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i Executive summary

Due to the extraordinary measure to cancel or postpone all Committee and Expert Group meetings, whether in-person, online or hybrid, scheduled between 7 March and 1 April 2022, the Working Group on North Atlantic Salmon (WGNAS), that was initially scheduled to take place in Copenhagen from the 28 March to the 7 April 2022 did not take place. However, some work was undertaken by WGNAS outside of this period and that work is reported here. Please refer to the WGNAS 2021 report for further information on the basis of the advice provided in May, 2022.

Pink salmon (*Oncorhynchus gorbuscha*) is a semelparous diadromous salmonid species, with a strict two-year lifecycle, and populations that spawn either in odd-or even-years. The natural range of Pink salmon in the Pacific and Arctic Oceans extends from 40°N to greater than 70°N, with the spawning distribution from 48°N (Puget Sound, Washington) to 64°N (Norton Sound, Alaska) in North America and from 44°N (North Korea) to 65°N (Anadyr Gulf, Russia) in Asia. The species has been introduced in various parts of the world, but only in the Great Lakes and in northwest Russia has Pink salmon established self-sustaining populations. The first attempts at introduction in the White Sea in 1957 failed to establish self-sustaining populations. In 1986 a second attempt using broodstock from a more northern location did establish self-sustaining odd-year populations in the White Sea and Kola Peninsula. Between 1960 and 2015 Pink salmon were regularly reported outside the area of introduction, with the majority of observations in the adjacent areas in the northern part of the Fennoscandian Peninsula. Occasionally reports were also made as far south as Scotland and Ireland. From 2017 Pink salmon have dramatically increased their range and abundance, with large numbers observed in the Barents- and Norwegian Seas, as well as rivers along the Atlantic coast of Norway and Finland where many also spawned. This increase in range abundance has been observed as far south as the Élorn river in France in NEAC and the Gander River in Newfoundland, Canada in NAC, with several hundreds of Pink salmon ascending rivers in Scotland, England, and Iceland. Some of these fish have been observed to spawn, for example in Scotland. This sudden increase in Pink salmon abundance has been linked with increases in Sea Surface Temperature (SST) in Arctic waters the winter before spawning.

The appearance of large numbers of (spawning) Pink salmon in European, and even Atlantic Canadian and Greenlandic rivers in 2017, 2019, and 2021 has caused concern among fisheries managers that this could have a negative impact on wild Atlantic salmon stocks. It is difficult to establish with any certainty what the impact will be as research into this recent phenomenon is only now producing the first published results, and much of the effects will depend on the scale of the Pink salmon population increase in future years, which could be driven by uncertain factors such as Climate Change. Pink salmon can compete with Atlantic salmon for resources such as food and access to spawning habitat. In freshwater Pink salmon fry/smolts could compete with Atlantic salmon juveniles during their short stay and subsequent seaward migration, especially in rivers where they spawn farther upstream. In the marine environment large numbers of Pink salmon can cause trophic cascades in marine ecosystems, impacting on other species such as other salmonids. Density-dependent competition with Atlantic salmon for prey resources at sea could impact on growth, as it does with other salmonid species in the native range of Pink salmon. Increased nutrient loads in rivers and associated reduction in water quality as a result of decomposing Pink salmon carcasses after spawning could also impact on Atlantic salmon juveniles in freshwater. The threat of viral- and bacterial pathogens carried by Pink salmon to Atlantic salmon is poorly understood and therefore difficult to assess.

It is also possible that some effects of Pink salmon on Atlantic salmon will be positive or neutral in nature, such as Pink salmon fry and ova providing a food source for Atlantic salmon juveniles or increased growth and survival in rivers enriched with nutrients from the Pink salmon carcasses left after spawning.

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. A series of marine surveys were conducted during the late 1960's through the early 1970's. Researchers concluded that the catch rates of Atlantic salmon were low compared to those at West Greenland, likely a result of a lower density of Atlantic salmon in the Irminger Sea. 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. However, there was a higher proportion of European origin salmon in the Irminger Sea and researchers hypothesised that as you move eastward, the proportion of European fish would increase. Subsequent 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 harvest at East Greenland. Studies on post-spawned salmon show that 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 three t 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.

The Labrador and Irminger seas and their associated coastal waters have long been known to be important feeding areas for Atlantic salmon. Relative to the West Greenland, little is known regarding the stock composition, biological characteristics, etc. of salmon off the coast of East Greenland and the information that is available is from decades past. Given the decreased abundance of Atlantic salmon across the species' range, a better understanding of the contemporary dynamics of Atlantic salmon off the coast of East Greenland is desired.

ii Expert group information

Expert group name	**Working Group on North Atlantic Salmon (WGNAS)**
Expert group cycle	Annual
Year cycle started	2022
Reporting year in cycle	1/1
Chair(s)	Dennis Ensing, UK
Meeting venue and date	Due to the extraordinary measure to cancel or postpone all Committee and Expert Group meetings, whether in-person, online or hybrid, scheduled between 7 March and 1 April 2022, the Working Group on North Atlantic Salmon (WGNAS) initially scheduled to take place in Copenhagen from the 28 March to the 7 April 2022 did not take place. Remote meetings to address ToRs 1.3 and 1.4 were held 14-16 February and 14 July 2022.

1 Introduction

1.1 Main tasks

At its 2021 Statutory Meeting, ICES resolved C. Res. 2021/2/FRSG18 that the Working Group on North Atlantic Salmon [WGNAS] (chaired by Dennis Ensing, UK) will meet at the ICES Secretariat 28 March -07 April 2022. However, due to the extraordinary measure to cancel or postpone all Committee and Expert Group meetings, whether in-person, online or hybrid, scheduled between 7 March and 1 April 2022, the Working Group on North Atlantic Salmon (WGNAS), that was initially scheduled to take place in Copenhagen did not take place.

As such, the full terms of reference were not met.

The sections of the report that provide the answers to the questions posed by NASCO, i.e. a limited number of the terms of reference, will be identified below as report sections are released by ICES.

Question		Section
	Posed by NASCO	
1	**With respect to Atlantic salmon in the North Atlantic area:**	
1.1	provide an overview of salmon catches and landings by country, including unreported catches and catch and release, and production of farmed and ranched Atlantic salmon in 2021[1];	
1.2	report on significant new or emerging threats to, or opportunities for, salmon conservation and management[2];	
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;	1.3
1.4	provide an overview of the East Greenland stock complex in terms of migration, stock composition, biological characteristics, historical landings, effort etc.;	1.4
1.5	provide a compilation of tag releases by country in 2021; and	
1.6	identify relevant data deficiencies, monitoring needs and research requirements;	
2	**With respect to Atlantic salmon in the North-East Atlantic Commission area:**	
2.1	describe the key events of the 2021 fisheries[3];	
2.2	review and report on the development of age-specific stock conservation limits, including updating the time-series of the number of river stocks with established CLs by jurisdiction;	
2.3	describe the status of the stocks, including updating the time-series of trends in the number of river stocks meeting CLs by jurisdiction;	
2.4	provide catch options or alternative management advice for the 2022/2023 - 2024/2025 fishing seasons, with an assessment of risks relative to the objective of exceeding stock conservation limits, or pre-defined NASCO Management Objectives, and advise on the implications of these options for stock rebuilding[4]; and	1.2

Question		Section
2.5	update the Framework of Indicators used to identify any significant change in the previously provided multi-annual management advice.	
3	**With respect to Atlantic salmon in the North American Commission area:**	
3.1	describe the key events of the 2021 fisheries (including the fishery at St Pierre and Miquelon)[3];	
3.2	update age-specific stock conservation limits based on new information as available, including updating the time-series of the number of river stocks with established CLs by jurisdiction;	
3.3	describe the status of the stocks, including updating the time-series of trends in the number of river stocks meeting CLs by jurisdiction;	
3.4	provide catch options or alternative management advice for 2022-2025 with an assessment of risks relative to the objective of exceeding stock conservation limits, or pre-defined NASCO Management Objectives, and advise on the implications of these options for stock rebuilding[4]; and	1.2
3.5	update the Framework of Indicators used to identify any significant change in the previously provided multi-annual management advice.	
4	**With respect to Atlantic salmon in the West Greenland Commission area:**	
4.1	describe the key events of the 2021 fisheries[3];	
4.2	describe the status of the stocks[5];	
4.3	provide catch options or alternative management advice for 2022-2024 with an assessment of risk relative to the objective of exceeding stock conservation limits, or pre-defined NASCO Management Objectives, and advise on the implications of these options for stock rebuilding[4]; and	1.2
4.4	update the Framework of Indicators used to identify any significant change in the previously provided multi-annual management advice.	

Notes:

1. *With regard to question 1.1, for the estimates of unreported catch the information provided should, where possible, indicate the location of the unreported catch in the following categories: in-river; estuarine; and coastal. Numbers of salmon caught and released in recreational fisheries should be provided.*

2. *With regard to question 1.2, ICES is requested to include reports on any significant advances in understanding of the biology of Atlantic salmon that is pertinent to NASCO.*

3. *In the responses to questions 2.1, 3.1 and 4.1, ICES is asked to provide details of catch, gear, effort, composition and origin of the catch and rates of exploitation. For homewater fisheries, the information provided should indicate the location of the catch in the following categories: in-river; estuarine; and coastal. Information on any other sources of fishing mortality for salmon is also requested. For 4.1, if any new surveys are conducted and reported to ICES, ICES should review the results and advise on the appropriateness of incorporating resulting estimates into the assessment process.*

4. *In response to questions 2.4, 3.4 and 4.3, provide a detailed explanation and critical examination of any changes to the models used to provide catch advice and report on any developments in relation to incorporating environmental variables in these models. Also provide a detailed*

explanation and critical examination of any concerns with salmon data collected in 2021 which may affect the catch advice considering the restrictions on data collection programmes and fisheries due to the COVID 19 pandemic.

5. *In response to question 4.2, ICES is requested to provide a brief summary of the status of North American and North-East Atlantic salmon stocks. The detailed information on the status of these stocks should be provided in response to questions 2.3 and 3.3.*

1.2 Atlantic salmon in the Northeast Atlantic, North American, and West Greenland Commission Areas

Due to the ICES suspension of meetings in March 2022, the WGNAS was not able to meet for the annual meeting scheduled 28 March – 07 April 2022 to respond to the ICES Terms of Reference to provide advice for NEAC, NAC, and WGC. However, the group did meet 14–16 February 2022 to address the ToRs for East Greenland and Pink salmon (ToRs 1.3 and 1.4). As such, report sections will be available on these latter points to support ICES advice to NASCO on these key issues later in 2022.

Towards the end of the ICES meetings suspension, the WGNAS Chair met with members of WGNAS to discuss the possibility of providing updated data series, assessments, and advice for the NASCO Commission areas given the status and availability of data, modellers, and the group members writ large. The challenges revealed themselves to be too great, and given the constraints of data and expertise availability, it was unanimously agreed that the work of WGNAS 2021 and the ICES advice provided in 2021 represent the best science and information available on these issues.

Fortunately, the work done by WGNAS and the ICES advice provided in 2021 were provided for 2021-2024 for NAC, 2021/2022 to 2023/2024 for NEAC, and 2021–2023 for WGC. As such, WGNAS' work in 2021 stands on its own without need for further update in 2022. While it was agreed to provide an updated assessment for WGC in 2022 due to the management measure, the work done in 2021 is not invalid because of this request. The work published by ICES in 2021 is thus the best available science and remains a valid source of information for resource managers and policy makers.

The WGNAS very much looks forward to working together in 2023.

1.3 Distribution and abundance of Pink salmon across the North Atlantic and advice on potential threats to wild Atlantic salmon

This report is based on information provided to an intersessional remote meeting of WGNAS that was held 14–16 February 2022, and subsequent literature review and request to provide data on Pink salmon abundance and distribution in jurisdictions across the North Atlantic.

1.3.1 Pink salmon ecology

Pink salmon naturally occur in the Pacific and Arctic Oceans from 40°N to greater than 70°N (Neave et al. 1967, Takagi et al. 1981). However, the spawning distribution of the species has a more restricted range from 48°N (Puget Sound, Washington) to 64°N (Norton Sound, Alaska) in North America and from 44°N (North Korea) to 65°N (Anadyr Gulf, Russia) in Asia (Heard, 1991; Mathisen, 1994; Fig. 1).

