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Status and future perspectives of pink salmon in the Nordic region

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Pink salmon are native to the North Pacific region but have spread due to introductions in north-west Russia. More than 800 000 pink salmon have been recorded in Nordic countries since 2017. The abundance has massively increased, with 50 times more pink salmon recorded in 2023 than 2017. Norway, including border rivers to Finland, has received the largest numbers, thereafter Greenland and Iceland. The areas with high abundances of pink salmon are expanding. Despite the massive invasion of pink salmon, and the risk of further spread within the Nordic region, the knowledge of impact on native salmonids and ecosystems is still poor, mainly due to lack of research funding. Mitigation efforts have been greatest in northern Norway by removal of pink salmon in rivers. Most of the Nordic countries seem not to have risk analyses or developed management plans to meet a potential increase in abundance of pink salmon.

Introduction

Pink salmon (*Oncorhynchus gorbuscha*), native to the Pacific Ocean, was introduced to the White Sea area and Kola Peninsula in Russia between 1956 and 1999 to establish a new fisheries resource (Bakshtansky 1980; Sandlund *et al.* 2019). As a result, invasive pink salmon have spread throughout the Barents Sea and North Atlantic Ocean. Pink salmon are anadromous, exhibiting a strict two-year life cycle and die after spawning, and therefore occur as separate odd and even year populations (Heard 1991). Odd-year populations have been observed ascending rivers in increasing numbers across the North Atlantic between 2017 and 2023, whereas even-year populations remain relatively small (ICES 2024).

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Studies from the Pacific region demonstrate that pink salmon can become highly abundant and have significant ecological effects, influencing species interactions and altering entire ecosystems in both freshwater and marine habitats (Ruggerone *et al.* 2023; Springer *et al.* 2018). Hindar *et al.* (2020) concluded that when invasive pink salmon occur in large numbers, there is a high risk of negative effects on the native salmonids Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*) and anadromous Arctic charr (*Salvelinus alpinus*), as well as on the ecosystems in rivers, fjords, at sea, and even on land.

From 2017, the area with high abundance of invasive pink salmon, where thousands of spawners enter single rivers, has expanded from Russia to northern Norway (Sandlund *et al.* 2019). Northern Norway has recorded a dramatic rise in pink salmon abundance during this period, in just four spawning cycles. In 2023, over 460 000 pink salmon were reported in rivers in the Finnmark region alone, surpassing the numbers of native Atlantic salmon (Berntsen and Havn 2024). If pink salmon continue to spread, southern Norway and neighbouring countries in the Nordic region may face a similar situation as northern Norway and become the gateway for further spread of pink salmon in the Atlantic Ocean and the Baltic Sea. Pink salmon have been recorded in all the Nordic countries from 2017, but so far only in relatively small numbers outside of northern Norway (Nielsen *et al.* 2020; Eliasen and Johannesen 2021; Staveley and Bergendahl 2022; Skóra *et al.* 2024). There is a need for monitoring the development of pink salmon in this region and inform effective management strategies for the future.

Aiming to examine the status and future perspectives of pink salmon across the Nordic region, we have established a network of researchers from all the Nordic countries. In this paper, we address the following aims: (i) examine the distribution, abundance and spread of pink salmon in the Nordic countries of Norway, Denmark, Iceland, the Faroe Islands, Finland, Greenland and Sweden; (ii) map the knowledge status of pink salmon in the Nordic countries; and (iii) assess the current pink salmon monitoring, management and awareness in the Nordic countries.

Material and methods

Distribution, abundance and spread of pink salmon in the Nordic countries

Observations of pink salmon across the Nordic countries come from several data sources including: a) catch reports from recreational angling in rivers (all countries) and in the sea (Norway, Greenland, Faroe Islands); b) catch reports from targeted removal fishing using nets, traps, harpoon etc. (Norway and Finland); c) drift count surveys (snorkelling counts), either aimed at counting native salmonids or directly counting pink salmon (Norway, Finland); d) surveys monitoring the run of native salmonids and pink salmon in rivers using video, sonar or counters (Norway, Finland, Sweden); and e) catch reports from either recreational net fishing (Greenland) or licenced bag-net fisheries in the sea (Norway). More information and links to data sources are described in question one of Table S1 in Supplementary Information.

