland, Spain, and Iceland with pop-off satellite tags ([PSAT]; Rikardsen *et al*., 2021) from 2008–2014 (Figure 5). Reconstructed migration paths of these tagged fish suggested that a few individuals from all five countries migrated into the Irminger Sea. However, individuals from the more northerly countries (Denmark and Norway) remained in the northern Irminger Sea, and those from more southerly countries (Spain and Ireland) were more oriented to the southern Irminger Sea in closer proximity to where previous Atlantic salmon research and fishing has occurred. Conversely, PSAT studies on Canadian origin post-spawned adults resulted in no individuals migrating to the east coast of Greenland, although only 16 individuals were tagged and released (Strøm *et al*., 2017).

Icelandic salmon were previously shown to be occupants of the Irminger Sea at various times during their marine residence (Figure 6). Daily locations were estimated from data storage tags (DSTs) obtained from adult returns originating from hatchery reared salmon released into a southwestern Icelandic river in 2005 and 2006 (Guðjónsson *et al*., 2015). The salmon were estimated to be southwest of Iceland in the Irminger Sea during the first summer months; in the autumn they moved towards the Faroe Islands and then migrated back to the Irminger Sea until

returning to the river. However, the daily positions were estimated from only seven individuals, none of which were estimated to migrate into the inshore waters of Greenland.

Bradbury *et al*. (2021) reported on a comprehensive genetic-based study that analyzed historical scale and tissue samples from across the North Atlantic against a comprehensive North Atlantic-wide baseline (Figure 7). Marine samples were collected from mixed-stock fisheries and historical surveys, 62 of which originated from surveys conducted off the coast of East Greenland in the early 1970s (Jensen and Lear, 1980). The samples collected from East Greenland were 85% European in origin and 15% North American in origin (Figure 8). The primary contributor was United Kingdom/Ireland – representing 76% of the samples – with other groups contributing 5% or less.

Summary

Very little contemporary information regarding Atlantic salmon off the coast of East Greenland exists, although new studies are starting to provide some insights for this area. Catch rates of Atlantic salmon in surveys were low compared to those at West Greenland, likely a result of a lower density of Atlantic salmon in the Irminger Sea of East Greenland. The biological characteristics of captured salmon were similar to those at West Greenland, suggesting that the salmon were using these two feeding areas in similar ways. The Irminger Sea has a higher proportion of European origin salmon than West Greenland and researchers hypothesised that as you move eastward, the proportion of European fish would increase. Tagging studies have demonstrated that salmon from Canada, Iceland, Ireland, Norway, UK (Scotland), UK (England and Wales), UK (Northern Ireland) and the United States all contribute to the landings at East Greenland. Northern European fish use this feeding area as well, although their distribution seems to be more northerly compared to salmon from southern Europe.

The fishery off the coast of East Greenland is small, with an annual quota of 3 tonnes set for 2021-2025 fisheries (Government of Greenland 2021) and reported landings averaging only 0.7 t per year since 2008. The low landings are assumed to be a result of the low human population density, which contributes to low fishing effort coupled with low density of Atlantic salmon off the coast of East Greenland.

Data deficiencies, monitoring needs, and research requirements

Given the decreased abundance of the species across its range, there is a need for a better understanding of the contemporary dynamics of Atlantic salmon off the coast of East Greenland.

Table 1 Annual distribution and percentage of reported catches for West and East Greenland since 1960. In some years (*) the fishery was suspended, the reported catch (+) was < 0.5 t or there was no (-) reported catch (data from ICES 2021a).**

Year	West (tonnes)	East (tonnes)	West (%)	East (%)	Total (tonnes)
1960	60	-	100	-	60
1961	127	-	100	-	127
1962	244	-	100	-	244
1963	466	-	100	-	466
1964	1539	-	100	-	1539
1965	861	-	100	-	861
1966	1338	-	100	-	1338
1967	1514	-	100	-	1514
1968	833	-	100	-	833
1969	2153	-	100	-	2153
1970	2107	-	100	-	2107
1971	2654	-	100	-	2654
1972	2023	-	100	-	2023
1973	2341	-	100	-	2341
1974	1917	-	100	-	1917
1975	2030	-	100	-	2030
1976	1175	-	100	-	1175
1977	1420	6	100	0	1426
1978	984	8	99	1	992
1979	1395	+	100	0	1395
1980	1194	+	100	0	1194

