

Distribution and abundance of pink salmon across the North Atlantic

Summary of the advice

ICES notes that both the abundance and geographic range of pink salmon (*Oncorhynchus gorbuscha*) have substantially increased in the North Atlantic since 2017. In 2021, the total number of observed and reported pink salmon was over 500 000, with the distribution ranging from northern Russian Federation to as far south as Scotland, Ireland, the Netherlands, and France.

ICES advises that pink salmon pose several potential threats to wild Atlantic salmon (*Salmo salar*) both in freshwater and marine ecosystems. In freshwater the main potential threats are competition for spawning sites and interspecific aggression during the spawning season, space and food for juveniles, potential transfer of pathogens and decreased water quality caused by the decomposition of dead post-spawning pink salmon. In the marine ecosystem the main potential threat is from competition for food.

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 latter 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 1.3 (pink salmon).

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, Russian Federation) in Asia (Heard, 1991; Mathisen, 1994; Figure 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. In many rivers these odd and even-year populations coexist. Both types spawn during late summer and autumn in 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 5–15°C and are generally higher for southern populations. Pink salmon tend 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 their natural range 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 some time – 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 and 8% in Prince William Sound, Alaska. Kaev and Radchenko (2021) reported rates of between 1 and 18% in populations from Sakhalin Island, Russian Federation. Early marine growth has repeatedly been correlated with overall survival in Pacific salmon species. Although it is not completely understood at present, 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/intraspecific 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 of 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; Pess *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) 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.

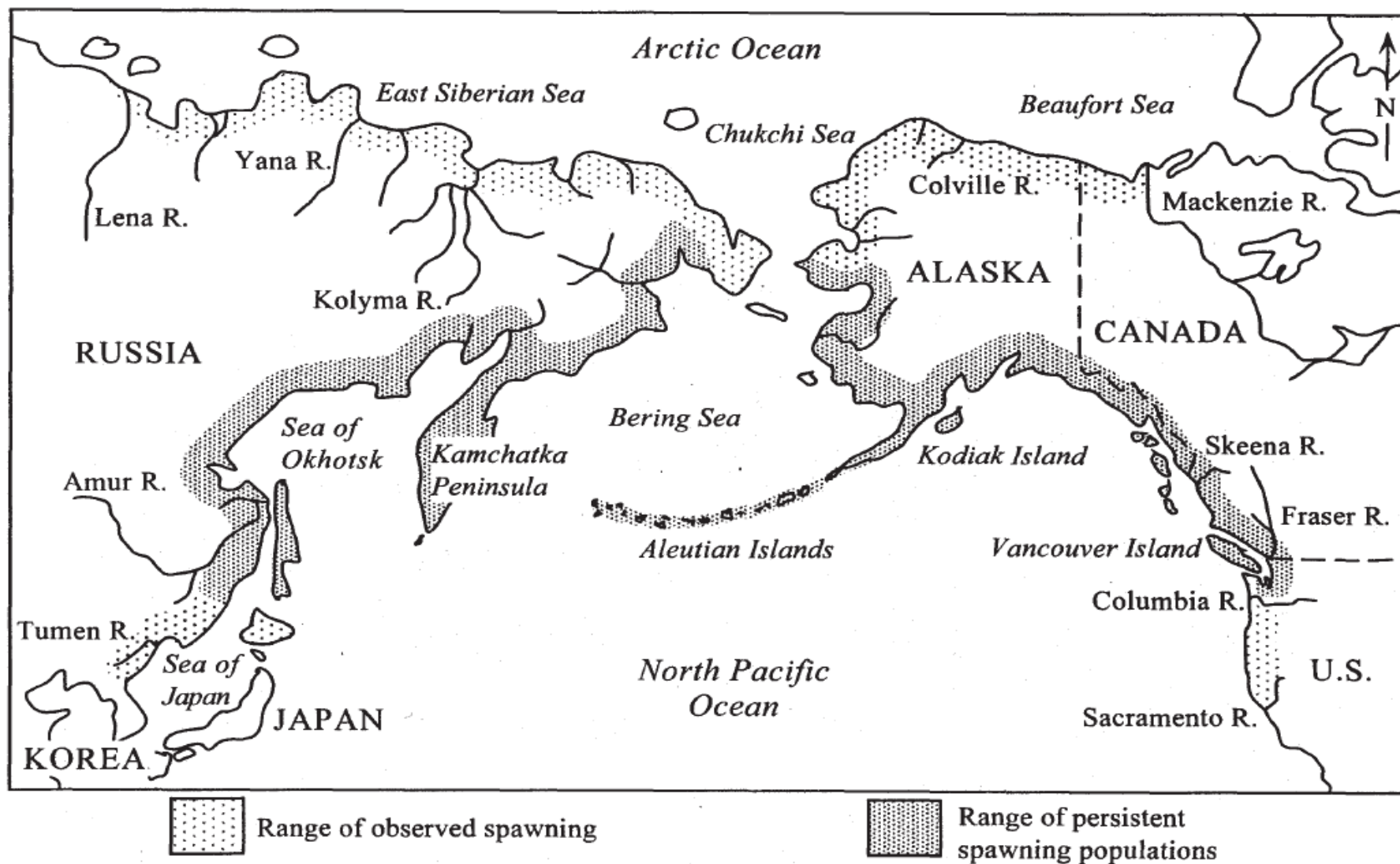


Figure 1 Geographical range of observed and persistent spawning of pink salmon in the Pacific and Arctic oceans after Hard *et al.* (1996).

Pink salmon distribution 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). This stocking occurred for most years until 1979 with variable results. Occasionally large numbers of adults were observed as a result, sometimes even outside the stocking area, 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 was 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 a 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 than 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. The stocking programme in northwestern Russia terminated in 1999 (Sandlund *et al.*, 2019).