The spread of pink salmon in Norway was assessed as a function of the change in river abundance between years. Our dataset on pink salmon abundance only includes true positives (e.g., no zeros), and in addition we are unable to account for differences in fishing effort (due to different sampling methods) between rivers and years. Modelling the spread of pink salmon from north to south using the river specific reported abundance will therefore not give an accurate description of the spread over time and result in inaccurate predictions. We therefore took a cautious and descriptive approach to the data analysis, and the spread of pink salmon in Norway was visualised by separating rivers into two categories: rivers with 1000 pink salmon or more and rivers with less than 1000, which resulted in a binary variable of 1 and 0, respectively. The abundance of 1000 pink salmon as a separator value was chosen to reflect the areas in Norway where the number of pink salmon is very high compared to the native species (as shown in Supplementary Information Figs. S1 and S2, where number of rivers above and below 1000 pink salmon and Atlantic salmon are shown from 2017–2023 and 2002–2023, respectively). As a geographical reference point, we included the

distance of each river in relation to the border to Russia. The distance from Russia was calculated as the distance (in km) along the coastline from the Russian border at Grense Jakobselv to the outlet of each river. The binary variable (response) was subsequently modelled as a function of the distance from the Russian border (predictor) for each year separately, using a binomial generalized linear model (GLM) with a logit link function (stats-package, R Core Team 2024). The resulting sigmoidal curves of probabilities from the logistic regression were plotted against the distance from Russia to visualise the spread and to identify at what distance the probability of having 1000 or more pink salmon had reached 50% (D_{50}) for each year individually. Model assumptions were validated using the DHARMa-package (Hartig 2024) and there were no signs of overdispersion.

Knowledge status of pink salmon in the Nordic countries

We mapped the knowledge status of pink salmon in the Nordic region by examining studies published in English in peer reviewed scientific international journals. We conducted a literature search in the Web of Science Core Collection on the 7 March 2025 with the date range "All years (1945–2025)" for TOPIC = pink salmon AND TOPIC = Nordic or Swe* or Finland or Finnish or Norw*or Icel* or Faro* or Denmark or Danish or Greenl* to find publications on pink salmon in the Nordic countries. The search yielded total 50 unique results, of which 22 were considered relevant for providing knowledge about invasive pink salmon in the Nordic region. Search results that did not concern pink salmon or the Nordic region, were excluded. We included one publication that we were aware of that did not appear in the search (Foldvik *et al.* 2024). We further screened reference lists in the 23 publications we had found to examine if there were relevant publications that were overlooked and found three additional papers (Berg 1961; Bjerknes 1977; Bjerknes & Vaag 1980). We are aware that adding publications that the authors were aware of outside of the Web of Science search results may add some bias to the literature review but it should not be to the extent that it compromises the analysis. The 26 publications that were regarded relevant were sorted according to the objectives of the studies.

Pink salmon monitoring, management, and awareness in the Nordic countries

To gain an understanding of the status, monitoring, management actions and awareness of pink salmon across the Nordic countries, seven questions were posed to scientists, via email and workshops, with expert knowledge on pink salmon and other anadromous salmonids in each country. The authors of this paper are the respondents of the questionnaire and had or were able to source the best available data and information regarding pink salmon in their respective country, including published reports from management. The total number of respondents was nine and split according to country: Norway = 2; Sweden = 2; Finland = 1; Iceland = 1; Denmark = 1; Greenland = 1; Faroe Islands = 1. This group were deemed to have the best knowledge, therefore this questionnaire was not sent out to a wider group, but in some cases, respondents were in consultation with other national experts to answer the questions accurately and collect supplementary information. The questions were:

1) How do we get pink salmon observations/reports of adult spawners?
2) How do we get pink salmon observations/reports of juveniles?
3) What are the management actions (e.g. local, national levels, rules, plans, decisions)?
4) Is there any research being conducted on pink salmon?
5) Is it possible to report pink salmon? Ease of reporting, economical rewards, open and use of data, increase knowledge.
6) Is there mandatory or motivational reporting of fish catches, including pink salmon?
7) Has there been any awareness/educational work?