Year	West (tonnes)	East (tonnes)	West (%)	East (%)	Total (tonnes)
1981	1264	+	100	0	1264
1982	1077	+	100	0	1077
1983	310	+	100	0	310
1984	297	+	100	0	297
1985	864	7	99	1	871
1986	960	19	98	2	979
1987	966	+	100	0	966
1988	893	4	100	0	897
1989	337	-	100	-	337
1990	274	-	100	-	274
1991	472	4	99	1	476
1992	237	5	98	2	242
1993*	-	-	-	-	-
1994*	-	-	-	-	-
1995	83	2	98	2	85
1996	92	+	100	1	92
1997	58	1	98	2	59
1998	11	-	100	-	11
1999	19	+	100	3	19
2000	21	-	100	-	21
2001	43	-	100	-	43
2002	9	-	100	-	9
2003	9	-	100	-	9
2004	15	-	100	-	15
2005	15	-	100	-	15
2006	22	-	100	-	22
2007	25	-	100	-	25
2008	26.2	0	100	0	26.2
2009	25.6	0.8	97	3	26.3
2010	38.1	1.7	96	4	39.6
2011	27.4	0.1	100	0	27.5
2012	32.6	0.5	98	2	33.1
2013	47	0	100	0	47.0
2014	57.8	0.1	100	0	57.9
2015	55.9	1	98	2	56.8
2016	25.7	1.5	95	6	27.1
2017	27.8	0.3	98	1	28.1
2018	39.0	0.8	98	2	39.9
2019	28.3	1.4	95	5	29.8
2020	30.9	0.8	97	3	31.7

** The figures in the table are rounded. Calculations were done with unrounded inputs, and computed values may not match exactly when calculated using the rounded figures in the table.

Table 2 Total number of Atlantic salmon fishing licences issued and the number of fishers reporting landings from West and East Greenland. Blank cells indicate that the data were not reported or were not available. Starting in 2018, all fishers are required to have a licence to fish for Atlantic salmon. Prior to 2018, only commercial fishers were required to have a licence (data from ICES [2021a]).

Year	Licences issued (number)	West fishers reporting (number)	East fishers reporting (number)
1987		551	
1988		510	
1989		392	
1990		354	
1991		410	
1992		212	
1993			
1994			
1995		145	
1996		163	
1997		81	

Year	Licences issued (number)	West fishers reporting (number)	East fishers reporting (number)
1998		69	
1999	424	103	
2000	179	46	
2001	451	80	
2002	480	41	
2003	150	42	
2004	157	66	
2005	185	75	
2006	166	141	
2007	261	132	
2008	262	143	
2009	293	136	9
2010	309	195	13
2011	242	112	5
2012	276	116	6
2013	328	94	1
2014	320	113	1
2015	310	180	9
2016	263	130	10
2017	282	141	2
2018	786	549	8
2019	717	614	24
2020	757	608	10

Table 3 Number of tags recovered, with location specified to at least the level of NAFO Division or ICES Statistical Area, at West and East Greenland, by country and origin and percentage of recoveries from East Greenland (reproduced from Reddin *et al*. [2012])**.**

Country	West Greenland	East Greenland	Total	% of recoveries at East Greenland
United States	2128	30	2158	1.4
Canada	1814	2	1816	0.1
Iceland	16	1	17	5.9
Norway	115	15	130	11.5
Ireland	139	2	141	1.4
UK (Scotland)	273	6	279	2.2
UK (England & Wales)	195	3	198	1.5
UK (Northern Ireland)	2	0	2	0
Total	4682	59	4741	1.2