Catches of odd-year pink salmon in the White Sea waters of the Murmansk region were below 100 t pre-2000 but increased to an average of > 200 t between 2002 and 2017 (Prusov and Zubchenko, 2021). Since 2019 the catch has exceeded 300 t, with a record provisional catch of 600 t in 2021 (Figure 2).

Outside the Russian Federation, pink salmon from the introduction programme that started in 1986 have been observed in a wide range of countries including Norway and Finland (Sandlund *et al.*, 2019), Faroe Islands (Eliassen 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 3, amended to 2020). After high catches in the 1970s, pink salmon catches in the Tana/Teno declined to zero after the first attempt to establish self-sustaining populations ended in 1979. The stocking programme restarted in 1986 and by the 1990s catches increased again to about 400–1000 individuals for odd years and below 100 for most even years. Russian stocking ceased in 1999, however odd-year catches continued with catches between 2001 and 2007 reaching the highest levels since between 1977 and 1991. All these fish must have been 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 the northern areas of the Russian Federation, Finland, Sweden, and Norway but also much further south such as in central and southern Norway, UK and Ireland, and as far south as France. In addition there are also observations from the northwest Atlantic, the NASCO NAC area, and the West Greenland Commission (WGC) area. The available pink salmon catches and observations are presented in Table 1 and figures 4 and 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 Élorne 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 of observed and reported pink salmon had more than doubled to 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/Russian Federation 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 United States (Ricker, 1972; Lear, 1975), but after some initial success few pink salmon were observed in Maine after 1927 (Heard, 1991). Another introduction occurred in Newfoundland, Canada between 1956 and 1966. Despite a maximum of 8500 natural spawners in the peak year 1967, runs declined throughout the 1970s (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 adults were subsequently reported from the Hudson Bay (Ricker and Loftus, 1968). Sandlund *et al.* (2019) report on a small unsuccessful introduction attempt 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 there as well as in Lake Huron, Lake Erie, and Lake Ontario (Kwain and Laurie, 1982; Heard, 1991). 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 as a result of small population size and genetic isolation from other pink salmon populations (Berg, 1979).

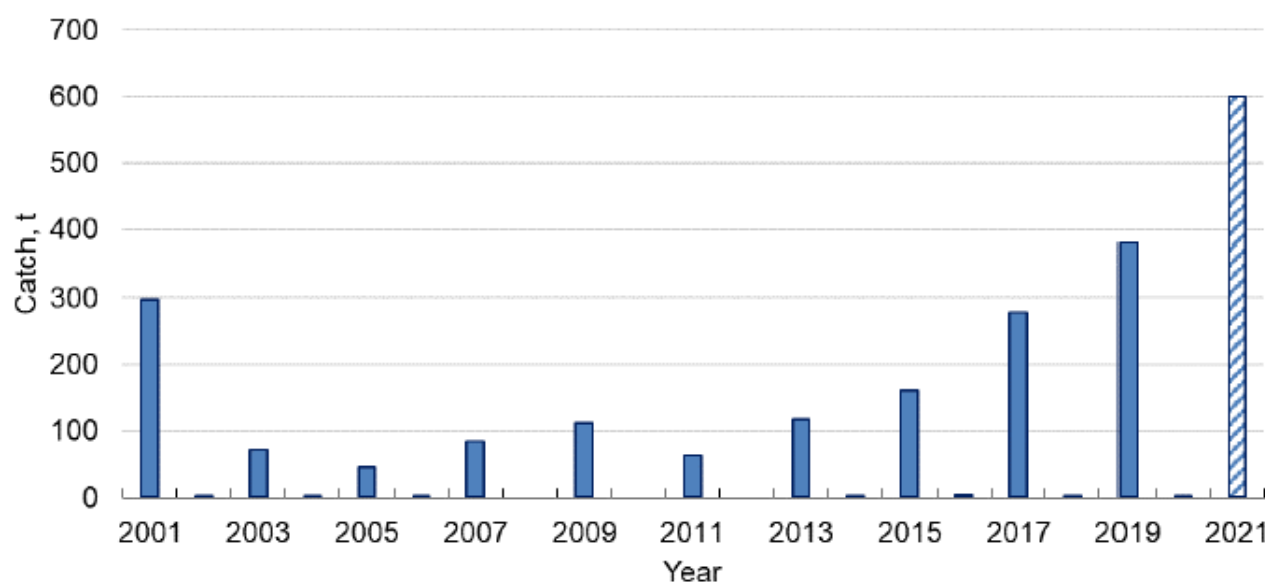


Figure 2 Nominal pink salmon catches in the White Sea waters of the Murmansk region in 2001–2021. Catch for 2021 is provisional (Prusov and Zubchenko [2021]).