Results

Distribution, abundance and spread of pink salmon in the Nordic countries

Most of the pink salmon were recorded in Norway, particularly in the northernmost part of the country, including the transboundary rivers shared with Finland (Fig. 1 and Table 1). Less than 2% of the total abundance was reported in other Nordic countries. The total reported abundance of pink salmon has increased between years (i.e. odd years) in Norway, Finland, Iceland and Greenland (Fig. 1 and Table 1). For Sweden, Denmark and the Faroe Islands the number of reported fish remains relatively small and has fluctuated between years (Fig. 1 and Table 1). Overall, the number of pink salmon recorded in the Nordic countries was 50 times higher in 2023 than in 2017.

The spread of pink salmon across Norway, in terms of rivers with 1000 or more pink salmon entering in a single year, has increased from 2017 to 2023 (Fig. 2, Table S2 and Fig S1. in the Supplementary Information). The sigmoid lines represent the probability of having 1000 or more pink salmon in a river plotted against the distance from the Russian border (Fig. 2). The regression between the likelihood of having more than 1000 pink salmon and the distance from Russia was highly significant for the years 2021 and 2023 ($p < 0.001$), significant for 2019 ($p = 0.02$), and not significant for 2017 ($p = 0.228$) (Table 2). A broken vertical line indicates the distance from Russia where there was a 50% probability of having 1000 or more pink salmon in a river. In 2017 there was no value for D_{50}. Between 2019 and 2023, D_{50} moved from 20 km to 380 km from the Russian border, respectively (Fig. 2). The distance along the entire Norwegian coastline, from Russia in the north to Sweden in the south, is approx. 2650 km. Assuming the same average spread as between 2017 and 2023, D_{50} would reach the Swedish border in about 42 years. However, assuming the same spread as between 2021 and 2023, D_{50} would reach the Swedish border in about 21 years.

Knowledge status of pink salmon in the Nordic countries

Of published studies of pink salmon in the Nordic region, eleven publications cover the life cycle in freshwater, five cover the life cycle in marine waters and ten cover the life cycle in both habitats. The objectives were mainly focused on mapping numbers and distribution, studying pink salmon biology and life history, summarising knowledge, and examining risks and consequences (Fig. 3). Only very few studies (6 of 26) have been performed to examine the effects of pink salmon on other salmonids and ecosystems. Very few studies have also been conducted on disease

Table 1. The total number of reported pink salmon in each of the Nordic countries for the odd years between 2017–2023.

	Greenland	Iceland	Faroe Islands	Norway/ Finland[1]	Sweden	Denmark	Total
2017	16	79	1	12 010*	44	10	12 160
2019	61	251	6	24 825*	5	0	25 148
2021	141	339	7	208 071*	70	8	208 636
2023	1021**	703	4	579 794*	13	4	581 539

[1]Includes the numbers of pink salmon in the border rivers between Norway and Finland (rivers Teno/Tana, Näätämöjoki/Neidenelva).

*Total number in 2017 includes 11 483 pink salmon reported in rivers and 527 captured at sea (245 in bag-/bend-nets and 282 from angling), total number in 2019 includes 19 075 pink salmon reported in rivers and 5750 captured at sea (5710 in bag-/bend-nets and 40 from angling), total number in 2021 includes 167 374 pink salmon reported in rivers and 40 697 captured at sea (38 933 in bag-/bend-nets and 1764 from angling), while the total number in 2023 includes 481 463 reported in rivers and 98 331 captured in the sea (98 249 in bag-nets and 82 from angling).