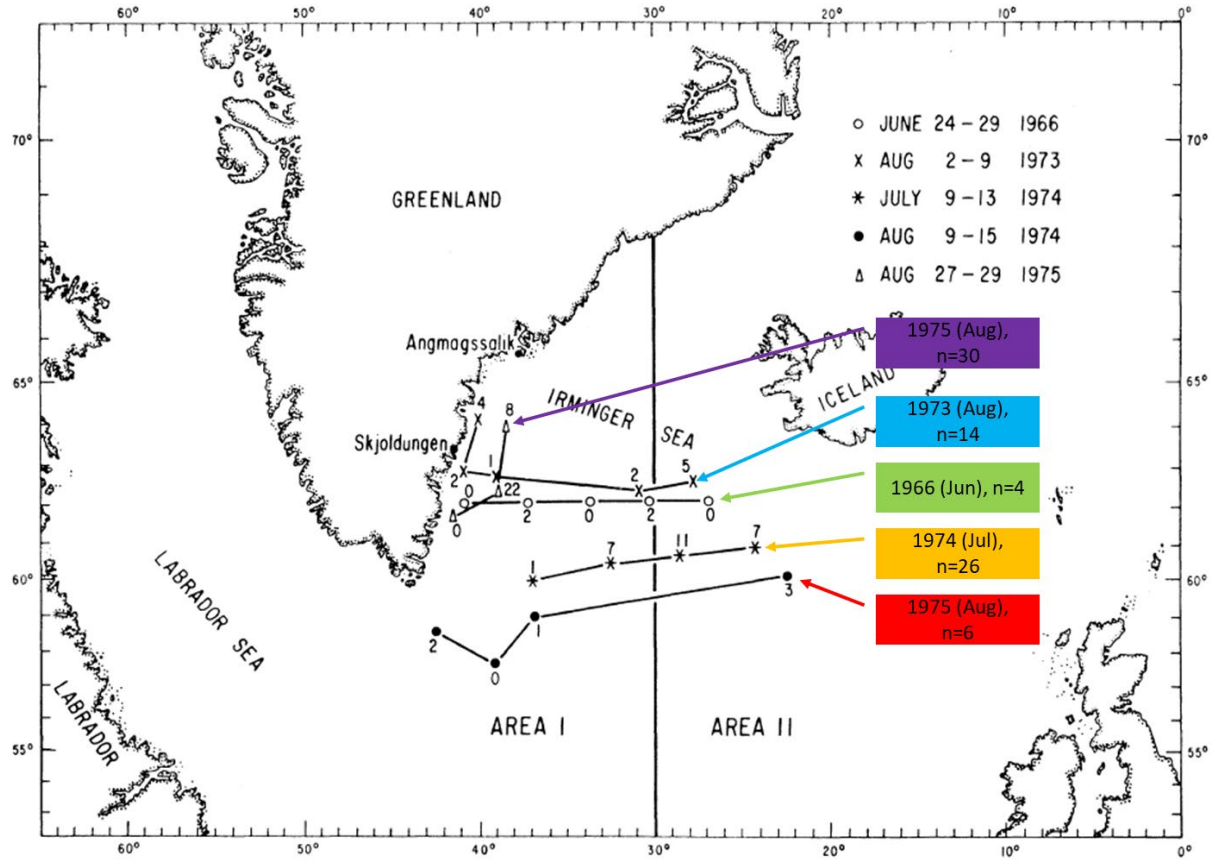

Figure 1 Irminger Sea stations surveyed by the RV Dana in 1966, 1973, 1974, and 1975. Stations were surveyed with driftnets, and the number of salmon caught at each station is noted (reproduced from Jensen and Lear [1980]). The *n* denotes the number of salmon at each transect.

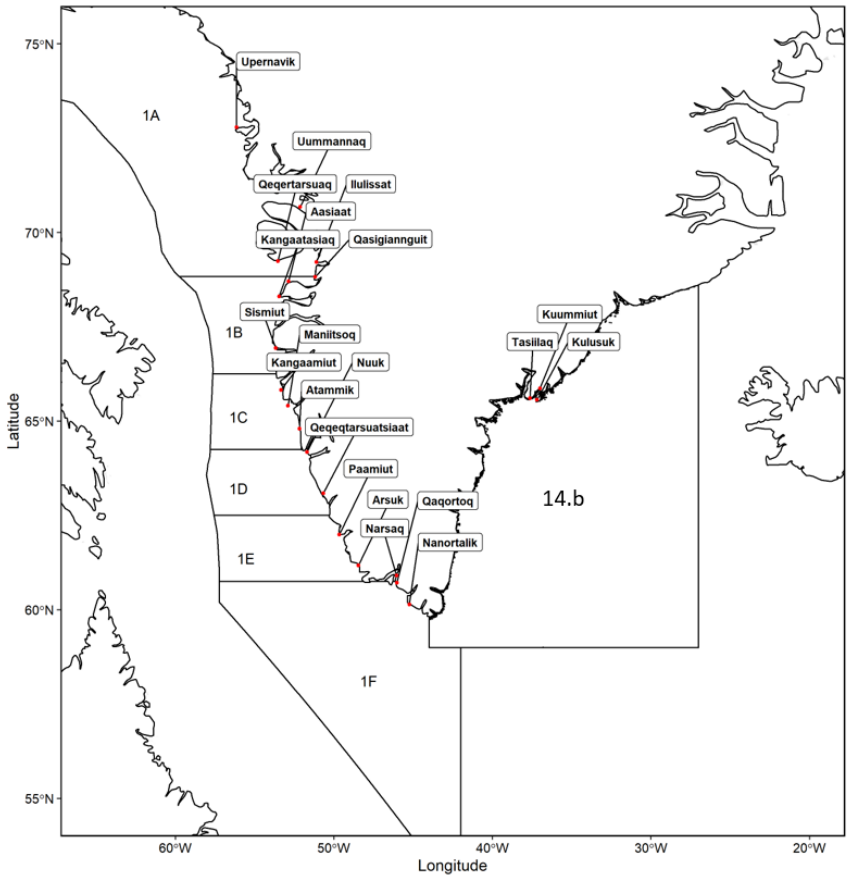

Figure 2 Map of southern Greenland showing communities in which Atlantic salmon have historically been landed and corresponding NAFO divisions (1A–1F) and ICES sub-area 14.b.