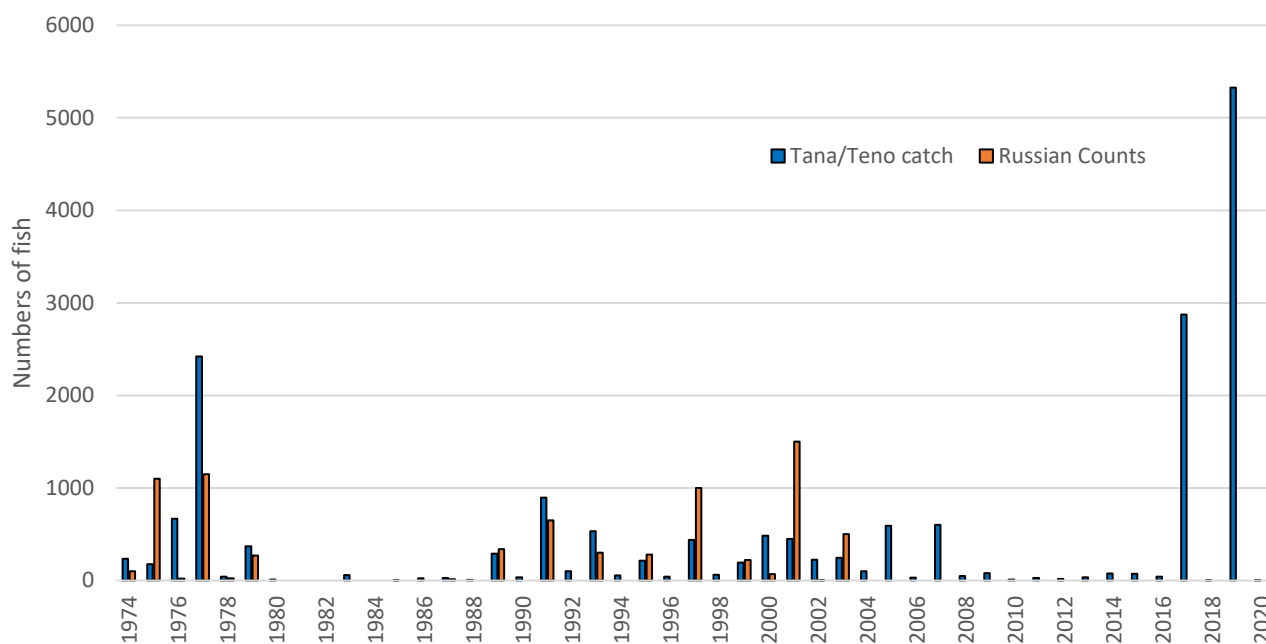


Figure 3 Sum of recorded catches of pink salmon in the river Tana/Teno in Norwegian and Finnish waters, 1974–2020 (data from Natural Resource Institute Finland [LUKE] and Tanavassdragets fiskeforvaltning, www.tanafisk.no), and counts of adult pink salmon in Russian catches 1974–2003 (Zubchenko *et al.* [2004]).

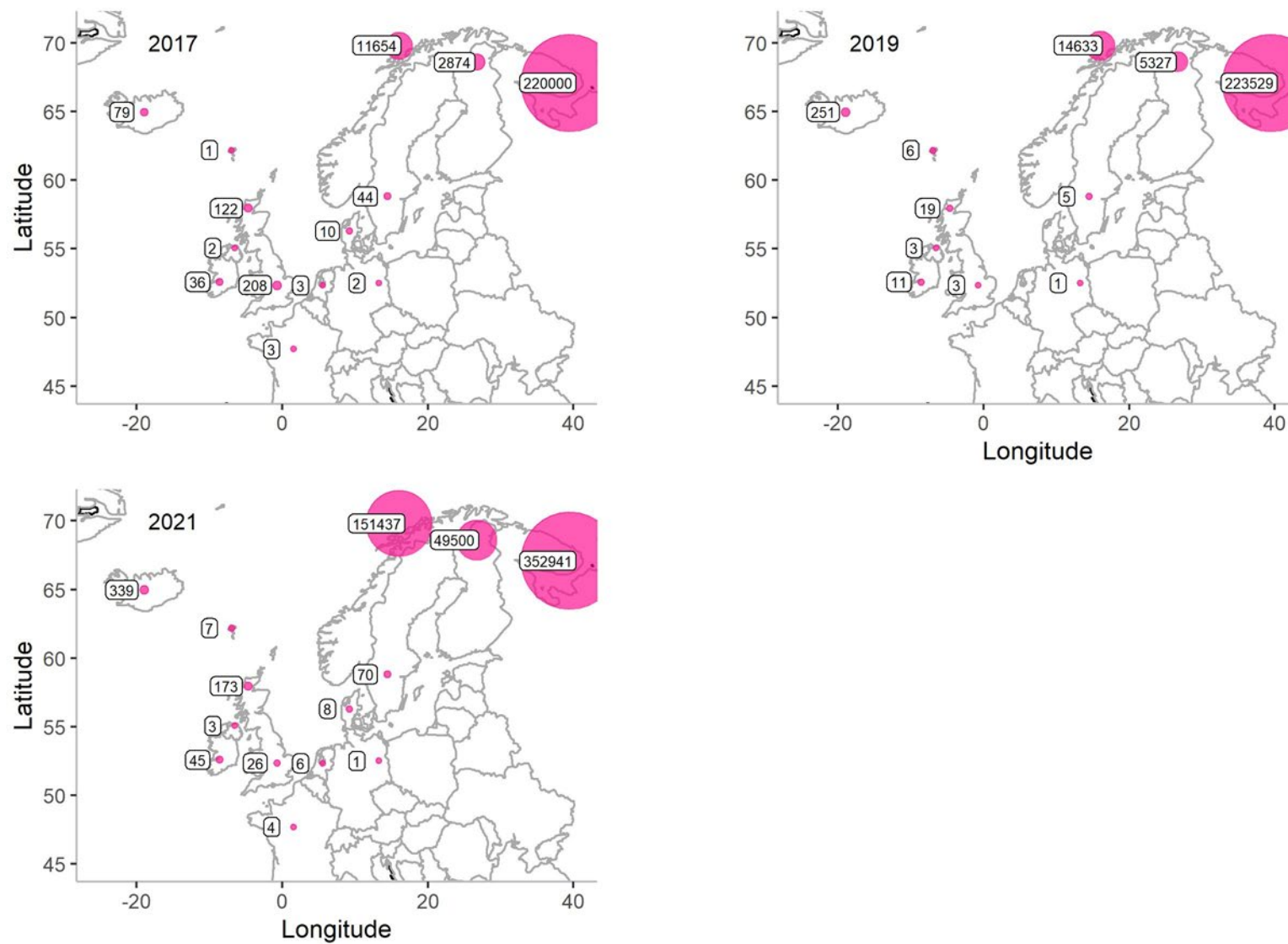


Figure 4 Numbers of pink salmon observed and reported by jurisdiction in the NEAC area (2017, 2019, and 2021).