**Total number from 2023 comprises of 1000 individuals based on observations of pink salmon in several rivers in east Greenland and 21 from catch reports.

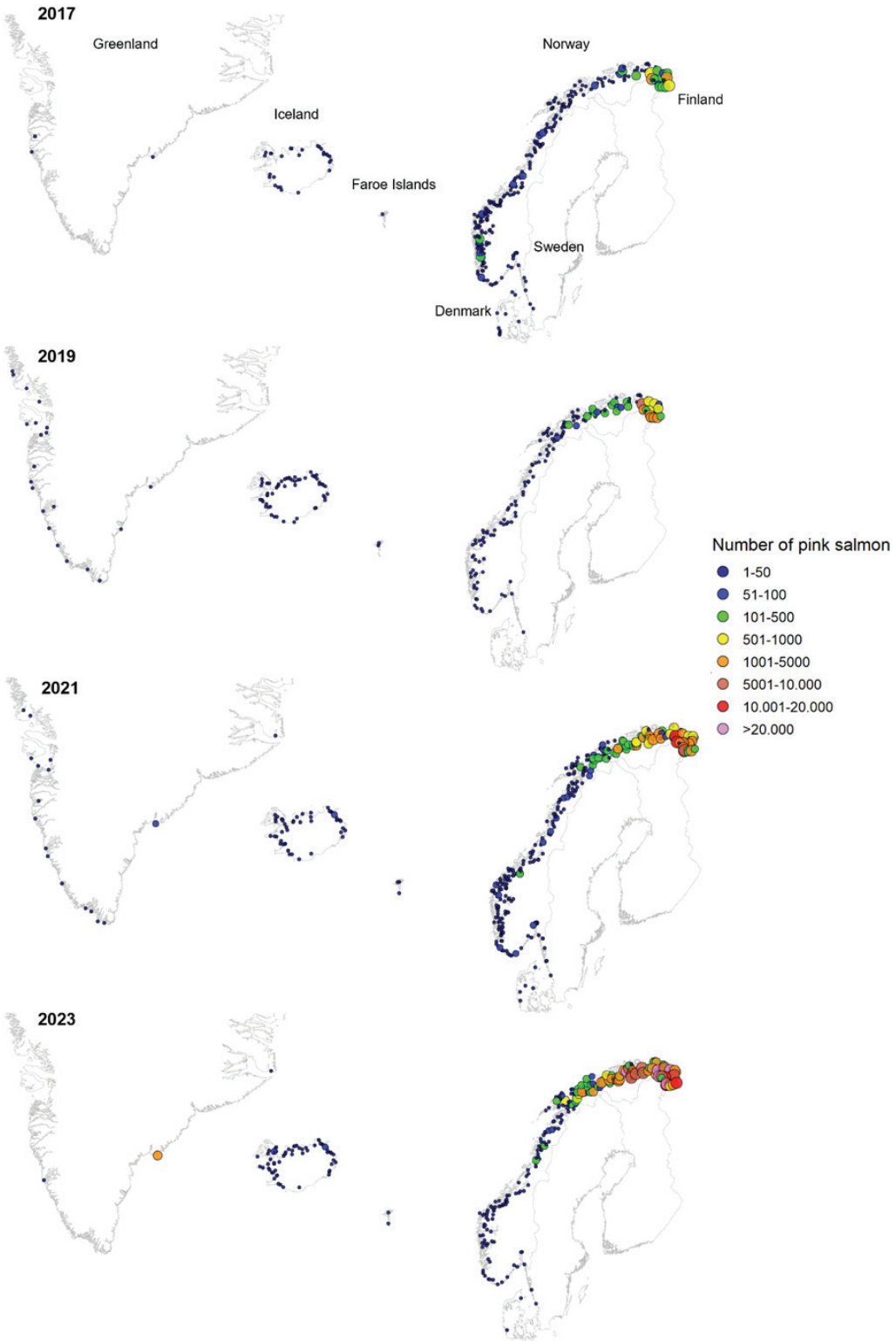

Fig. 1. Distribution and number of pink salmon observed in rivers across the Nordic region during odd years from 2017–2023.