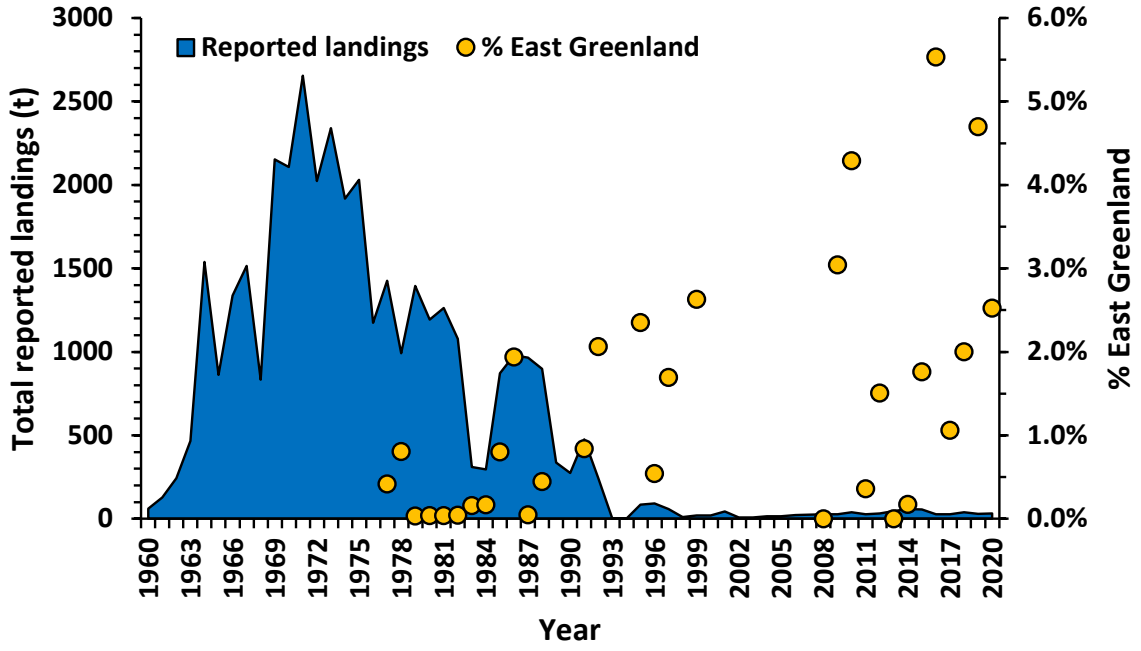

Figure 3 Reported landings (in tonnes) of Atlantic salmon at Greenland from 1960–2020 and percentage of landings that are attributed to having come from East Greenland (data from ICES [2021a]).