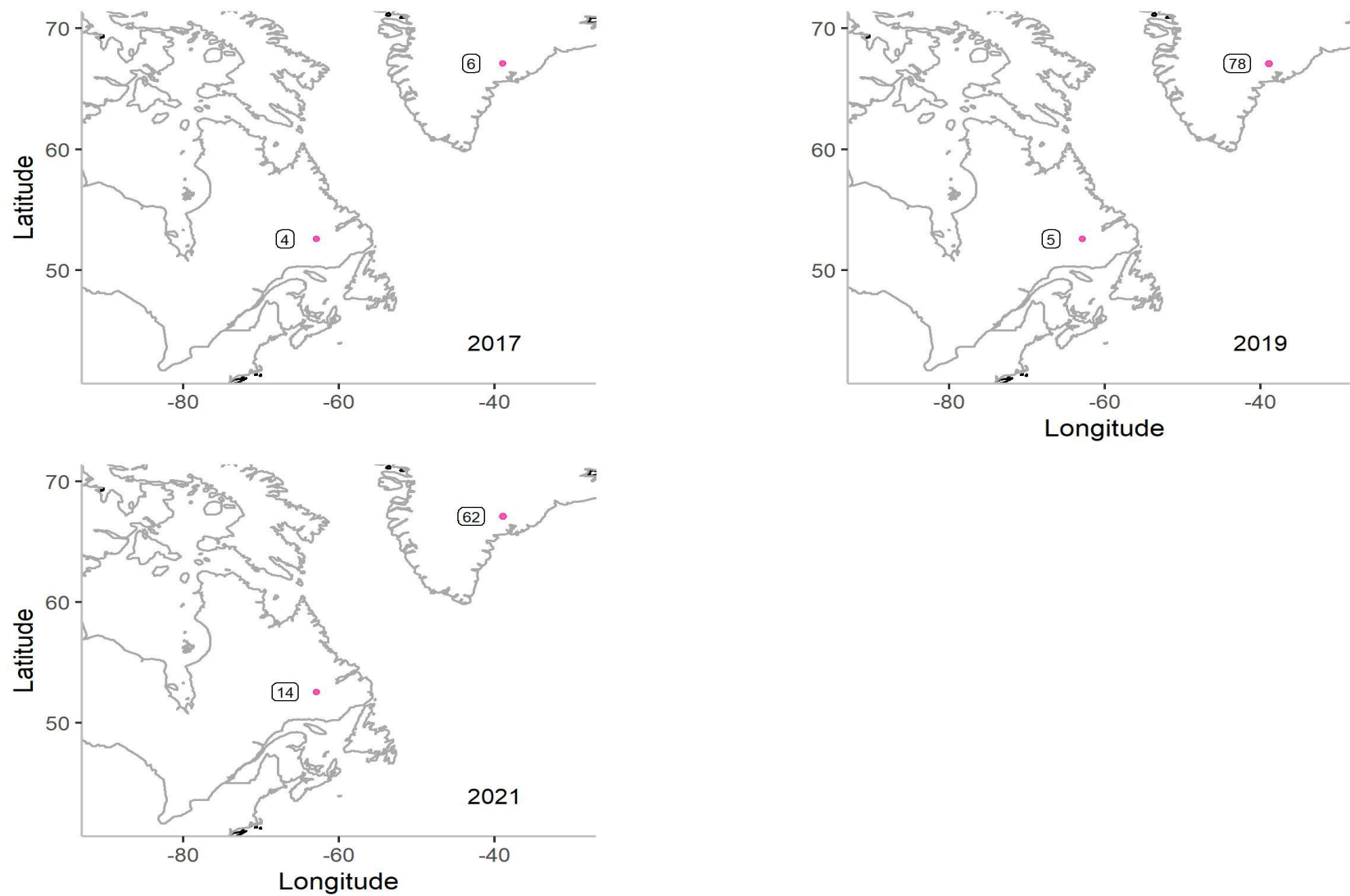


Figure 5 Numbers of Pink salmon observed and reported by jurisdiction in the NAC and WGC areas (2017, 2019, and 2021).

Table 1 Numbers of pink salmon reported in NASCO areas (2017–2021).

NASCO area	Jurisdiction	2017	2018	2019	2021	Total
NAC	Canada	4		5	14	23
NEAC	Denmark	10			8	18
	Faroe Islands	1		6	7	14
	Finland*	2874		5327	49500	57701
	France	3			4	7
	Germany	2		1	1	4
	Iceland	79	1	251	339	670
	Ireland	36		11	45	92
	Netherlands	3			6	9
	Norway	11654	14633	254	151437	177978
	Russian Federation (north-west)**	220000		223529	352941	796470
	Sweden	44		5	70	119
	UK (England & Wales)	208	1	3	26	238
	UK (Northern Ireland)	2		3	3	8
	UK (Scotland)	122		19	173	314
WGC	Greenland	6	4	78	62	150

* Figures for Finland are for Tana/Teno.

** Russian numbers estimated from tonnes caught; assume a mean weight of 1.7 kg per fish as per ICES (2018). 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).

Potential threats of pink salmon to wild Atlantic salmon

Although it is difficult to predict the direct impacts of pink salmon on Atlantic salmon, research on the invasion of Pacific salmonids in South America clearly shows that native fish species decline and other non-native species such as rainbow trout (*Oncorhynchus mykiss*) and American mink (*Neovison vison*) benefit (Heggenes *et al.*, 1988, Muñoz *et al.*, 2021). And this in turn could have negative effects on Atlantic salmon.