Pink salmon have an almost exclusive two-year lifecycle, with populations that spawn in odd-and even-years having evolved into distinct genetic entities with varying degrees of genetic isolation between them. In many rivers these odd- and even-year populations coexist. Both types spawn during late summer and autumn in the clean, coarse gravel in areas of shallow (10–100 cm) pools and riffles of small to large rivers. They have a preference for moderately fast (30–150 cm/s) currents. Pink salmon generally avoid spawning in deep, slow-moving water or on muddy, sandy, or silted substrate (Heard, 1991). Water temperatures during the peak of spawning range from about 5°C to 15°C and are generally higher for southern populations. Pink salmon tends to spawn closer to the head-of-tide than other species of Pacific salmon, generally within 50 km of a river mouth (Heard, 1991). However, Pink salmon populations from large river systems such as the Fraser River and Skeena River in Canada are known to migrate up to 500 km upstream to spawn, and a substantial fraction of other populations may spawn intertidally (Jones, 1978).

Pink salmon mature at the smallest average size of any species of Pacific salmon (1.0–2.5 kg) and show marked sexual dimorphism (Beacham and Murray, 1985). Spawning populations throughout much of the natural range of Pink salmon may be extremely large, often exceeding hundreds of thousands of adult fish (Heard, 1991). Freshwater mortality of juvenile Pink salmon is high, ranging from about 75% to over 99%, and the majority of this mortality occurs before emergence from the gravel (Hunter, 1959). After emerging from the gravel, Pink salmon alevins migrate rapidly downstream, generally in schools and usually during the hours of darkness (Heard, 1991). Juveniles grow most rapidly during their residence in the nearshore marine environment. Preferred prey items are small crustaceans, such as euphausiids, amphipods, and cladocerans (McDonald, 1960). After residing in estuaries and nearshore habitat for a few weeks to a few months, Pink salmon move offshore where they migrate at sea for 12–16 months (Heard, 1991). Adult Pink salmon prey preferences include zooplankton, squid and fish (Davis *et al*., 2009).

Smolt to adult survival in Pink salmon appears to vary widely among years and rivers/areas. Cross *et al.* (2008) reported rates varying between 3–8% in Prince William Sound, Alaska. Kaev and Radchenko (2021) reported rates between 1–18% in populations from Sakhalin Island, Russian Federation. Early marine growth has repeatedly been correlated with overall survival in Pacific salmon species. Although there is a current lack of understanding of, the exact mechanism of the timing, magnitude and sources of stage-specific marine survival and early growth of Pink salmon are probably governed by a combination of prey availability, smolt quality, inter/intra-specific competition, predation and ocean conditions (Cross *et al*., 2008).

Pink salmon have been found to stray at higher rates than other species of Pacific salmon (e.g., Horrall, 1981). High straying rates (>50%) have been observed in some studies, whereas other studies reported lower rates between 0.1 and 12% (Hard *et al*., 1996). However, there is substantial evidence of very rapid range expansion in Pink salmon when conditions are favourable (e.g. Heard, 1991; Press *et al*., 2014 and references therein). The frequent spawning of Pink salmon in areas without permanent spawning populations well outside the usual spawning range (Figure 1.1) also suggests that Pink salmon homing behaviour is highly plastic (Hard *et al*., 1996). It appears that levels of straying in Pink salmon may vary widely among populations and within populations under different conditions.

1.3.2 Pink salmon in the North Atlantic

Pink salmon was first introduced in the White Sea region of the Russian Federation in 1957, from local hatcheries using broodstock from the southern part of the island of Sakhalin (Zubchenko *et al*, 2004). The stocking with this material occurred for most years until 1979 with variable results. Occasionally large numbers of adults were observed as a result of this stocking activity, sometimes even outside the area of stocking such as in 1960 when 20–25 t were caught in northern Norwegian waters (Berg, 1961). Despite reports of Pink salmon spawning in some Russian rivers between 1957 and 1979, a self-sustaining population was not established and the programme therefore terminated (Sandlund *et al*., 2019).

Nevertheless between 1957 and 1979 Pink salmon were occasionally recorded from the Kara Sea to Iceland, and from Scotland to Denmark (Mills, 1991).

A second attempt to establish persistent self-sustaining Pink salmon population in the White Sea commenced in 1986 with the stocking of locally reared fry from eggs collected from an odd-year Pink salmon population from the Ola River, draining into the Sea of Okhotsk, near Magadan, Russian Federation (Sandlund *et al*., 2019). It was hoped that broodstock with a more northern distribution would be a better fit for stocking in the White Sea area compared to the broodstock from the southern part of the island of Sakhalin that was used before as it was assumed the Ola river population of Pink salmon was better adapted to the colder climate in Arctic Russia. In 1987 and 1999 it was also attempted to introduce even-year Pink salmon in the White Sea area by releasing fry from even-year populations from the Ola River, but despite observing returning adults in the years after release this proved unsuccessful in establishing a large self-sustaining population (Sandlund *et al*., 2019). However, a small but persistent self-sustaining even-year Pink salmon population has been established in the White Sea, resulting in small catches (max. 30 t) in the White Sea post 2000 and observations of even-year fish have been made in northern Norwegian and Finnish rivers. Since 1999 no more stocking of Pink salmon has occurred in Arctic Russia (Sandlund *et al*., 2019).

The odd-year Pink salmon from the Ola River have established self-sustaining populations of significant size in the White Sea, with annual catches below 100 t pre-2000, but increasing to an average of >200 t between 2002 and 2017 after the bumper-year in 2000 (300 t) (Prusov and Zubchenko, 2021). Since 2019 the catch has exceeded 300 t, with a record provisional catch of 600 t in 2021 (Figure 1.2).

Outside the Russian Federation Pink salmon from the introduction programme that started in 1986 have been observed in a wide range of countries: such as Norway and Finland (Sandlund *et al*., 2019), Faroe Islands (Eliasen and Johannesen, 2021), Scotland (Armstrong *et al*., 2018), Ireland (Millane *et al*., 2019) and Greenland (Nielsen *et al*., 2020). Long-term time-series of observations and/or catches of Pink salmon outside the White Sea area are rare, but Sandlund *et al*., (2019) published an overview of catches in the Norwegian/Finnish Tana/Teno system in northernmost Norway and Finland between 1974 and 2017 (Figure 1.3). After high catches in the 1970s, Pink salmon catches in the Tana/Teno declined to 0 after the first attempt to establish self-sustaining populations ended in 1979. Only in the 1990s did catches increase again to about 400–1 000 individuals for odd-years, and below 100 for most even-years. Between 2001 and 2007, odd-year catches reached the highest levels since 1977 and 1991, after the Russian stocking had ceased in 1999, which means all these fish are naturally spawned. Between 2007 and 2015 catches markedly decreased, to some of the lowest levels seen for both odd- and even-years in the time-series. This was mirrored in a 2007–2017 time-series of Pink salmon catches in the nearby Neiden River (Sandlund *et al*., 2019).

Since 2017 Pink salmon catches and observations of odd-year fish have increased dramatically, in both the Russian Federation, northern Fennoscandia, but also much further south such as central and southern Norway, the UK and Ireland, and as far south as France. In addition there are also observations from the Northwest Atlantic, the NASCO North Atlantic Commission (NAC) area as well as in the North East Atlantic Commission (NEAC) area.

The Working Group has collated the Pink salmon catches and observations provided by WGNAS members since 2017 in Table 1.1 and Figures 1.4 and 1.5.

From the maps and the figures it is clear that both the number and geographical spread of Pink salmon in the North Atlantic has dramatically increased from 2017 onwards. In 2017 numbers reported to WGNAS exceeded 230,000 and observations were as far south as the Élorn river in France in NEAC and the Gander River in Newfoundland, Canada in NAC. In 2019, the number of reports increased again to over 238,000 but with a much reduced southern distribution compared to 2017. In 2021 the total number again increased to well over 500,000 with record numbers reported from as far south as Scotland, Ireland, the Netherlands, and France. NAC also reported a record number of 14 individuals in 2021. Even-year reports outside northernmost Norway/Finland/Russia remained very low between 2017–2021 with only a single report from UK (England and Wales).

Pink salmon have also been introduced in other areas in the North Atlantic, but none of these introductions have managed to establish self-sustaining populations, with the exception of the Laurentian Great Lakes in North America (Heard, 1991). Between 1906 and 1926 Pink salmon fry and fingerlings were introduced in many rivers in the state of Maine in the USA (Ricker, 1972; Lear, 1975) but after some initial success few Pink salmon were observed in Maine after 1927 (Heard, 1991). Another introduction of Pink salmon in the North Atlantic occurred in Newfoundland, Canada, between 1956 and 1966. Despite a maximum of 8500 natural spawner in the peak year 1967 runs declined throughout the 1970's (Lear, 1975) and none were thought to exist in 1991 (Heard, 1991). In the Hudson Bay area in northern Ontario, Canada, Pink salmon ova, fry, and fingerlings were stocked into Goose Creek in 1956, but no adult Pink salmon were subsequently reported from the Hudson Bay (Ricker and Loftus, 1968). Sandlund *et al*. (2019) report on a small introduction attempt of Pink salmon to southern Norway in 1976. In the Great Lakes Pink salmon were accidentally introduced into Lake Superior in 1956, and have since been firmly established in Lake Superior, Lake Huron, Lake Erie, and Lake Ontario (Heard, 1991; Kwain and Laurie, 1982). Some notable differences between these populations that complete their lifecycle in freshwater and the anadromous donor population from the Lakelse River in British Columbia (Canada) are lower fecundity, smaller size, variable ages at maturity, and a different body shape (Heard, 1991). These appear to be adaptations to the less favourable growth conditions in freshwater relative to the marine environment, possibly facilitated by rapid genetic drift due to small population size and genetic isolation from other Pink salmon populations (Berg, 1979).

1.3.3 Potential threats of Pink salmon to wild Atlantic salmon

The recent increases in numbers and the range expansion of Pink salmon in the North Atlantic have resulted in the publication of a range of peer-reviewed papers and risk-assessments on the potential threats of Pink salmon to wild Atlantic salmon. Presented here is a summary of these potential threats.

1.3.3.1 Spawning

Spatial and/or temporal overlap in spawning has been documented as a potential threat that Pink salmon pose to Atlantic salmon. In the North Atlantic Pink salmon are reported to enter rivers from late May to late September (VKM, 2020; Prusov and Zubchenko, 2021; Millane *et al*., 2019). Most Pink salmon are recorded from the lower reaches of rivers (Armstrong *et al*., 2018; VKM, 2020), but occasionally they can penetrate farther upstream as for example a fish was observed 318 km from the head-of-tide in the River Wupper catchment, a tributary of the River Rhine, in Germany in 2019 (pers. comm. Armin Nemitz and Marko Freese). Pink salmon spawning has been observed in early to mid-August and early September in Scotland (Armstrong *et al*., 2018), between early August and early October in the Murmansk area of the Russian Federation (Prusov and Zubchenko, 2021), and between early August and early September in Norway (VKM, 2020). Atlantic salmon in the North Atlantic generally spawn between mid-October and early January (Webb and McLay, 1996). However, some Atlantic salmon populations in northern Norway spawn as early as mid- to late September (VKM, 2020). As Pink salmon can spawn as late as early October in Arctic Europe there is a possibility that early spawning Atlantic salmon and late spawning Pink salmon compete for spawning sites, which can have a negative impact on native Atlantic salmon in these northern areas.

In addition to spatial and/or temporal overlap in spawning there is another possible threat from Pink salmon facing adult Atlantic salmon when entering rivers to spawn. Pink salmon display high levels of interspecific aggression at spawning time, and Pink salmon have been reported to attack Atlantic salmon that are at the spawning sites preparing for spawning (Veselov and Zyuganov, 2016). Atlantic salmon have highly variable timing entering rivers on their spawning migration. Most returning Atlantic salmon enter rivers between May and October, but in some areas (Denmark, Scotland, and England) fish enter rivers all-year round (Klemetsen, 2003). This means there is a high possibility of contact between spawning Pink salmon in August/September and migrating adult Atlantic salmon. Especially if large numbers of Pink salmon are present in rivers during the Atlantic salmon spawning migration they could pose a threat to Atlantic salmon by inflicting physical damage or stress.