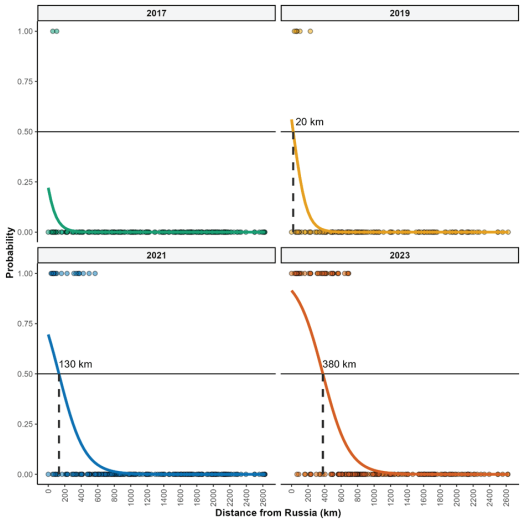

Fig. 2. Estimated probability (0–1) of having 1000 or more pink salmon in single rivers in Norway for the odd years between 2017–2023 plotted against the distance from Russia. The 50% probability is shown with a black horizontal line and the corresponding distance from the Russian border is indicated with a dotted line and labelled when appropriate ($p < 0.05$).

agents (2 of 26), toxicology (1 of 26), genetics (1 of 26), interactions with aquaculture (0 of 26) or on social and economic dimensions (2 of 26). Most studies were published from 2018 until present (23 of 26, 88%), but three studies were published between 1961–1980 (Fig. 3).

Pink salmon monitoring, management, and awareness in the Nordic countries

Answers from the questionnaire from each of the seven Nordic countries were compiled in detail in Table S1 in the Supplementary Information and are summarised below. The accompanied scientific literature was either cited in the answers from the questionnaire or closely related to the actual answers to give more thorough support of the current situation as outlined in the following sections.

Collection of observations and reports of pink salmon

Records of pink salmon occurrence and abundance in the Nordic countries come from targeted monitoring programs, catch reports and citizen observations. Most information has been collected from reports of recreational catches and monitoring programs typically focusing on other anadromous salmonids, mostly Atlantic salmon. The targeted monitoring programs employ different methods including counting fences, sonar stations, video arrays, snorkeling, and environmental DNA (eDNA). In addition, monitoring data have also been obtained from fishways and traps used in targeted removal of pink salmon. In Norway, weirs and other traps in rivers, aiming

Table 2. Results of the generalized linear models on the probability of having 1000 or more pink salmon in a river in Norway (logistic regression) as a function of distance from the Russian border for each year independently. The full model includes both the distance from Russia and year as predictor variables. The reduced models are testing the regression against the distance from Russia as the explanatory variable, for each year independently.

		Odds ratio	*z*-value	*p*-value
2017				
	Intercept	0.28	–1.09	0.274
	Distance from Russia	0.98	–1.20	0.228
2019				
	Intercept	1.28	0.33	0.745
	Distance from Russia	0.99	–2.28	0.023
2021				
	Intercept	2.29	1.74	0.083
	Distance from Russia	0.99	–4.80	< 0.001
2023				
	Intercept	10.75	4.43	< 0.001
	Distance from Russia	0.99	–6.13	< 0.001