Freshwater ecosystem

Competition between adults

Spatial and 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 (Millane *et al.*, 2019; VKM, 2020; Prusov and Zubchenko 2021). Most pink salmon are recorded from the lower reaches of rivers (Armstrong *et al.*, 2018; VKM, 2020), but occasionally they can migrate farther upstream (e.g. it has been reported that 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). 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 region 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 (Web 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 temporal overlap in spawning there is another possible threat from pink salmon interacting with adult Atlantic salmon when entering rivers to spawn. Pink salmon display high levels of interspecific aggression at spawning time and have been reported to attack Atlantic salmon that are preparing to spawn at their sites (Veselov and Zyuganov, 2016). Atlantic salmon have highly variable timing entering rivers on their spawning migration. For most returners, this is 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. This is especially the case if large numbers of pink salmon are present in rivers during the Atlantic salmon spawning migration, as they could then pose a threat to the Atlantic salmon by inflicting physical damage and/or stress.

Competition between juveniles

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. Heard, 1991; Sandlund *et al.*, 2019). 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 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 Kola Peninsula in the White Sea (Veselov *et al.*, 2016). Also VKM (2020) reported that observations in northwestern Russian rivers suggest that there is competition for food between pink and Atlantic salmon fry. It is thus very likely that in areas of co-occurrence the North Atlantic 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, 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.

Hybridization

Hybridization 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 the two species would survive to create backcrosses with either parental species.

Water quality

Because of their strictly semelparous life history adult pink salmon die after spawning (e.g. Heard, 1991). The decomposition of the bodies of post-spawning salmon cause substantial nutrient releases (e.g. Juday *et al.*, 1932; Gende *et al.*, 2004; Soto *et al.*, 2007). This in turn can cause excessive algal growth (Correll, 1998; Veraart *et al.*, 2008; Muñoz *et al.*, 2020;) and low-oxygen conditions (Bernthal *et al.*, 2021), which are particularly detrimental to salmonids (Schinegger *et al.*, 2016).

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 1980s, 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 [*Oncorhynchus keta*], pink, and sockeye [*Oncorhynchus nerka*] 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 is in Ruggerone *et al.* (2003), who reported that in odd-numbered years (when Asian populations of 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 even-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 historical low for many stocks (e.g. Utne *et al.*, 2020).

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 of 75 not too many conclusions can be drawn.

Parasites can pose a substantial threat to the persistence of Atlantic salmon stocks. However, VKM (2020) reported on a literature study that found no evidence of *Gyrodactylus salaris* infestation in pink salmon. It is therefore unlikely that pink salmon could exacerbate the *G. salaris* threat to Atlantic salmon. A similar situation was reported for the salmon louse (*Lepeophtheirus salmonis*). Several studies have reported that pink salmon are resistant to this louse (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 as a result of pink salmon, yet others such as *Ichthyobodo necator* and *Ichthyobodo salmonis* could have this potential (VKM, 2020). In general this topic is poorly researched and more research into this is needed.

Potential positive effects of pink salmon on wild Atlantic salmon

Some of the potential negative effects outlined above 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. 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 salmon (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, brown trout (*Salmo trutta*), and Arctic charr (*Salvelinus alpinus*). Pink salmon ova could also be a potential food source for Atlantic salmon, as consumption of the 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 their decomposing carcasses after spawning, as discussed as a potential threat in the previous section. 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 are well documented. For example Swain and Reynolds (2015) reported a positive relationship between densities of sculpins and spawning biomass of both 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 substantial numbers in North Atlantic coastal streams.

The issue of scale and other caveats

An important caveat is that we are limited in our ability to assess the threats posed by pink salmon due to the substantial data gaps that exist. These gaps will have to be addressed in order to improve the accuracy of and reduce the uncertainty in risk assessments for pink salmon in the North Atlantic.

Another caveat is that the impact of many of the effects of pink salmon on Atlantic salmon will depend on the relative number of pink salmon that are present. 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 2017 to 2021. This could indicate that the likelihood of impacts on and threats to native Atlantic salmon are equally increasing.

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 2000s in the North Pacific (Springer and van Vliet, 2014) and possibly also since 2017 in the North Atlantic. 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 2000s (Springer and van Vliet, 2014). It is possible that such a link also exists for the North Atlantic, 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 the species in the White Sea (VKM, 2020). It is very likely that pink salmon will continue to spread to Norwegian rivers on a regular basis, increasing their range and abundance, initially mainly in odd years (VKM, 2020). 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 SST is driven into a suboptimal range in critical areas for the species' production.

Data deficiencies, monitoring needs, and research requirements

VKM (2020) listed 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.

ICES recommends a monitoring of the presence of pink salmon in the three NASCO commission areas, and this to be reported annually to be collated and included in the annual WGNAS report.