1.3.3.2 Freshwater ecosystems

Another potential threat Pink salmon pose to Atlantic salmon in freshwater is competition for food and space at the juvenile stages. It has been documented that the diet of Pink salmon fry is similar to that of Atlantic salmon juveniles (Veselov and Zyuganov, 2016). If the Pink salmon fry and Atlantic salmon juveniles occupy the same space for any length of time, it would be possible for these two species to compete for resources, including food. The literature on Pink salmon ecology suggests that in their native range fry migrate out to sea almost immediately after emergence from the gravel (e.g. Sandlund *et al*. 2019, Heard, 1991). However, Sandlund *et al*. 2019 report that in Norwegian rivers Pink salmon fry were found to feed on chironomid larvae and cyclopoid copepods and smolts on predominately on copepods. In addition chironomid pupae and simuliid larvae were observed in the stomachs of Pink salmon smolts in the River Indera on the White Sea side of the Kola Peninsula in the Russian Federation (Veselov *et al*., 2016). Also VKM (2020) reported that observations in Arctic Russian rivers suggest that competition for food between Pink- and Atlantic salmon fry may be severe. It is thus very likely that in the North Atlantic area juvenile Atlantic salmon experience some level of competition with Pink salmon juveniles. This competition is likely more severe in larger rivers where Pink salmon spawn much farther upstream compared to small rivers, and thus would take longer on their seaward migration in such systems, increasing the freshwater feeding period (VKM, 2020). The impact of this competition would also likely be very dependent on the number of Pink salmon juveniles present, with higher numbers of Pink salmon fry and smolts increasing the level of threat to Atlantic salmon.

Atlantic salmon juveniles are also likely subjected to competition for space with juvenile Pink salmon in freshwater, but information on this is not available at present (VKM, 2020). But just like competition for food in freshwater between these two species, the impact of competition for space is likely dependent on the number of juvenile Pink salmon present and their distribution in space and time.

1.3.3.3 Pathogens

Viral- and bacterial pathogens carried by Pink salmon could also be a threat to wild Atlantic salmon. Among the viruses, Infectious Haematopoietic Necrosis (IHN) and Viral Haemorrhagic Septicaemia (VHS) are of particular concern as they can cause severe diseases in Atlantic salmon (e.g. Mulcahy and Wood, 1986). IHN was not found in a sample of Pink Salmon from the Tana and Neidenelva (Sandlund *et al*. 2019), but as this was based on a single small sample (N=75) not too many conclusions can be drawn from this. It is difficult to quantify the pathogen threat as this topic is not well researched, as an overview of potential viral- and bacterial pathogens present in Pink salmon and their threat to Atlantic salmon showed generally moderate to low confidence in assessing this risk (VKM, 2020).

Parasites can pose a substantial threat to the persistence of Atlantic salmon stocks. For example the monogean trematode *Gyrodactylus salaris* has caused mortality averaging 86% in Norwegian Atlantic salmon populations (Johnsen and Jensen, 1991) and had damaged the Norwegian salmon industry by an estimated $ 655 million when assessed in 2004 (Denholm *et al*., 2016). VKM (2020) reported on a literature study finding no evidence of G. salaris infestation in Pink salmon. It is therefore unlikely that Pink salmon could exacerbate the G. salaris threat to Atlantic salmon. A similar situation can be reported for another important parasite of Atlantic salmon, the Salmon louse (*Lepeophtheirus salmonis*). Several studies have reported that Pink salmon are resistant to *L. salmonis* (e.g. Jones *et al*. 2007; Sutherland *et al*. 2011). Therefore Pink salmon are also unlikely to increase the *L. salmonis* threat to Atlantic salmon. The threat of other parasites such as *Caligus* spp., and *Anisakis simplex* are also not likely to increase due to Pink salmon, yet others such as *Ichthyobodo necator* and *I. salmonis* could have this potential (VKM, 2020). In general this topic is poorly researched and more research into this is needed.

1.3.3.4 Hybridisation

Hybridisation between Atlantic salmon and Pink salmon is not considered a likely threat. In laboratory environments it is possible to produce crosses between these two species, but as crosses produced low numbers of embryos and no offspring survived to the stage of sexual maturity in a study by Devlin *et al*. (2021) it is unlikely that under natural conditions any hybrid individuals between Atlantic- and Pink salmon would survive to create backcrosses with either parental species.

1.3.3.5 Water quality

Because of their strictly semelparous life-history a die-off of adult Pink salmon occurs after spawning (e.g. Heard, 1991), causing substantial nutrient releases when their bodies subsequently decompose. In British Columbia (Canada) and Alaska (USA) this nutrient input is an essential part of the functioning of river-, lake- and terrestrial ecosystems, which are often nutrient-poor and the (Pink) salmon derived nutrients are an important part of the total nutrient capitol of these systems (e.g. Gende *et al*., 2004). Juday *et al*. (1932) reported that spawning Sockeye salmon (*O. nerka*) transported more than two million kg of organic matter and 5000 kg of phosphorus annually to the Karluk Lake system in Alaska. The nutrient poor Pacific coastal ecosystems have evolved around the annual nutrient input by spawning salmon. When such events happen outside the natural range of Pacific salmon the large quantities of organic matter and phosphorus could easily cause increases in the trophic level of rivers and lakes. This in turn can cause excessive algal growth (Muñoz *et al*., 2020; Correll 1998; Veraart *et al*. 2008) and low-oxygen conditions (Bernthal *et al*., 2021), which are particularly detrimental to salmonids (Schinegger *et al*., 2016). In southern Chile and Argentina Pacific salmonids have been established since the early 20th century and various species are currently considered invasive (e.g. Soto *et al*., 2007). In the nutrient-poor Patagonian and Andean streams the spawning runs of the non-native Chinook salmon (*O. tshawytscha*) have caused considerable increases in phosphorous, but less so for nitrogen (Soto *et al*., 2007). This has resulted in increases in algal biomass and changes to stream ecology (Muñoz *et al*., 2021). But as these streams are lacking indigenous salmonids it is difficult to predict changes in other geographical areas that do have populations of indigenous salmonids fish such as the North Atlantic. What is clear from the South American Pacific salmonid invasion is that native fish species decline, and that other invasive species such as Rainbow trout (*O. mykiss*) and American mink (*Neovison vison*) benefit, possible because of co-evolution with Pacific salmonids in their native range (Muñoz *et al*., 2020).

1.3.3.6 Marine Ecosystems

Large abundances of Pink salmon can cause trophic cascades in marine ecosystems, as has been observed in the Gulf of Alaska and the Bering Sea since the 1980's when Pink salmon abundance substantially increased in these areas (Ruggerone and Irvine, 2018). Density-dependent competition for common prey resources among the three most abundant salmon species in the North Pacific (Chum- (*O. keta*), Pink-, and Sockeye salmon), which are all primarily planktivorous, resulted in reduced growth and increased age-at-maturity with increasing biomass in these species (Debertin *et al*., 2016). A clear example of this was reported by Ruggerone *et al*. (2003) who reported that in odd-numbered years (when Asian Pink salmon are most abundant) competition with Pink salmon resulted in significantly smaller size-at-age of adult Sockeye salmon, and up to 45% lower marine survival compared to smolts migrating during odd-numbered years, causing a 22% reduction in numbers of returning adults for those cohorts. Such effects could also be expected to occur in the North Atlantic, if Pink salmon numbers keep increasing to a point where their densities start creating competition for prey resources with Atlantic salmon. Competition with the predominantly piscivorous Atlantic salmon (Rikardsen and Dempson, 2011) might be less compared to the situation in the North Pacific where Pink salmon compete with large numbers of primarily planktivorous Chum- and Sockeye salmon. However, zooplankton is a substantial part of the diet of Atlantic salmon in most marine areas and life-stages, and competition for these resources could compromise growth and survival even further in the current situation where marine survival is already at a historic low for many stocks (e.g. Utne *et al*., 2021).

1.3.4 Potential positive and neutral effects of Pink salmon on wild Atlantic salmon

Some of the potential negative effects discussed under section 2 can also manifest themselves as neutral or positive. One example of this would be that juvenile Pink salmon in rivers containing Atlantic salmon would not only be potential competitors for resources, but could also be potential food sources for Atlantic salmon parr and smolts. Sandlund *et al.* (2019) reported predation on Pink salmon fry by migrating Atlantic salmon smolts in Norwegian rivers, suggesting Pink salmon juveniles can indeed be a potential food source for Atlantic salmon smolts and parr. As Pink salmon smolts can spend several weeks feeding in large schools in estuaries and the nearshore area (Heard, 1991) they could in theory become an available food source for Atlantic (post) smolts on their outward migration. In the native range of Pink salmon the juveniles of this species are at times the dominant food source for other juvenile salmonids (Sockeye- and Chinook salmon) (Karpenko, 1982). It is possible that in the North Atlantic too, Pink salmon juveniles could become a part of the diet of native salmonids such as Atlantic salmon, Browntrout (*S. trutta*), and anadromous Arctic charr (*Salvelinus alpinus*). The ova of Pink salmon could be a potential food source for Atlantic salmon as well, as consumption of Pink salmon ova by juvenile Atlantic salmon in Russian and Norwegian rivers has been reported by Rasputina *et al.*, (2016) and Dunlop *et al.*, (2021).

Another potential positive effect of Pink salmon could be the nutrient release from the decomposing carcasses after spawning, as discussed as a potential threat in paragraph 2.5. In their native range this process is an important source of nutrients in these nutrient-poor ecosystems. The effects of this nutrient input in the fish communities in the freshwater streams and lakes in the North Pacific area is well documented. For example Swain and Reynolds (2015) reported a positive relationship between densities of sculpins and spawning biomass of Pink- and Chum salmon in 21 coastal streams in British Columbia (Canada), and even some evidence that sculpin condition increased with salmon densities (Swain *et al.*, 2014). Similar effects have been reported in salmonids. Wipfli *et al.* (2003) found increased growth in juvenile salmonids with Pacific salmon carcass additions in both artificial stream channels and natural streams, while Denton *et al.* (2009) reported that growth rates of resident salmonids increased with the availability of Pacific salmon ova and fry and blowfly larvae associated with salmon carcasses left after spawning. Similar effects might be expected for Atlantic salmon juveniles too if Pink salmon appear in numbers in North Atlantic coastal streams.

Many other effects of Pink salmon on wild Atlantic salmon could be neutral in nature. For example if invasive Pink salmon carry novel pathogens that Atlantic salmon are immune to it will likely not impact the Atlantic salmon populations negatively or positively. Similar neutral effects might occur in river systems where Pink salmon and Atlantic salmon are temporally and spatially isolated at all life-stages. In such cases the chance of direct interactions between the two species is small.

1.3.5 The issue of scale and other caveats

An important caveat in the discussion of potential effects of Pink salmon on wild Atlantic salmon is the numbers of Pink salmon that are present. The relative impact of many of the effects discussed in sections 2 and 3 will depend on the numbers of Pink salmon. For example a small number of Pink salmon fry in a coastal stream in the north Atlantic are not very likely to have an impact on the availability of food for native Atlantic salmon juveniles. Another example relevant to the threat of novel parasites transmitting to Atlantic salmon via Pink salmon is that the overall availability of host individuals is the main constraint limiting parasite population growth in fish (Bagge *et al.*, 2004). This would mean that such events were unlikely to occur when Pink salmon abundance is low, but more likely to occur with increasing Pink salmon population numbers. The data available on the numbers of odd-year Pink salmon present in the North Atlantic appear to indicate an ever increasing abundance from 2015 to

2021. This could indicate that the likelihood of impacts on and threats to native Atlantic salmon are equally increasing.

A second important caveat is that there are many unknowns in assessing the threats to Atlantic salmon from the Pink salmon invasion. As seen in this document the first empirical studies on the effects of Pink salmon on the ecosystems in the North Atlantic have been published in the scientific literature in recent years, but much is still unknown. There is literature available on the interactions between Pink salmon and other salmonid species from the Pink salmon's native range as well as regions where it was introduced. But as the species can adapt to local conditions, data from other regions cannot always be relied on to apply to the North Atlantic as well.

Substantial data gaps are also limiting the ability to correctly assess threats of Pink salmon to Atlantic salmon. VKM (2020) listed such data gaps: uncertainty in the total numbers of Pink salmon; the degree of spatial and temporal overlap in spawning between Pink and Atlantic salmon; the ecology of Pink salmon fry in northern European rivers, the freshwater residence of Pink salmon fry; Pink salmon pathogens; and Pink salmon behaviour in the marine phase in the North Atlantic. These gaps will have to be addressed in order to improve the accuracy of- and uncertainty in risk assessments for Pink salmon in the North Atlantic in the future.