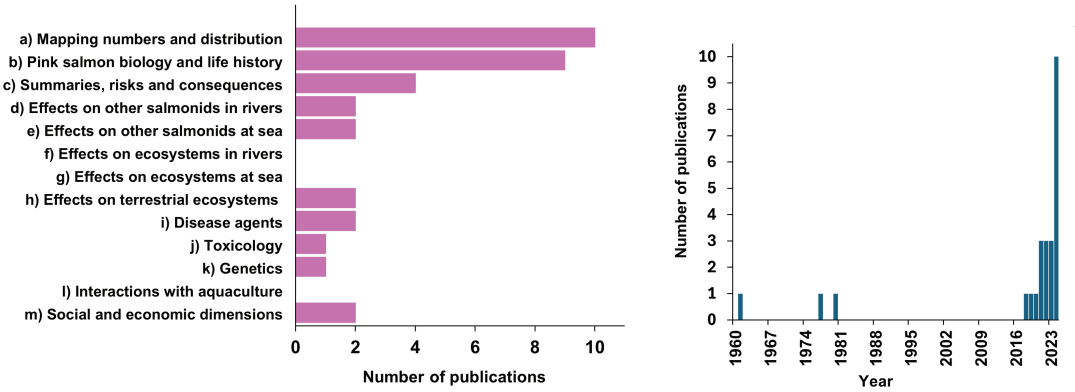

Fig. 3. Left panel: Number of studies of pink salmon in the Nordic countries published in international peer reviewed scientific journals in 1961–2024, sorted by study objective. The total number of studies was 26, and many studies covered more than one study objective. References to studies are given in the footnote* Right panel: Number of studies published per year.

*References for studies of pink salmon and the study objectives identified for each study, with letters after each reference corresponding to the study objectives in the figure: Bengtsson *et al.* (2023): b, e; Berg (1961): a; Bjerknes (1977): a, b; Bjerknes and Vaag (1980) a, b; Bonde and Stien (2024): h; Cottier-Cook *et al.* (2024): c; Diaz Pauli *et al.* (2023): b, e; Dunlop *et al.* (2021a): d; Dunlop et al (2021b): h; Eliasen and Johannesen (2021): a, b; Erkinaro *et al.* (2022): b; Erkinaro *et al.* (2024): b, d; Erkinharju *et al.* (2024): i; Finnsson *et al.* (2024): m; Foldvik *et al.* (2024): j; Guay *et al.* (2024): m; Holopainen *et al.* (2025): i; Lennox *et al.* (2023): c; Maduna *et al.* (2024): a, k; Mo *et al.* (2018): c; Nielsen *et al.* (2024): a; Nielsen *et al.* (2020): a; Paulsen *et al.* (2022): b; Sandlund *et al.* (2019): a, c; Skóra *et al.* (2024): a, b; Staveley and Bergendahl (2022): a.

at intercepting and removing ascending pink salmon, were operated in 18 rivers in 2021 and 51 rivers in 2023, mostly in the northern part of the country (Frøiland *et al.* 2024). Data from these removal activities provide detailed information on pink salmon occurrence, numbers and run timing. In the River Tana/Teno in northernmost Norway and Finland, tributary-specific information on development of pink salmon abundance and distribution in different parts of the large watershed has been collected in connection with Atlantic salmon monitoring program by sonars, video cameras and snorkeling surveys (Erkinaro and Orell 2022; Anon. 2024).

Some published information on juvenile pink salmon is available from few rivers in Norway, Finland, and Iceland (Sandlund *et al.* 2019; Muladal and Fagard 2022; Erkinaro *et al.* 2022; 2024; Skóra *et al.* 2024). These data have mostly been collected by fyke-nets and electrofishing.

Reporting of pink salmon

Catch reports from fishers are important information sources especially at the beginning of detecting new invasive fish species. All countries encourage reporting of pink salmon in catches and most have information and websites facilitating registration of pink salmon catches and observations. In Sweden, a strong effort has been made to communicate and encourage the reporting of pink salmon observations (as recreational catch reporting is voluntary) through an online portal for reporting aquatic native and invasive species at the SLU Swedish Species Information Centre (https://rapportera.artfakta.se/eftersokta/rappen/formular). In Norway, Iceland, Finland and partly in Denmark, reporting of migratory salmonid catches, including pink salmon, in rivers is mandatory. In the Faroe Islands and Greenland, there are no requirements to report pink salmon catches as such, but in Greenland, reporting requirements for the Atlantic salmon fishery includes the possibility to document pink salmon catches.