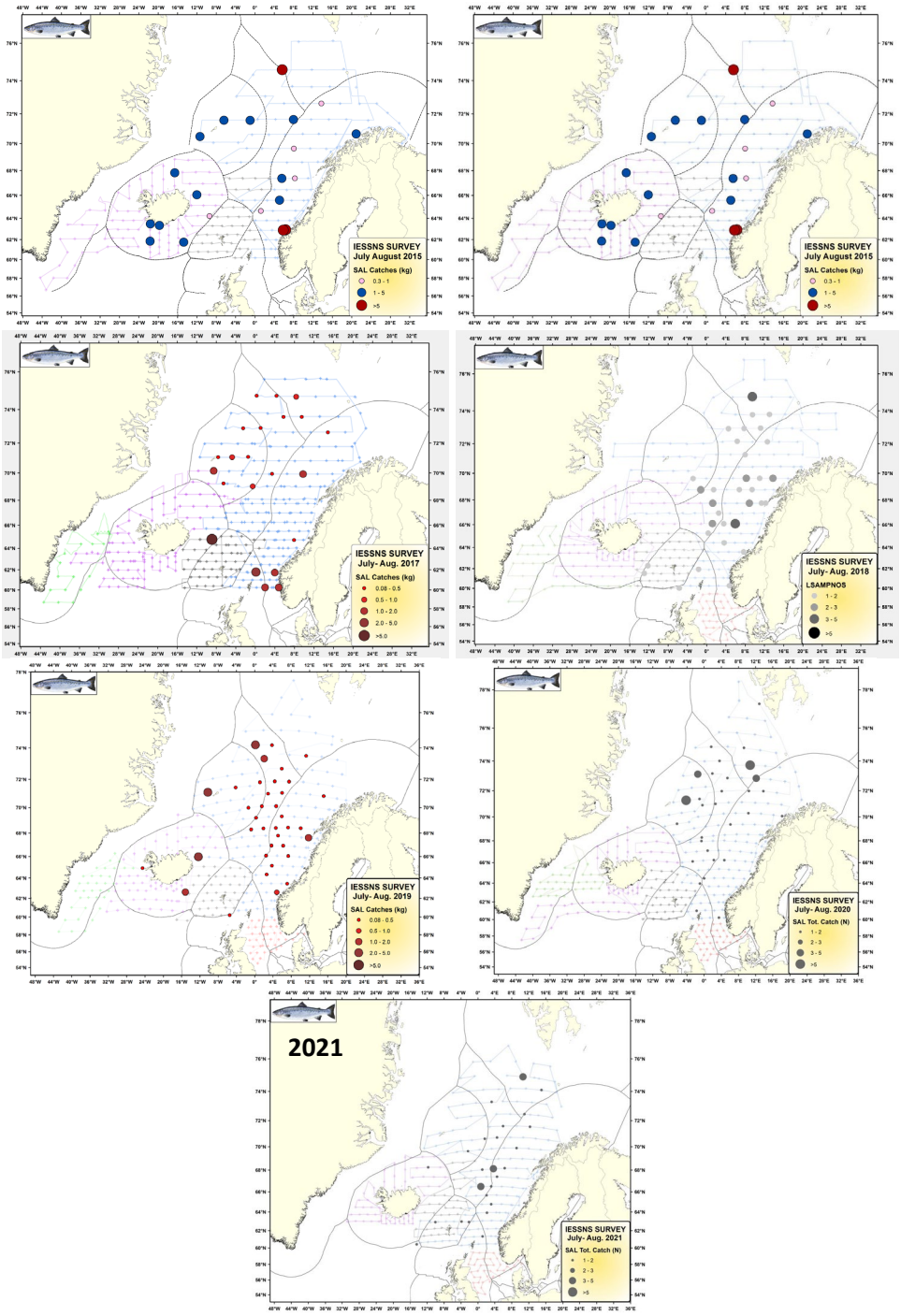

Figure 4 Stations and catches (in numbers) of salmon at surface trawl stations during the 2015–2021 International Ecosystem Summer Survey in the Nordic Seas (reproduced from ICES [2015, 2016, 2017, 2018, 2019, 2020b, 2021b]). Note that scale and colour vary between years.