A final caveat that needs to be addressed is Climate Change. There are indications that Climate Change is a major driver of the increases in Pink salmon abundance since the 2000's in the North Pacific (Springer and van Vliet, 2014) and possibly since 2017 in the North Atlantic as well. It is specifically higher Sea Surface Temperatures (SSTs) that correspond with the increase in abundance of Pink salmon in the North Pacific since the early 2000's (Springer and van Vliet, 2014). It is possible that such a link exists for the North Atlantic too as higher winter SSTs appeared to both explain higher returns of adult Pink salmon the following summer to rivers in northern Fennoscandia and higher commercial catches of Pink salmon in the White Sea in northwest Russia (VKM, 2020). It is generally difficult to predict the effects of something as unpredictable as Climate Change, but VKM (2020) predict with very high confidence that it is very likely Pink salmon will continue to spread to Norwegian rivers on a regular basis, increasing their range and abundance, initially mainly in odd years. However, it is important to note that Climate Change could also act to eventually limit (southern) range expansion and even abundance of Pink salmon in the North Atlantic when Climate Change drives SST into a suboptimal range for Pink salmon in critical areas for Pink salmon production.

1.3.6 Recommendations

The Working Group recommends a monitoring of the presence of Pink salmon in the three NASCO commission areas, and this to be reported to the Working Group annually to be collated and included in the annual report.

1.4 An overview of the East Greenland stock complex in terms of migration, stock composition, biological characteristics, historical landings, and effort.

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 being European in origin and almost exclusively comprised of Southern European stocks (Ireland, UK (Scotland), UK (England and 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, although the proportion of North American salmon in the catches is smaller and it is assumed that more Northern European stocks (Norway, Russia, Finland, Iceland, Sweden and Denmark) contribute given the proximity to Europe (Jensen, 1990).

Greenland's population lives exclusively along the coast in numerous towns and settlements (Figure 1.6; Government of Greenland, 2021). In 2021, the population of Greenland was approximately 56,000 with 6% (approximately 3000) living along the southeastern coast of Greenland across seven settlements.

1.4.1 Fishery at East Greenland

The commercial fishery for Atlantic salmon started in the early 1960's (ICES 2021a; Figure 1.7). The first reported landings from East Greenland were in 1977 and amounted to 6 t (0.4% of the total Greenland harvest; **Table 1.2**). Since then, landings for East Greenland have been reported in 31 of the 44 years, have totalled 70 t and have averaged 2.2 t per year, which equates to 1.4% of the total reported Greenland harvest. 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 1.4**). 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, reported landings of Atlantic salmon at East Greenland have always remained well below that at West Greenland (Jensen, 1990).

1.4.2 Historical Survey Efforts at East Greenland

Given the increasing Atlantic salmon fishery at West Greenland in the mid 1960's and subsequent investigations into the impacts of that fishery on the contributing stocks, there was a recognised 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 organised to survey the waters of the Irminger Sea in 1966, 1973, 1974 and 1975. Results from these early survey efforts were summarized and reported by Jensenand Lear (1980).

Survey activities occurred over 21 days in total (Figure 1.8) during June 1966 (5), August 1973 (5), July 1974 (4) August 1974 (4) and August 1975 (3) and involved polyfilament nylon nets in 1966 and monofilament nets of varying lengths, depths and mesh sizes in the remainder of the 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 given their proximity to that continent (88.5% for eastern samples versus 73.5% for western samples), although the differences were not statistically significant. One sea-winter 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 which are similar to salmon sampled at West Greenland (Sheehan *et al*. 2019; 2021a; 2021b; ICES 2021a).

Standardised 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 CPUE estimates from the fishery at West Greenland from the 1970's. Irminger sea CPUE estimates ranged from 1.5 salmon captured per 100 commercial nets in July 1966 to 11.9 in August 1975 with an estimate of 0.7 for commercial fishing activities conducted in 1972. 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 located 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 the Angmagssalik fjord (near Tasiilaq) and Skjöldungen Sound (~300 km southwest of Tasiilaq) (Thorsteinsson and Gudjónsson 1986; Figure 1.6) in 1985. Numerous fishing techniques and gears were deployed to survey for demersal fish and shrimp to characterise 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 employed to capture salmon.

A series a floating/surface gillnets of varying lengths and mesh sizes were set in the 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, drift nets were deployed. No salmon were caught within the Angmagssalik Fjord, but three salmon were captured outside of the fjord. No salmon were captured within the northern part of the Skjöldungen Sound while 398 salmon were captured in the southern part of the sound. Insufficient details are provided to calculate CPUEs. 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).

1.4.3 Contemporary Survey Efforts at East Greenland

The International Ecosystem Summer Survey in the Nordic Seas (IESSNS) has been conducted annually since 2007 (ICES, 2015; ICES, 2016; ICES, 2017; ICES, 2018a; ICES, 2019; ICES, 2020b; ICES, 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 1.9). The survey employs a standardized pelagic swept area trawl method, which is capable of catching Atlantic salmon post-smolts and adults, although the main objective of the survey is to provide an annual age-segregated abundance index for northeast Atlantic mackerel. A few hundred Atlantic salmon have been collected over the time series with 263 being captured since 2017. Although the survey covers part of the Irminger Sea (Figure 1.9), 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 than within the Norwegian Sea and off the coast of West Greenland.

As part of the EU funded SMOLTRACK project, researchers 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 1.6) during September 2021 to investigate the feasibility of catching Atlantic salmon at East Greenland and tagging them as part of the migration monitoring project. 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 via longline and most fish were capture via gillnets. Trolling was attempted at the end of the trip and it was concluded to be a well suited method for future efforts as a few salmon were captured. 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 harvest at West Greenland has occurred almost every year since 1968 (ICES, 2021a). In 2020, a contingency sampling plan was initiated to collect biological characteristics data and samples from the Greenland harvest due to travel restrictions associated with the Covid-19 pandemic. One aspect of the plan involved a Citizen Science programme where individual fishers, including those from East Greenland, were asked to provide samples from their harvest. 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, but only 14 samples were provided 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 to the harvest at East Greenland.

1.4.4 Stock composition of the East Greenland complex

Since the early 1960's, a total of 5481 tag recoveries have been reported from Greenland, of which only 59 were from East Greenland (Reddin *et al*. 2012; Table 1.4). The low number of recoveries from East Greenland is consistent with relatively low fishing effort and harvest 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 the 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 1.10). Reconstructed migration paths of these tagged fish suggested that 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 individuals from more southerly countries (Spain and Ireland) were more oriented to the southern Irminger Sea in closer proximity to where the 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 1.11). 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 fall 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 and none of these individuals 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 1.12). Marine samples were collected from mixed-stock fisheries and from historical surveys, of which 62 samples originated from surveys conducted off the coast of East Greenland in the early 1970's (Jensen and Lear 1980). The samples collected from East Greenland were 85% European in origin and 15% North American in origin (Figure 1.13). The primary contributor was the United Kingdom/Ireland reporting group, which represented 76% of the samples, with other identified reporting groups contributing 5% or less.

1.4.5 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. A series of marine surveys were conducted during the late 1960's through the early 1970's. Researchers concluded that the catch rates of Atlantic salmon were low compared to those at West Greenland, likely a result of a lower density of Atlantic salmon in the Irminger Sea. 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. However, there was a higher proportion of European origin salmon in the Irminger Sea and researchers hypothesised that as you move eastward, the proportion of European fish would increase. Subsequent 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 harvest at East Greenland. Studies on post-spawned salmon show that 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 three t 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.

The Labrador and Irminger seas and their associated coastal waters have long been known to be important feeding areas for Atlantic salmon. Relative to the West Greenland, little is known regarding the stock composition, biological characteristics, etc. of salmon off the coast of East Greenland and the information that is available is from decades past. Given the decreased abundance of Atlantic salmon across the species' range, a better understanding of the contemporary dynamics of Atlantic salmon off the coast of East Greenland is desired.

Table 1.1 Numbers of Pink salmon reported in NASCO commission areas (2017– 2021).

NASCO area	Jurisdiction	Year	No. of fish
NAC	Canada	2017	4
NAC	Canada	2019	5
NAC	Canada	2021	14
NEAC	Denmark	2017	10
NEAC	Denmark	2021	8
NEAC	Faroe Islands	2017	1
NEAC	Faroe Islands	2019	6
NEAC	Faroe Islands	2021	7
NEAC	Finland*	2017	2874
NEAC	Finland*	2019	5327
NEAC	Finland*	2021	49500
NEAC	France	2017	3
NEAC	France	2021	4
NEAC	Germany	2017	2
NEAC	Germany	2019	1
NEAC	Germany	2021	1
WGC	Greenland	2017	6
WGC	Greenland	2018	4
WGC	Greenland	2019	78
WGC	Greenland	2021	62
NEAC	Iceland	2017	79
NEAC	Iceland	2018	1
NEAC	Iceland	2019	251
NEAC	Iceland	2021	339
NEAC	Ireland	2017	36

NASCO area	Jurisdiction	Year	No. of fish
NEAC	Ireland	2019	11
NEAC	Ireland	2021	45
NEAC	Netherlands	2017	3
NEAC	Netherlands	2021	6
NEAC	Norway	2017	11654
NEAC	Norway	2019	14633
NEAC	Norway	2020	254
NEAC	Norway	2021	151437
NEAC	Russia (north-west)**	2017	220000
NEAC	Russia (north-west)**	2019	223529
NEAC	Russia (north-west)**	2021	352941
NEAC	Sweden	2017	44
NEAC	Sweden	2019	5
NEAC	Sweden	2021	70
NEAC	UK (EandW)	2017	208
NEAC	UK (EandW)	2018	1
NEAC	UK (EandW)	2019	3
NEAC	UK (EandW)	2021	26
NEAC	UK (Northern Ireland)	2017	2
NEAC	UK (Northern Ireland)	2019	3
NEAC	UK (Northern Ireland)	2021	3
NEAC	UK (Scotland)	2017	122
NEAC	UK (Scotland)	2019	19
NEAC	UK (Scotland)	2021	173

* Figures for Finland are for Tana/Teno.

** Russian numbers estimated from t caught; assume a mean weight of 1.7 kg per fish as per ICES (2018b) . Russian data for 2018 and 2020 not currently available but catches were relatively much lower than 'odd-years' as per graph in Prusov and Zubchenko (2021).

Table 1.2 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 (t)	East (t)	West	East	Total (t)	Year	West (t)	East (t)	West	East	Total (t)
1960	60	-	100%	-	60	1991	472	4	99%	1%	476
1961	127	-	100%	-	127	1992	237	5	98%	2%	242
1962	244	-	100%	-	244	1993*	-	-	-	-	-
1963	466	-	100%	-	466	1994*	-	-	-	-	-
1964	1539	-	100%	-	1539	1995	83	2	98%	2%	85
1965	861	-	100%	-	861	1996	92	+	100%	1%	92
1966	1338	-	100%	-	1338	1997	58	1	98%	2%	59
1967	1514	-	100%	-	1514	1998	11	-	100%	-	11
1968	833	-	100%	-	833	1999	19	+	100%	3%	19
1969	2153	-	100%	-	2153	2000	21	-	100%	-	21
1970	2107	-	100%	-	2107	2001	43	-	100%	-	43
1971	2654	-	100%	-	2654	2002	9	-	100%	-	9

Year	West (t)	East (t)	West	East	Total (t)	Year	West (t)	East (t)	West	East	Total (t)
1972	2023	-	100%	-	2023	2003	9	-	100%	-	9
1973	2341	-	100%	-	2341	2004	15	-	100%	-	15
1974	1917	-	100%	-	1917	2005	15	-	100%	-	15
1975	2030	-	100%	-	2030	2006	22	-	100%	-	22
1976	1175	-	100%	-	1175	2007	25	-	100%	-	25
1977	1420	6	100%	0%	1426	2008	26.2	0	100%	0%	26.2
1978	984	8	99%	1%	992	2009	25.6	0.8	97%	3%	26.3
1979	1395	+	100%	0%	1395	2010	38.1	1.7	96%	4%	39.6
1980	1194	+	100%	0%	1194	2011	27.4	0.1	100%	0%	27.5
1981	1264	+	100%	0%	1264	2012	32.6	0.5	98%	2%	33.1
1982	1077	+	100%	0%	1077	2013	47	0	100%	0%	47.0
1983	310	+	100%	0%	310	2014	57.8	0.1	100%	0%	57.9
1984	297	+	100%	0%	297	2015	55.9	1	98%	2%	56.8
1985	864	7	99%	1%	871	2016	25.7	1.5	95%	6%	27.1
1986	960	19	98%	2%	979	2017	27.8	0.3	98%	1%	28.3
1987	966	+	100%	0%	966	2018	39.0	0.8	98%	2%	39.9
1988	893	4	100%	0%	897	2019	28.3	1.4	95%	5%	29.8
1989	337	-	100%	-	337	2020	30.9	0.8	97%	3%	31.7
1990	274	-	100%	-	274						