Research conducted on pink salmon

All countries, apart from Denmark and the Faroe Islands, have undertaken or have ongo-

ing research in some regard to pink salmon. For instance, in Sweden, Finland, Norway and Greenland, eDNA river surveys have been undertaken to determine the distribution of pink salmon (e.g., Fossøy *et al.* 2022; Nielsen *et al.* 2024). These countries, together with Denmark, are also part of a European wide North Atlantic Salmon Conservation Organisation (NASCO) project "PINKTrack", which aims to develop best practice eDNA methods to map the distribution of pink salmon in the North Atlantic and inform appropriate management responses. In addition, as part of the research project "Pink salmon in Sweden", eDNA has been used to investigate whether adult spawners have occurred in rivers draining into the Baltic Sea. Similarly, eDNA has been used to detect patterns in annual occurrence of pink salmon in tributaries across the large Teno/Tana catchment in Finland and Norway (Fossøy *et al.* 2022). In-river feeding of pink salmon juveniles has been studied in the Teno/Tana river system by use of stable isotope and stomach content analyses (Erkinaro *et al.* 2024). Despite the huge numbers of pink salmon in Norway in recent years, there has been little funded research at present, which poses significant limits to the knowledge and understanding of the effects of pink salmon throughout aquatic ecosystems. Although, effects of pink salmon carcasses on other salmonids as well as scavenging by avian and terrestrial animals have recently been investigated (Bonde and Stien 2024; Dunlop *et al.* 2021a,b).

Management of pink salmon

Management actions regarding pink salmon have differed substantially across the Nordic countries, with massive efforts in the areas with the largest abundances of pink salmon in northern Norway, and few management actions elsewhere. However, the level of actions is not necessarily linked to the abundance of pink salmon in each country but can also depend on government and management interest in tackling non-native species. Risk assessment reports have been produced by Norway (Hindar *et al.* 2020) and Sweden (Petersson *et al.* 2018) to outline potential impacts caused by pink salmon and propose mitigation measures. A recent paper from Iceland highlights the need for such risk assessments and management responses within their national jurisdiction (Finnsson *et al.* 2024).

In 2023, Norway began an extensive pink salmon removal scheme as part of a governmental national strategy (Frøiland *et al.* 2024). Several trap types were tested to capture and remove pink salmon in lower parts of rivers. Other removal methods, such as netting, harpooning and removal from fishways were also used. The use of artificial intelligence (AI) to recognise pink salmon from other fish species was tested. In 2023, a total of 94 Norwegian rivers, mostly in the northern part of the country, were subject to pink salmon removal campaigns, and ca. 250 000 pink salmon were caught (Frøiland *et al.* 2024).

In the Finnish part of the Teno/Tana river in 2023, special fishery opportunities targeting pink salmon were introduced and approximately 15 000 pink salmon were removed. Since 2021, all salmon fishing has been banned in this system, however, local fishers with fishing rights, were issued pink salmon fishing permits (Hakaste 2023). In addition, a targeted pink salmon fishery where local Sami fishers developed methods based on traditional salmon fishing nets was organized in 2023 (drift net, beach seine) that were modified and specifically designed for pink salmon fishing (Lukkari *et al.* 2024).

Certain rules and regulations regarding caught pink salmon are in place, for example, in Norway, Finland, and Sweden, all caught pink salmon must be killed and not returned to the water. In Denmark, permissions have been given to allow culling if caught as bycatch for Atlantic salmon and trout brood stock purposes. Temporary exceptions to use seine nets in rivers in Iceland have been granted to allow catch of pink salmon to aid removal. No specific management actions have yet been outlined in the Faroe Islands or Greenland regarding pink salmon.