Sources and references

- Armstrong, J. D., Bean, C. W., and Wells A. 2018. The Scottish invasion of Pink salmon in 2017. *Journal of Fish Biology*, 93, 8–11. <https://doi.org/10.1111/jfb.13680>
- Bagge, A. M., Poulin, R., and Valtonen, E. T. 2004. Fish population size, and not density, as the determining factor of parasite infection: a case study. *Parasitology*, 128(Pt 3), 305–313. <https://doi.org/10.1017/s0031182003004566>
- Beacham, T. D., and Murray, C. B. 1985. Variation in length and body depth of pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) in southern British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences*, 42(2), 312–319.
- Berg, M. 1961. Pink salmon (*Oncorhynchus gorbuscha*) in northern Norway in the year 1960. *Acta borealia, A. Scientia*, 17, 1–24.
- Berg, R. E. 1979. External morphology of the pink salmon, (*Oncorhynchus gorbuscha*), introduced into Lake Superior. *Journal of the Fisheries Research Board of Canada* 36, 1283–1287. <https://doi.org/10.1139/f79-183>
- Berthal, F. R., Armstrong, J. D., Nislow, K. H., and Metcalfe, N. B. 2022. Nutrient limitation in Atlantic salmon rivers and streams: Causes, consequences, and management strategies. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 32(6), 1073–1091. <https://doi.org/10.1002/aqc.3811>
- Correll, D. I. 1998. The role of phosphorus in the eutrophication of receiving waters: a review. *Journal of Environmental Quality*. 27, 261–266. <https://doi.org/10.2134/jeq1998.00472425002700020004x>
- Cross, A. D., Beauchamp, D. A., Myers, K. W., and Moss, J. H. 2008. Early Marine Growth of Pink Salmon in Prince William Sound and the Coastal Gulf of Alaska During Years of Low and High Survival. *Transactions of the American Fisheries Society*, 137: 927–939. <https://doi.org/10.1577/T07-015.1>
- Davis, N. D., Volkov, A. V., Efimkin, A. Y., Kuznetsova, N. A., Armstrong, J. L., and Sakai, O. 2009. Review of BASIS salmon food habits studies. *North Pacific Anadromous Fish Commission Bulletin*, 5, 197–208.
- Debertin A. J., Irvine, J. R., Holt, C. A., Oka, G., and Trudel, M. 2016. Marine growth patterns of southern British Columbia chum salmon explained by interactions between density-dependent competition and changing climate. *Canadian Journal of Fisheries and Aquatic Sciences*, 74, 1077–1087. <https://doi.org/10.1139/cjfas-2016-0265>
- Denton, K. P., Rich, H. B., Jr., and Quinn, T. P. 2009. Diet, Movement, and Growth of Dolly Varden in Response to Sockeye Salmon Subsidies. *Transactions of the American Fisheries Society*, 138, 1207–1219. <https://doi.org/10.1577/T09-006.1>
- Devlin, R. H., Biagi, C. A., Sakhrani, D., Fujimoto, T., Leggatt, R. A., Smith, J. L., and Yesaki, T. Y. 2021. An assessment of hybridization potential between Atlantic and Pacific salmon. *Canadian Journal of Fisheries and Aquatic Sciences*. 79(4): 670–676. <https://doi.org/10.1139/cjfas-2021-0083>
- Dunlop, K., Eloranta, A. P., Schoen, E., Wipfli, M., Jensen, J. L., Muladal, R., and Christensen, G. N. (2021). Evidence of energy and nutrient transfer from invasive Pink salmon (*Oncorhynchus gorbuscha*) spawners to juvenile Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) in northern Norway. *Ecology of Freshwater Fish*, 30(2), 270–283. <https://doi.org/10.1111/eff.12582>
- Eliassen, K., and Johannesen, U. V. 2021. The increased occurrence of *Oncorhynchus gorbuscha* (Walbaum, 1792) in the Faroe Islands. *BioInvasions Records*, 10(2), 390–395, <https://doi.org/10.3391/bir.2021.10.2.17>
- Gende, S. M., Quinn, T. P., Willson, M. F., Heintz, R. A., and Scott, T. M. 2004. Magnitude and Fate of Salmon-Derived Nutrients and Energy in a Coastal Stream Ecosystem. *Journal of Freshwater Ecology*, 19, 149–160. <https://doi.org/10.1080/02705060.2004.9664522>
- Hard, J. J., Kope, R. G., Grant, W. S., Waknitz, F. W., Parker, L. T., and Waples, R. S. 1996. Status review of Pink salmon from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC, 25, 131 pp.
- Heard, W. R. 1991. Life history of Pink salmon (*Oncorhynchus gorbuscha*). In: Groot C, Margolis L (eds) *Pacific salmon life histories*. UBC Press, Vancouver, pp. 119–232.
- Heggenes, J., and Borgstrøm, R. 1988. Effect of mink, *Mustela vison* Schreber, predation on cohorts of juvenile Atlantic salmon, *Salmo salar* L., and brown trout, *S. trutta* L., in three small streams. *Journal of Fish Biology* 33: 885–894.
- Horrall, R. M. 1981. Behavioral Stock-Isolating Mechanisms in Great Lakes Fishes with Special Reference to Homing and Site Imprinting. *Canadian Journal of Fisheries and Aquatic Sciences*, 38, 1481–1496. <https://doi.org/10.1139/f81-201>