Table 1.3 Total number of Atlantic salmon fishing licences issued and the number of fishers reporting landings from West and East Greenland. Blanks cells indicate that the data were not reported or 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 (No.)	West fishers reporting (No.)	East fishers reporting (No.)	Year	Licences issued (No.)	West fishers reporting (No.)	East fishers reporting (No.)
1987		551		2004	157	66	
1988		510		2005	185	75	
1989		392		2006	166	141	
1990		354		2007	261	132	
1991		410		2008	262	143	
1992		212		2009	293	136	9
1993				2010	309	195	13
1994				2011	242	112	5

Year	Licences issued (No.)	West fishers reporting (No.)	East fishers reporting (No.)	Year	Licences issued (No.)	West fishers reporting (No.)	East fishers reporting (No.)
1995		145		2012	276	116	6
1996		163		2013	328	94	1
1997		81		2014	320	113	1
1998		69		2015	310	180	9
1999	424	103		2016	263	130	10
2000	179	46		2017	282	141	2
2001	451	80		2018	786	549	8
2002	480	41		2019	717	614	24
2003	150	42		2020	757	608	10

Table 1.4 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 the 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	2 128	30	2 158	1.4
Canada	1 814	2	1 816	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 and Wales)	195	3	198	1.5
UK (Northern Ireland)	2	0	2	0
Total	4 682	59	4 741	1.2

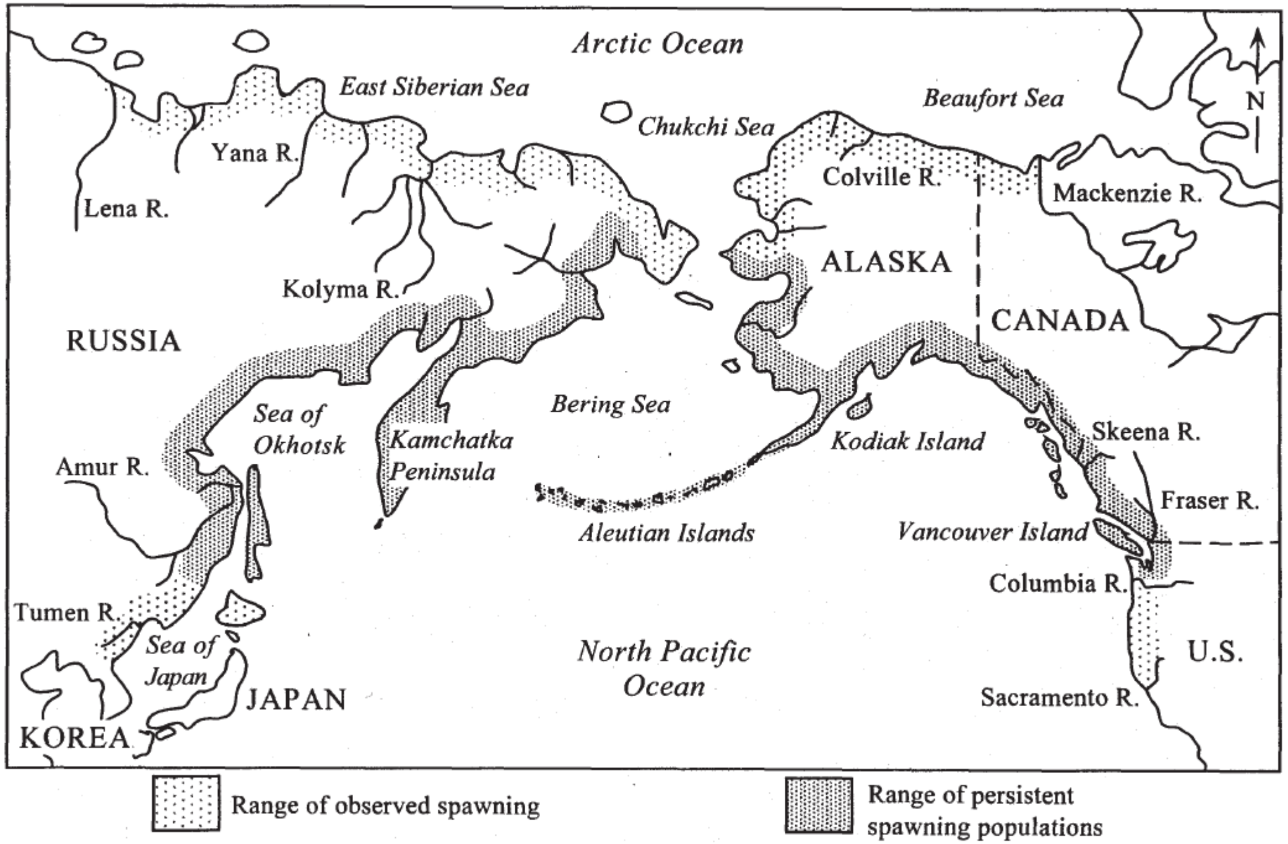


Figure 1.1 Geographical range of observed and persistent spawning of Pink salmon in the Pacific and Arctic Oceans after Hard *et al.*, 1996.

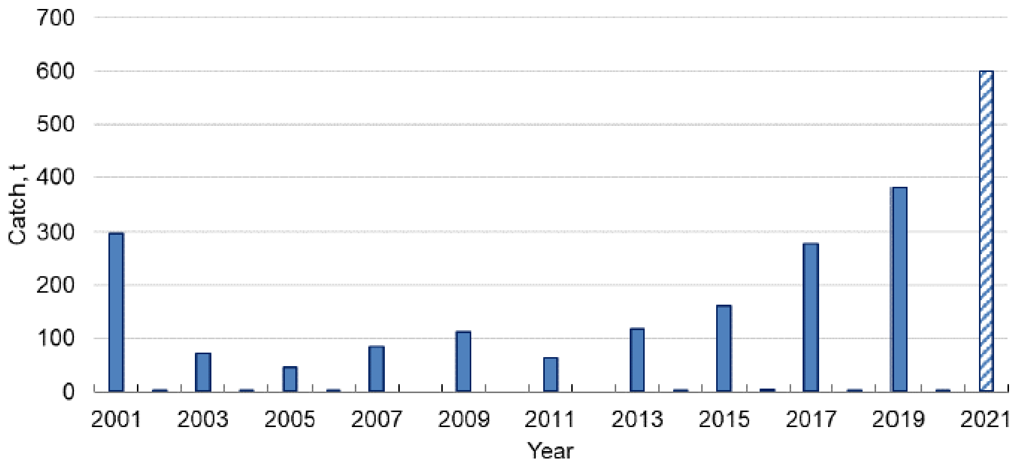


Figure 1.2 Nominal Pink salmon catches in Murmansk region in 2001-2021. Catch for 2021 is provisional (Prusov and Zubchenko , 2021).

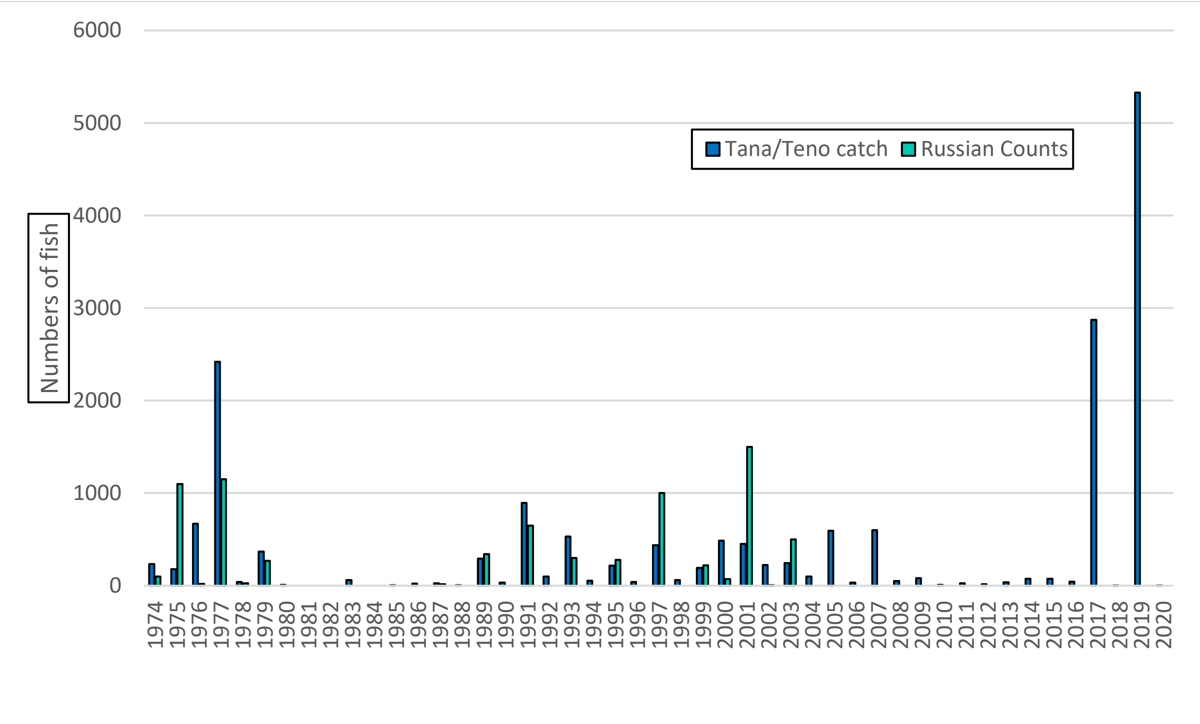


Figure 1.3 Sum of recorded catches of Pink salmon in the river Tana/Teno in Norwegian and Finnish waters, 1974–2020 (data from LUKE and Tanavassdragets fiskeforvaltning, www.tanafisk.no), and counts of adult Pink salmon in Russian catches 1974–2003 (Zubchenko *et al*. 2004).

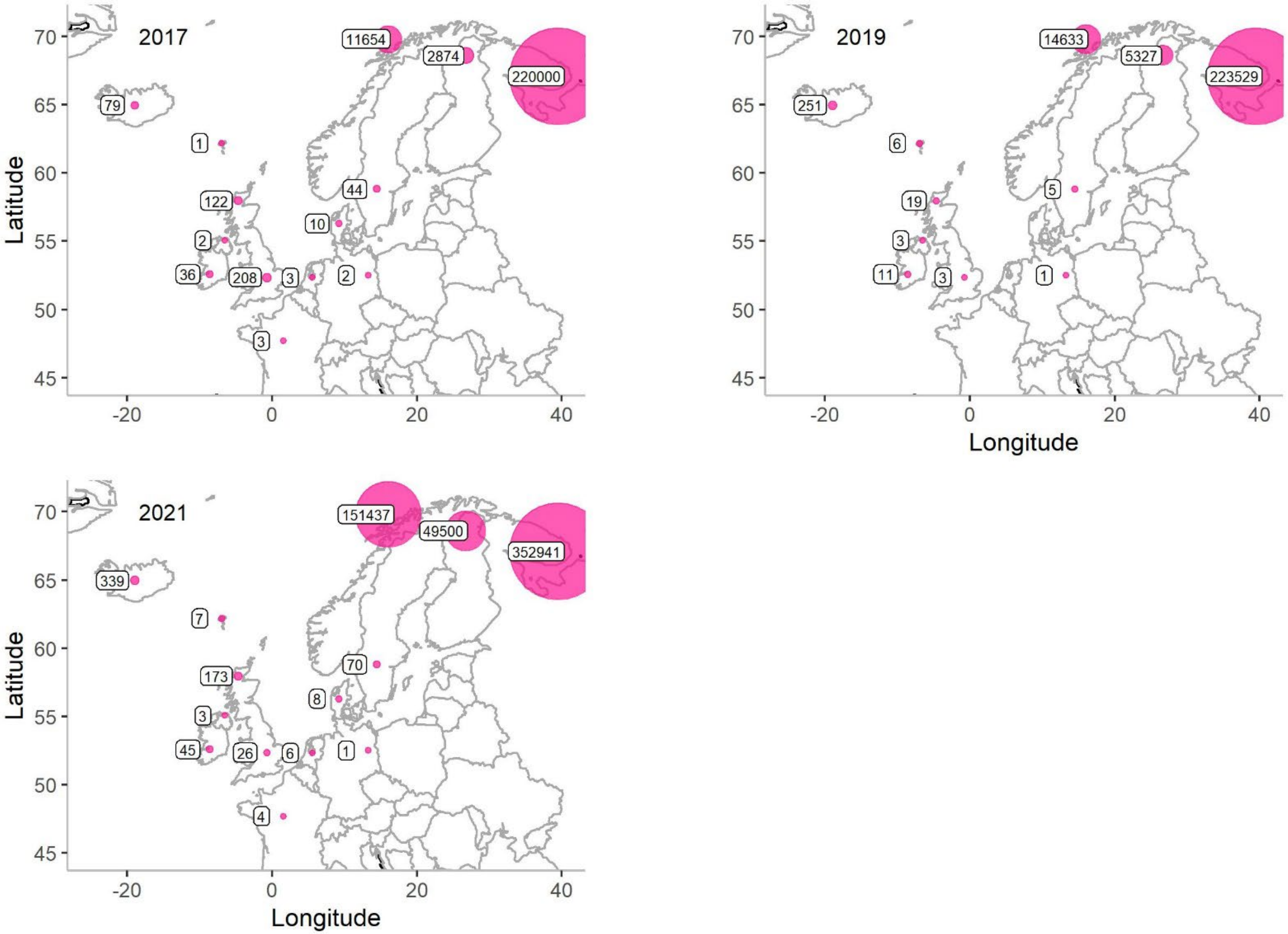


Figure 1.4 Numbers of Pink salmon reported by jurisdiction in the NEAC area (2017, 2019 and 2021).