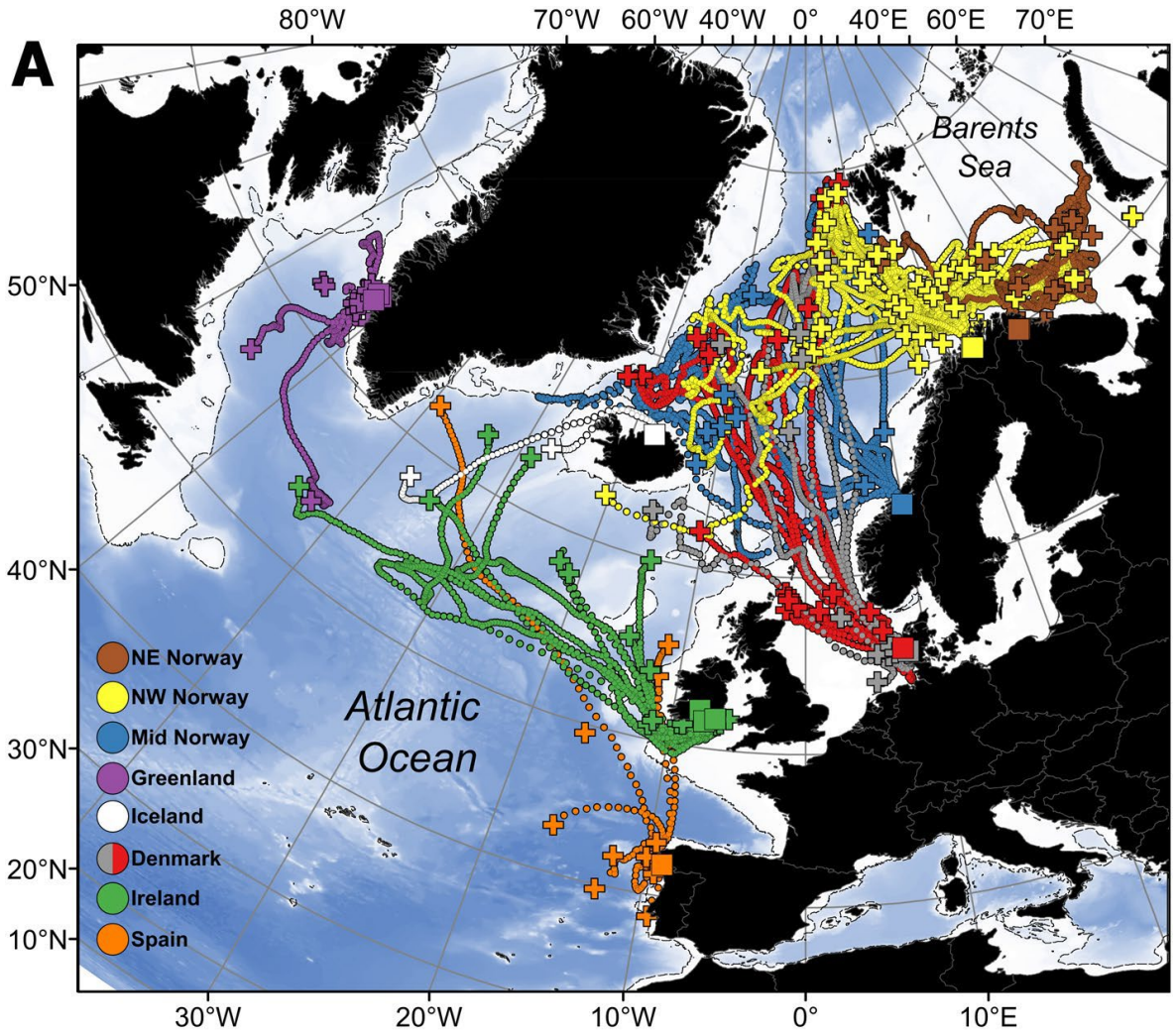

Figure 5 Migrations of Atlantic salmon tagged in eight different geographic areas: release locations post-tagging are shown by squares, estimated daily geographic location of 105 salmon is shown by circles, while crosses show the pop-up location of the tags. The dashed line represents the 500 m depth contour with darker blue indicating increasing depth (reproduced from Rikardsen *et al.* [2021]).