- Hunter, J. G. 1959. Survival and Production of Pink and Chum Salmon in a Coastal Stream. Journal of the Fisheries Research Board of Canada., 16, 835–886. <https://doi.org/10.1139/f59-061>
- ICES. 2018. Report of the Working Group on North Atlantic Salmon (WGNAS), 4–13 April 2018, Woods Hole, MA, USA. ICES CM 2018/ACOM:21. 386 pp.
- ICES. 2022. Working Group on North Atlantic Salmon (WGNAS). ICES Scientific Reports. 4:39. 40 pp. <http://doi.org/10.17895/ices.pub.19697368>
- Jones, D. 1978. Pink salmon stock predictions--S.E. Alaska. - Tech. Rep. for Period July 1, 1977 to June 30, 1978, Anadromous Fish Conservation Act Proj. No. AFC-59-1, Alaska Dep. Fish Game, Juneau, AK., 27 p
- Jones, S. R., Fast, M. D., Johnson, S. C., and Groman, D. B. 2007. Differential rejection of salmon lice by Pink and chum salmon: disease consequences and expression of proinflammatory genes. Diseases of Aquatic Organisms, 75(3), 229–238. <https://doi.org/10.3354/dao075229>
- Karpenko, V. I. 1982. Biological peculiarities of juvenile coho, sockeye, and Chinook salmon in coastal waters of east Kamchatka. Soviet Journal of Marine Biology, 8(6), 317–324.
- Klemetsen, A., Amundsen, P. A., Dempson, J. B., Jonsson, B., Jonsson, N., O'Connell, M. F., and Mortensen, E. 2003. Atlantic salmon *Salmo salar* L., brown trout *Salmo trutta* L. and Arctic charr *Salvelinus alpinus* (L.): a review of aspects of their life histories. Ecology of Freshwater Fish, 12, 1–59. <https://doi.org/10.1034/j.1600-0633.2003.00010.x>
- Kaev, A. M., and Radchenko, V. I. 2021. Patterns of Growth of the Pink Salmon *Oncorhynchus gorbuscha* in Year-Classes with Different Survival Rates during the Marine Life-history Phase. Technical Report NPAFC, Technical Report. <https://doi.org/10.1134/S1063074021070026>
- Kwain, W.-H., and Lawrie, A. H. 1981. Pink Salmon in the Great Lakes, Fisheries, 6:2, 2–6.
- Lear, W. H. 1975. Evaluation of the transplant of Pacific Pink salmon (*Oncorhynchus gorbuscha*) from British Columbia to Newfoundland. J. Fish. Res. Board Can., 32, 2343–2356.
- Mathisen, O., A. 1994. Spawning characteristics of the pink salmon (*Oncorhynchus gorbuscha*) in the eastern North Pacific Ocean Aquaculture Research, 25, 147–156. <https://doi.org/10.1111/are.1994.25.s2.147>
- McDonald, J. 1960. The Behaviour of Pacific Salmon Fry During Their Downstream Migration to Freshwater and Saltwater Nursery Areas. Journal of the Fisheries Research Board of Canada. 17:655–676. <https://doi.org/10.1139/f60-051>
- Millane, M., Walsh, L., Roche, W. K., and Gargan, P. G. 2019. Unprecedented widespread occurrence of Pink Salmon *Oncorhynchus gorbuscha* in Ireland in 2017. Journal of Fish Biology, 95, 651–654. <https://doi.org/10.1111/jfb.13994>
- Millane, M., Roche, W. K., and Gargan, P. G. 2019. Assessment of potential ecological impacts of Pink salmon and their capacity for establishment in Ireland. Inland Fisheries Ireland Research & Development report. 13 pp.
- Mills, D. 1991. Ecology and management of Atlantic salmon. Chapman and Hall, London.
- Mulcahy D., and Wood, J. 1986. A natural epizootic of infectious haematopoietic necrosis in imported Atlantic salmon, *Salmo salar* L., reared in the enzootic region. Journal of Fish Diseases, 9, 173–175. <https://doi.org/10.1111/j.1365-2761.1986.tb01001.x>
- Muñoz, N. J., Reid, B., Correa, C., Neff, B. D., and Reynolds, J. D. 2021. Non-native Chinook Salmon Add Nutrient Subsidies and Functional Novelty to Patagonian Streams. Freshwater Biology, 66, 495–508. <https://doi.org/10.1111/fwb.13655>
- Neave, F., Ishida, T., and Murai, S. 1967. Salmon of the North Pacific Ocean. VII. Pink salmon in offshore waters. International North Pacific Fisheries Commission., 22, 1–39.
- Nielsen, J., Rosing-Asvid, A., Meire, L., and Nygaard, R. 2020. Widespread occurrence of Pink salmon (*Oncorhynchus gorbuscha*) throughout Greenland coastal waters. Journal of Fish Biology, 96, 1505–1507. <https://doi.org/10.1111/jfb.14318>
- Pess, G. R., Quinn, T. P., Gephard, S. R., and Saunders, R. 2014. Re-colonization of Atlantic and Pacific rivers by anadromous fishes: linkages between life history and the benefits of barrier removal. Rev Fish Biol Fisheries 24, 881–900. <https://doi.org/10.1007/s11160-013-9339-1>.
- Prusov, S. V., & Zubchenko, A. V. (2021) Pink salmon in the Murmansk region. International Seminar on Pink Salmon in the Barents Region and Northern Europe 2021. NIBIO Svanhovd, Kirkenes, Norway and via videoconference 27-28 October 2021. County Governor of Troms and Finnmark, pp. 20-24. <https://www.statsforvalteren.no/contentassets/00239d2ba9f943fca27579b97da1021c/report-pink-salmon-seminar-2021-with-appendix.pdf> (accessed online on 06/09/2022).