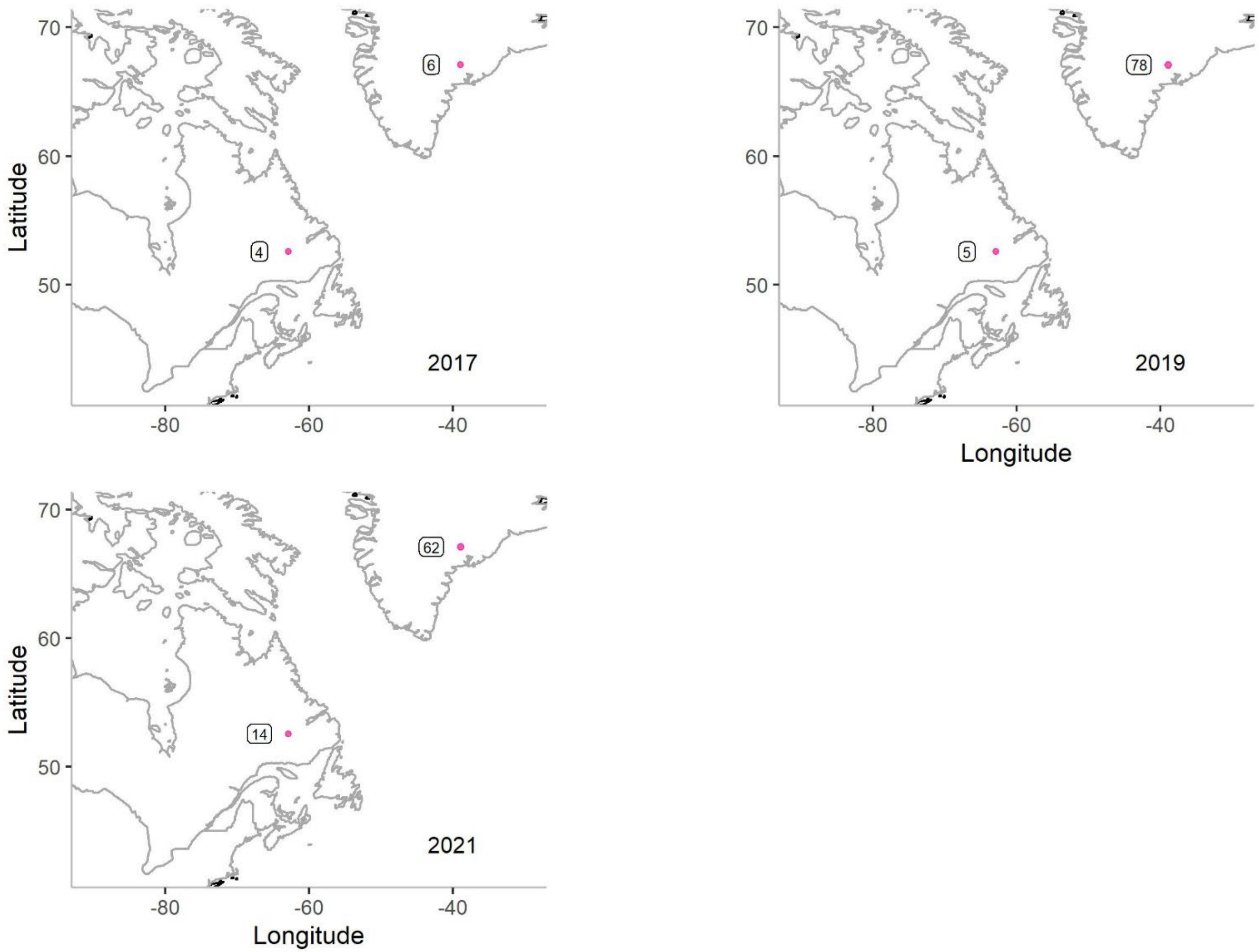


Figure 1.5 Numbers of Pink salmon reported by jurisdiction in the NAC and WGC areas (2017, 2019 and 2021).

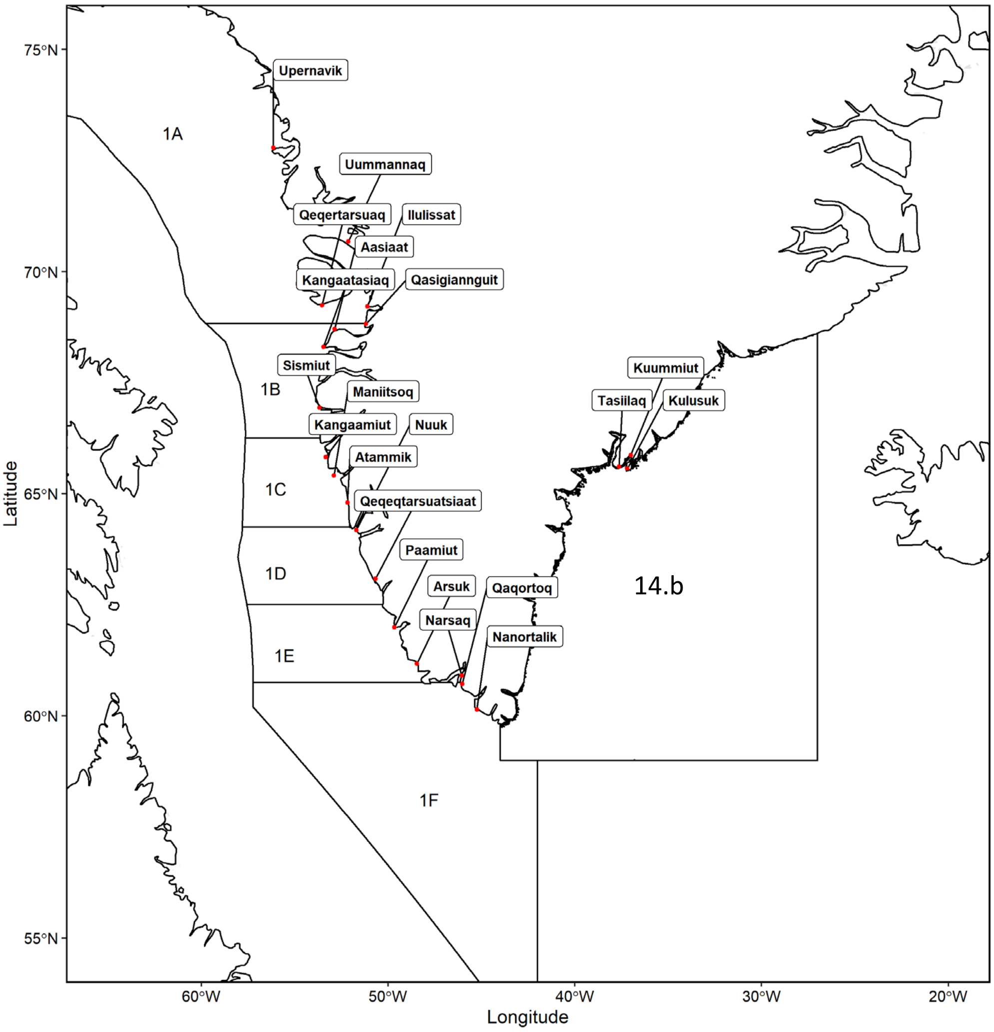


Figure 1.6 Map of southern Greenland showing communities to which Atlantic salmon have historically been landed and corresponding NAFO divisions (1A-1F) and ICES sub-area 14.b.

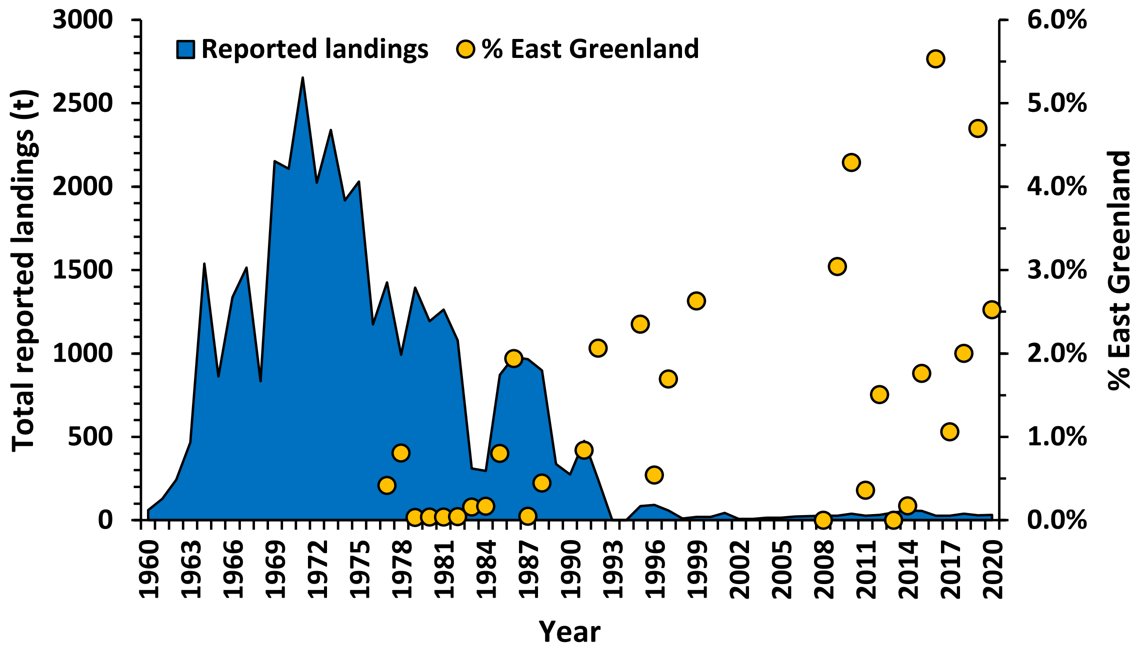


Figure 1.7 Reported landings (t) of Atlantic salmon at Greenland from 1960–2020 and percentage of landings that are attributed to having come from East Greenland (data from ICES 2021a).