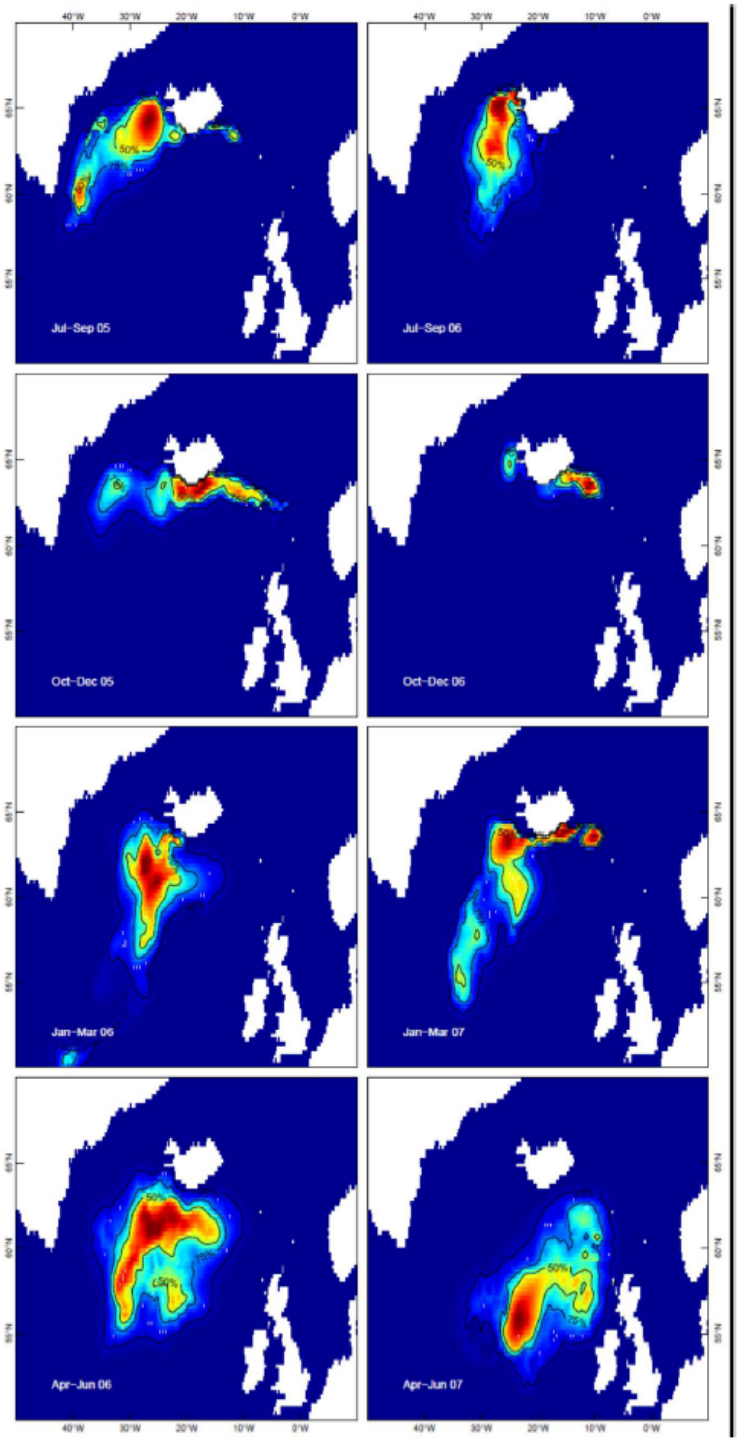

Figure 6 Estimated usage distribution from hatchery reared DST tagged Icelandic salmon divided into year-quarters. The fish released in 2005 are on the left and the fish released in 2006 on the right. The mean posterior probability is calculated for each cell and the top 50%, 75%, and 95% areas are shown (reproduced from Guðjónsson *et al*. [2015]).

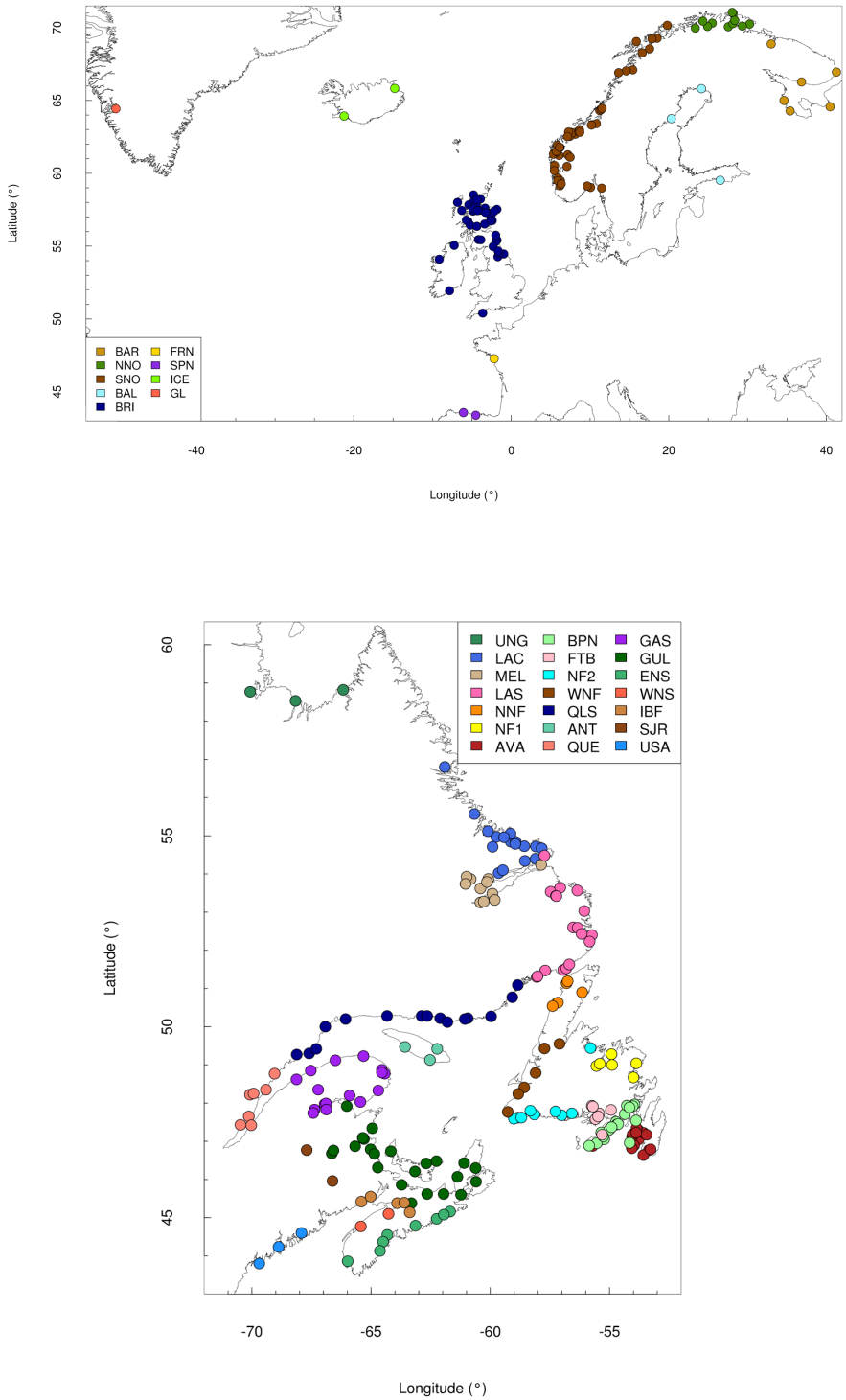

Figure 7 Map of sample locations for comprehensive North Atlantic-wide genetic baseline for North American (top) and European (bottom) reporting groups (reproduced from ICES [2020a]).