- Rasputina, E. N., Shustov, Y. A., and Tyrkin, I. A. 2016. Eggs of Pink salmon *Oncorhynchus gorbuscha* as additional nontraditional food of juvenile Atlantic salmon *Salmo salar* in rivers of the Kola Peninsula. Russian Journal of Biological Invasions, 7, 294–296. <https://doi.org/10.1134/S2075111716030115>
- Ricker, W. E., and Loftus, K. H. 1968. Pacific salmon move east. Fisheries Council of Canada, Ann. Rev., 43, 37–39.
- Ricker, W. E. 1972. Heredity and environmental factors affecting certain salmonid populations, in: The Stock Concept in Pacific Salmon. Simon, R. C., and Larkin, P. A. eds., 19–160, H.R. MacMillan Lecture Fisheries. University of British Columbia, Vancouver.
- Rikardsen, A. H., and Dempson, J. B. 2011. Dietary life-support: the marine feeding of Atlantic salmon. In Atlantic salmon ecology. Edited by Ø. Aas, S. Einum, A. Klemetsen, and J. Skurdal. Wiley-Blackwell, Oxford. pp. 115–144. <https://doi.org/10.1002/9781444327755.ch5>
- Ruggerone, G. T., Zimmermann, M., Myers, K. W., Nielsen, J. L. and Rogers, D. E. 2003. Competition between Asian Pink salmon (*Oncorhynchus gorbuscha*) and Alaskan sockeye salmon (*O. nerka*) in the North Pacific Ocean. Fisheries Oceanography, 12, 209–219. <https://doi.org/10.1046/j.1365-2419.2003.00239.x>
- Ruggerone, G. T., and Irvine, J. R. 2018. Numbers and Biomass of Natural- and Hatchery-Origin Pink Salmon, Chum Salmon, and Sockeye Salmon in the North Pacific Ocean, 1925–2015. Marine and Coastal Fisheries, 10: 152–168. <https://doi.org/10.1002/mcf2.10023>
- Sandlund, O. T., Berntsen, H. H., Fiske, P., Kuusela, J., Muladal, R., Niemelä, E., Uglem, I., et al., 2019. Pink salmon in Norway: the reluctant invader. Biological Invasions 21, 1033–1054. <https://doi.org/10.1007/s10530-018-1904-z>
- Schinegger, R., Palt, M., Segurado, P., and Schmutz, S. 2016. Untangling the effects of multiple human stressors and their impacts on fish assemblages in European running waters. The Science of the total environment, 573, 1079–1088.
- Soto, D., Arismendi, I., Di Prinzio, C., and Jara, F. 2007. Establishment of Chinook salmon (*Oncorhynchus tshawytscha*) in Pacific basins of southern South America and its potential ecosystem implications. Revista Chilena de Historia Natural, 80, 81–98. <http://dx.doi.org/10.4067/S0716-078X2007000100007>
- Springer, A. M., and van Vliet, G. B. 2014. Climate change, Pink salmon, and the nexus between bottom-up and top-down control in the sub-arctic Pacific Ocean and Bering Sea. PNAS, 111(18), E1880–E1888. <https://doi.org/10.1073/pnas.1319089111>
- Sutherland, B. J., Jantzen, S. G., Sanderson, D. S., Koop, B. F., and Jones, S. R. 2011. Differentiating size-dependent responses of juvenile Pink salmon (*Oncorhynchus gorbuscha*) to sea lice (*Lepeophtheirus salmonis*) infections. Comparative Biochemistry and Physiology Part D: Genomics and Proteomics, 6(2), 213–223.
- Swain, N. R., Hocking, M. D., Harding, J. N., and Reynolds, J. D. 2014. Effects of salmon on the diet and condition of stream-resident sculpins. Canadian Journal of Fisheries and Aquatic Sciences 71, 521–532. <https://doi.org/10.1139/cjfas-2013-0159>
- Swain, N. R., and Reynolds, J. D. 2015. Effects of salmon-derived nutrients and habitat characteristics on population densities of stream-resident sculpins. PLoS One, 1, 10(6):e0116090. <https://doi.org/10.1371/journal.pone.0116090>
- Takagi, K., Aro, K. V., Hartt, A. C. and Dell, M. B. 1981. Distribution and origin of pink salmon (*Oncorhynchus gorbuscha*) in offshore waters of the North Pacific Ocean. International North Pacific Fisheries Commission Bulletin, 40, 1–195.
- Utne, K. J., Thomas, K., Jacobsen, J. A., Fall, J., Ó. Maoiléidigh, N., Thorsen Broms, C., and Melle, W. 2020. Feeding interactions between Atlantic salmon (*Salmo salar*) postsmolts and other planktivorous fish in the Northeast Atlantic. Canadian Journal of Fisheries and Aquatic Sciences, 78(3), 255–268. <https://doi.org/10.1139/cjfas-2020-0037>
- Veraart, A. J., Romani, A. M., Tornés, E., and Sabater, S. 2008. Algal response to nutrient enrichment in forested oligotrophic stream. Journal of Phycology, 44(3), 564 – 572.
- Veselov, A. E., and Zyuganov, V. V. 2016. Influence of the eastern invader Pink salmon (*Oncorhynchus gorbuscha*) on the ecosystem Pearl mussel (*Margaritifera margaritifera*) – Atlantic salmon (*Salmo salar* L) in the Varzuga and Kere't rivers of the White Sea basin. Success of Modern Science and Education, 2, 38 pp.
- Veselov, A. E., Pavlov, D. S., Baryshev, I. A., Efremov, D. A., Potutkin, A. G., and Ruchiev, M.A. 2016. Polymorphism of smolts of Pink salmon *Oncorhynchus gorbuscha* in the Indera River (Kola Peninsula), J Ichthyol, 56,:571–576. <https://doi.org/10.1134/S0032945216040159>
- Veselov, A. E., Pavlov, D. S., Baryshev, I. A., Efremov, D. A., Potutkin, A. G., & Ruchiev, M.A. (2016) Polymorphism of smolts of Pink salmon *Oncorhynchus gorbuscha* in the Indera River (Kola Peninsula), J Ichthyol, 56,:571–576.

VKM, Hindar, K., Hole, L. R., Kausrud, K., Malmstrøm, M., Rimstad, E., Robertson, L., Sandlund, O. T., Thorstad, E. B., Vollset, K. W., de Boer, H., Eldegard, K., Järnegren, J., Kirkendall, L., Måren, I., Nielsen, A., Nilsen, E. B., Rueness, E., & Velle, G. (2020). Assessment of the risk to Norwegian biodiversity and aquaculture from Pink salmon (*Oncorhynchus gorbuscha*). Scientific Opinion of the Panel on Alien Organisms and Trade in Endangered Species (CITES). VKM report 2020:01, ISBN: 978-82-8259-334-2, ISSN: 2535-4019. Norwegian Scientific Committee for Food and Environment (VKM), Oslo, Norway.

Web, J. H., & McLay, H. A. (1996). Variation in the time of spawning of Atlantic salmon (*Salmo salar*) and its relationship to temperature in the Aberdeenshire Dee, Scotland. Canadian Journal of Fisheries and Aquatic Sciences, 53(12), 2739–2744. <https://doi.org/10.1139/f96-24>

Wipfli, M.S., Hudson, J. P., Caouette, J. P., and Chaloner, D. T. 2003. Marine subsidies in freshwater ecosystems: salmon carcasses increase the growth rates of stream-resident salmonids. Transactions of the American Fisheries Society 132, 371–381.

Zubchenko, A. V., Veselov, A. E., and Kalyuzhin, S. 2004. Pink Salmon (*Oncorhynchus gorbuscha*): problems in acclimatization in Europe, North Russia. Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk.

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<https://doi.org/10.17895/ices.advice.21020050>.