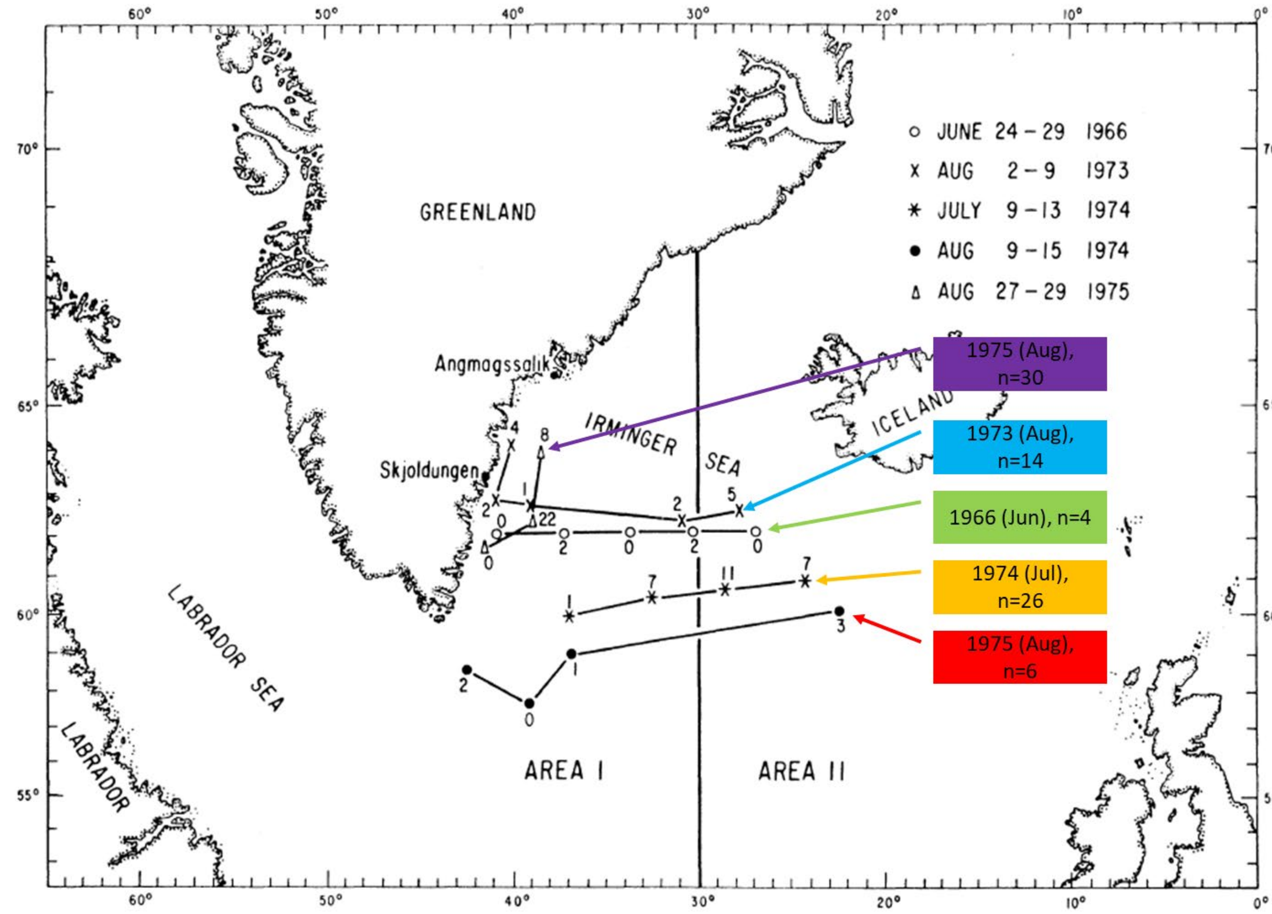


Figure 1.8 Irminger Sea stations surveyed by the R/V Dana in 1966, 19973, 1974 and 1975. Stations were surveyed via driftnets and the number of salmon caught at each station is noted (reproduced from Jensen and Lear 1980).

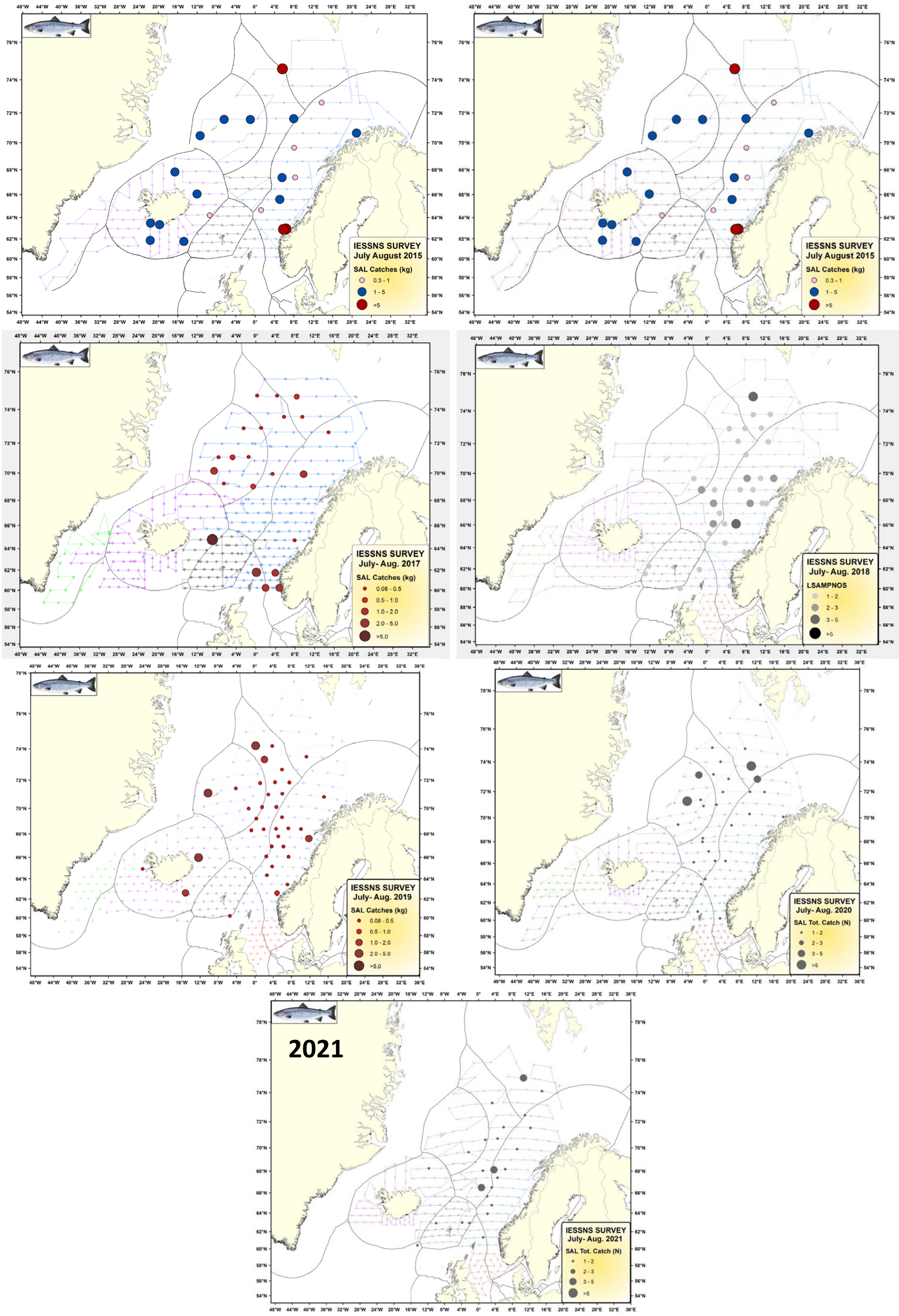


Figure 1.9 Stations and catches (numbers) of salmon at surface trawl stations during the 2015–2021 International Ecosystem Summer Survey in the Nordic Seas (reproduced from ICES 2015; ICES 2016; ICES 2017; ICES 2018b; ICES 2019; ICES 2020b; ICES 2021b).

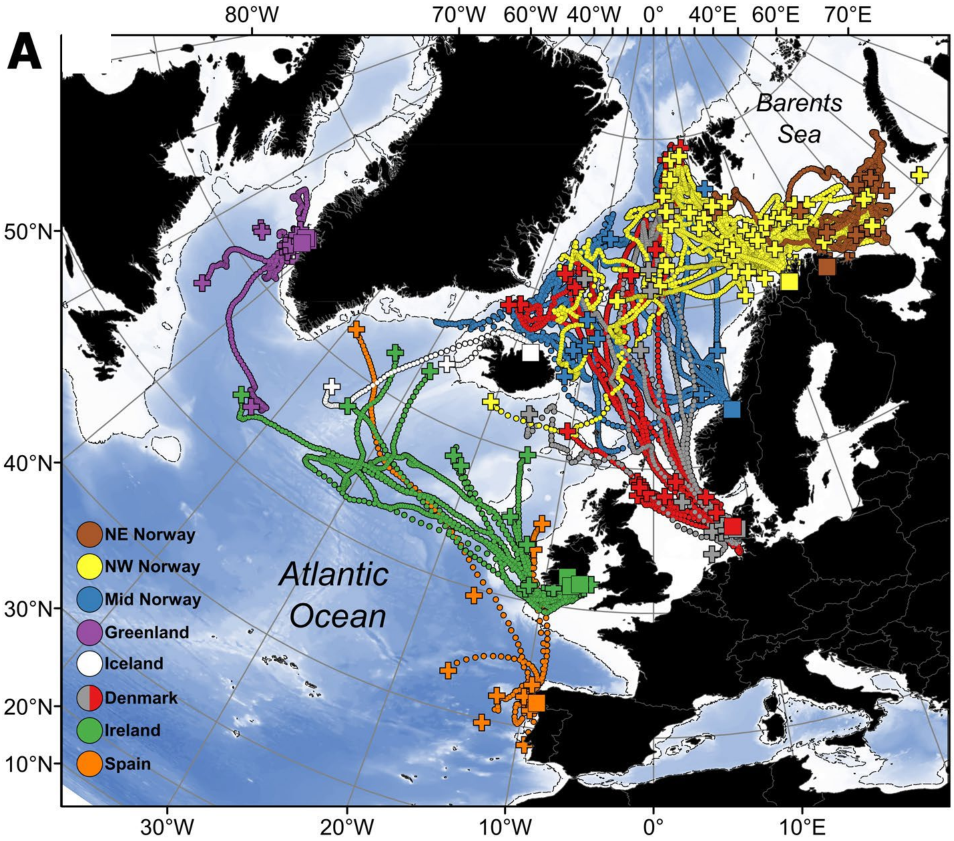


Figure 1.10 Migrations of Atlantic salmon tagged in eight different geographic areas: release locations post tagging are shown by squares, estimated daily geographic location of 105 salmon is shown by circles and crosses show the pop-up location of the tags. Dashed line represents the 500 m depth contour with darker blue indicating increasing depth (reproduced from Rikardsen *et al*. 2021).

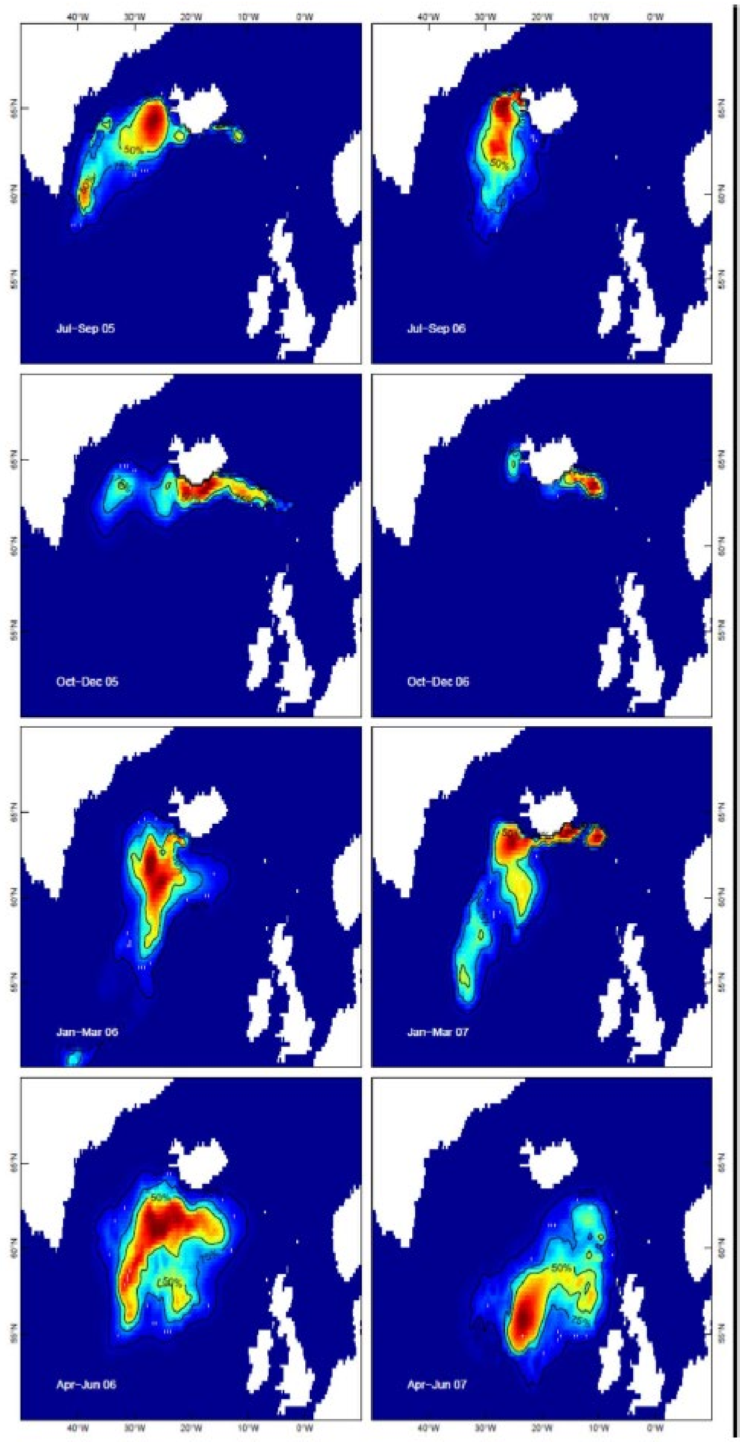
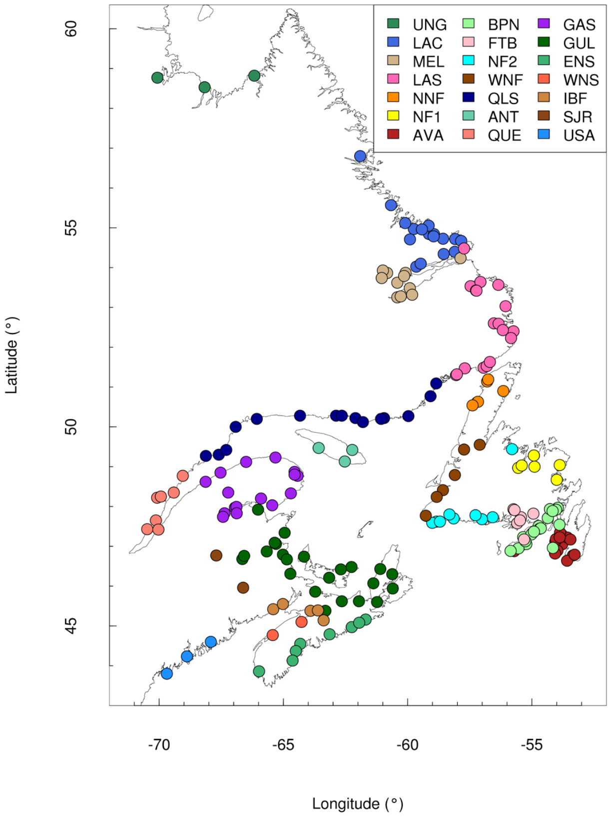