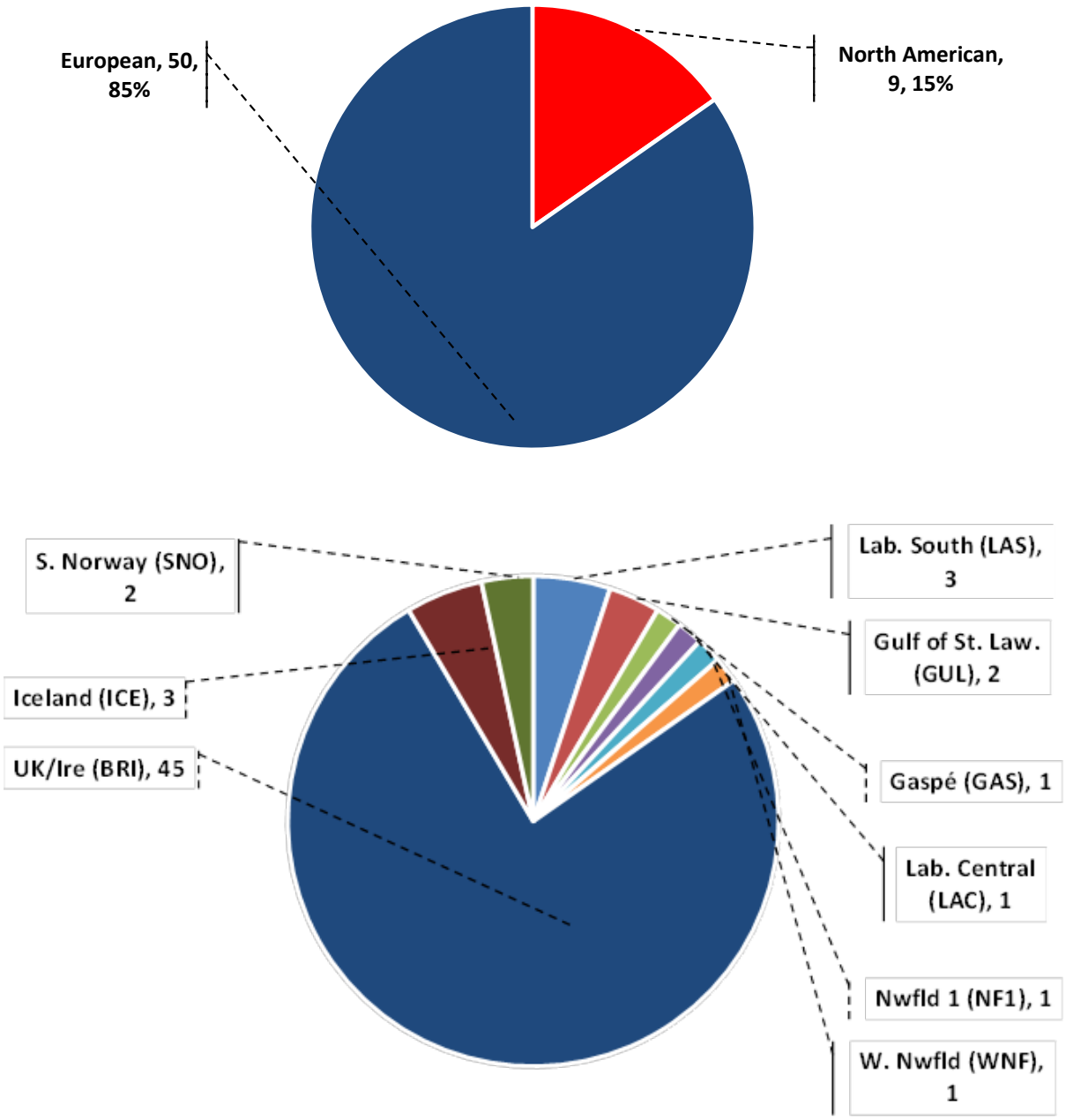

Figure 8 Continent and region of origin contributions (number, percentage) for adult Atlantic salmon samples collected off the coast of East Greenland during July-August 1973–1975 as reported by Bradbury *et al*. (2021). Sample locations of reporting groups are identified in Figure 7.

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