Figure 1.11 Estimated usage distribution from hatchery reared DST tagged Icelandic salmon divided into year-quarters. The fish released in 2005 are on the left and the fish released in 2006 on the right. The mean posterior probability is calculated for each cell and the top 50%, 75% and 95% areas are shown (reproduced from Guðjónsson *et al*. 2015).



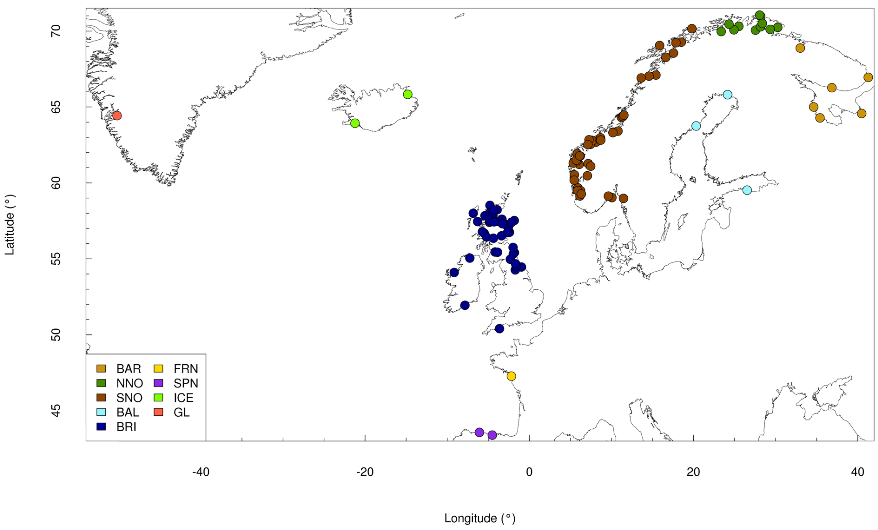
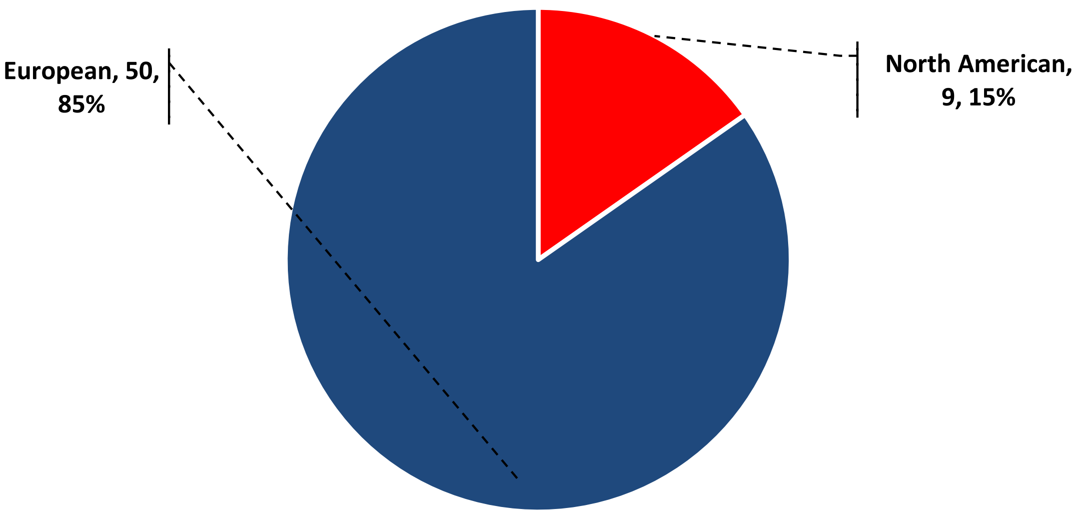


Figure 1.12 Map of sample locations for comprehensive North Atlantic-wide genetic baseline for North American (top) and European (bottom) reporting groups (reproduced from ICES 2020a).



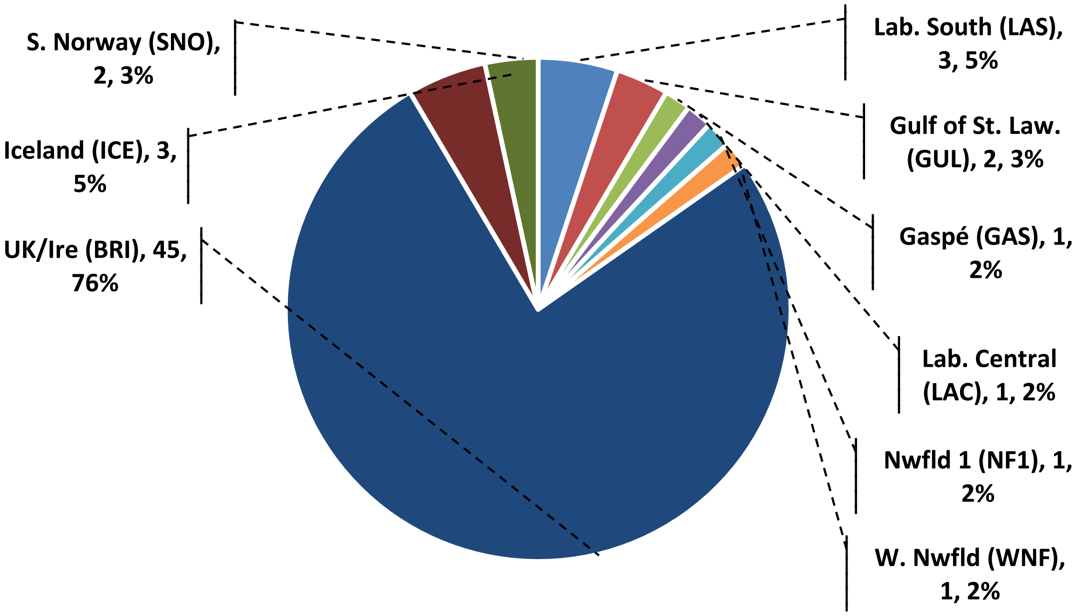


Figure 1.13 Continent and region of origin contributions (number, percentage) for adult Atlantic salmon samples collected off the coast of East Greenland during July-August 1973–1975 as reported by Bradbury *et al*. (2021). Sample location are identified in Figure 2.

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Annex 1: List of participants

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* Contribution of data and a report made for the February 2022 meeting, prior to the suspension of the Russian Federation by ICES.

Annex 2: Resolutions

2021/2/FRSG18 The **Working Group on North Atlantic Salmon** (WGNAS), chaired by Dennis Ensing, UK, will meet at ICES HQ 28 March–7 April 2022 to:

a) Address relevant points in the Generic ToRs for Regional and Species Working Groups for each salmon stock complex;

b) Address questions posed by NASCO:

1. With respect to Atlantic salmon in the North Atlantic area:

1.1 provide an overview of salmon catches and landings by country, including unreported catches and catch and release, and production of farmed and ranched Atlantic salmon in 2021[1];

1.2 report on significant new or emerging threats to, or opportunities for, salmon conservation and management[2];

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.;

1.5 provide a compilation of tag releases by country in 2021; and

1.6 identify relevant data deficiencies, monitoring needs and research requirements;

2. With respect to Atlantic salmon in the North-East Atlantic Commission area:

2.1 describe the key events of the 2021 fisheries[3];

2.2 review and report on the development of age-specific stock conservation limits, including updating the time-series of the number of river stocks with established CLs by jurisdiction;

2.3 describe the status of the stocks, including updating the time-series of trends in the number of river stocks meeting CLs by jurisdiction;

2.4 provide catch options or alternative management advice for the 2022/2023 - 2024/2025 fishing seasons, with an assessment of risks relative to the objective of exceeding stock conservation limits, or pre-defined NASCO Management Objectives, and advise on the implications of these options for stock rebuilding[4]; and

2.5 update the Framework of Indicators used to identify any significant change in the previously provided multi-annual management advice.

3. With respect to Atlantic salmon in the North American Commission area:

3.1 describe the key events of the 2021 fisheries (including the fishery at St Pierre and Miquelon)[3];

3.2 update age-specific stock conservation limits based on new information as available, including updating the time-series of the number of river stocks with established CLs by jurisdiction;

3.3 describe the status of the stocks, including updating the time-series of trends in the number of river stocks meeting CLs by jurisdiction;

3.4 provide catch options or alternative management advice for 2022-2025 with an assessment of risks relative to the objective of exceeding stock conservation limits, or pre-defined NASCO Management Objectives, and advise on the implications of these options for stock rebuilding[4]; and

3.5 update the Framework of Indicators used to identify any significant change in the previously provided multi-annual management advice.

4. With respect to Atlantic salmon in the West Greenland Commission area:

4.1 describe the key events of the 2021 fisheries[3];

4.2 describe the status of the stocks[5];

4.3 provide catch options or alternative management advice for 2022-2024 with an assessment of risk relative to the objective of exceeding stock conservation limits, or pre-defined NASCO Management Objectives, and advise on the implications of these options for stock rebuilding[4]; and

4.4 update the Framework of Indicators used to identify any significant change in the previously provided multi-annual management advice.

Notes:

1. *With regard to question 1.1, for the estimates of unreported catch the information provided should, where possible, indicate the location of the unreported catch in the following categories: in-river; estuarine; and coastal. Numbers of salmon caught and released in recreational fisheries should be provided.*

2. *With regard to question 1.2, ICES is requested to include reports on any significant advances in understanding of the biology of Atlantic salmon that is pertinent to NASCO.*

3. *In the responses to questions 2.1, 3.1 and 4.1, ICES is asked to provide details of catch, gear, effort, composition and origin of the catch and rates of exploitation. For homewater fisheries, the information provided should indicate the location of the catch in the following categories: in-river; estuarine; and coastal. Information on any other sources of fishing mortality for salmon is also requested. For 4.1, if any new surveys are conducted and reported to ICES, ICES should review the results and advise on the appropriateness of incorporating resulting estimates into the assessment process.*

4. *In response to questions 2.4, 3.4 and 4.3, provide a detailed explanation and critical examination of any changes to the models used to provide catch advice and report on any developments in relation to incorporating environmental variables in these models. Also provide a detailed explanation and critical examination of any concerns with salmon data collected in 2021 which may affect the catch advice considering the restrictions on data collection programmes and fisheries due to the COVID 19 pandemic.*

5. *In response to question 4.2, ICES is requested to provide a brief summary of the status of North American and North-East Atlantic salmon stocks. The detailed information on the status of these stocks should be provided in response to questions 2.3 and 3.3.*

WGNAS will report by 12 April 2022 for the attention of ACOM.

Only experts appointed by national Delegates or appointed in consultation with the national Delegates of the expert's country can attend this Expert Group