Awareness and educational work

Owing to the widespread occurrence of pink salmon since 2017, most Nordic countries have

initiated and conducted campaigns and educational work to increase the awareness surrounding this invasive species. Information has been disseminated throughout the media, such as TV, radio, newspapers and social media. Media sources cannot be underestimated as an important way to spread scientific information to the public, for instance, this has been a beneficial tool to reach remote communities in parts of Greenland. Webinars, seminars and lectures have been held to the public, angling associations and university students to provide information regarding the identification and occurrence of pink salmon, and the potential threats posed by pink salmon. In Norway, Sweden, Denmark and Finland, websites have been established to provide further information on the biology of pink salmon, potential threats, status updates and reporting tools.

Discussion

In this study, we show that the abundance of pink salmon has increased tremendously in the Nordic countries since 2017, and that the area with a high abundance of pink salmon is expanding. We further show that despite the massive invasion in northern areas, the knowledge of pink salmon in the Nordic region is still very poor, particularly on the impact on other salmonids and ecosystems. There are efforts to map numbers and distribution of adult pink salmon in all the Nordic countries, but little effort on monitoring reproductive success and juveniles. The Norwegian government initiated massive mitigation efforts to remove pink salmon from rivers in 2023. The results of our survey indicate that the rest of the Nordic countries seem to have poorly developed mitigation strategies to meet the future risks related to the invasive pink salmon. Accounting for spatially explicit variables such as river hydrogeomorphology, which can aid pink salmon productivity and identifying high productive areas (Yamada *et al*. 2024), could assist in prioritising monitoring and management efforts. However, the lack of data, particularly on reproductive success and juvenile production from Nordic rivers with pink salmon spawning hampers such an approach.

Most of the pink salmon in the Nordic countries have so far been recorded in northern Norway. Greenland and Iceland have the largest numbers of pink salmon recorded within the rest of the Nordic region. The numbers of pink salmon reported in Greenland are highly uncertain as there are many rivers and a scattered human population, and the abundance of pink salmon in Greenland may in general be underestimated.

The recent increase in pink salmon abundance in Norway and Russia, close to the introduced source population in northwestern Russia, is likely related to increasing ocean temperatures (Hindar *et al.* 2020, Lennox *et al.* 2023). For pink salmon, the most critical period during the marine phase is probably spring to early summer when juveniles enter the ocean, thus increased survival during this phase may be crucial for development of pink salmon populations (Lennox *et al.* 2023; Dunmall *et al.* 2025). Indeed, spring temperatures along the north-west Russian and Norwegian coasts have increased during the past ca. 20 years and the marine habitat has likely become more suited for better survival of young pink salmon (Dunmall *et al.* 2025). Similarly, increasing ocean temperatures on the coastal areas of Iceland and Greenland have probably provided more suitable marine habitat for pink salmon since the 1990s (Dunmall *et al.* 2025). In contrast, estimates of suitability of the marine environment for pink salmon have not indicated a positive development further south in the North Atlantic area (Dunmall *et al.* 2025).

The expanding high abundance of pink salmon in the northernmost Nordic region allowed us to predict the future distribution in terms of expansion of the area with high abundances. Estimation of the probability of run size of 1000 or more pink salmon in a single river (Fig. 2) showed that the 50% probability level moved faster westward and southward along the Norwegian coast with time; ca. 20 km from 2017 to 2019, 110 km from 2019 to 2021 and 250 km from 2021 to 2023. Assuming a similar spread of the areas with high abundance as during 2017-2023, rivers all over Norway from the Russian to the Swedish border, would have the same high levels of pink salmon as presently recorded

in Northern Norway in 21–42 years. It must be pointed out that this is a simple estimate based on the assumption that the conditions in rivers and at sea are similar throughout this area, which may not be true. Variations in self-recruiting local populations of pink salmon may also create changes to these predicted numbers. Predicting the future in an era of rapid climate change is also a challenge. Moreover, the strong mitigation measures, with large-scale removals of pink salmon in most rivers in northern Norway, especially since 2023 (Frøiland *et al*. 2024; Dunmall *et al*. 2025), may reduce the dispersal of large runs of pink salmon.

It could be argued that the large increase in reported pink salmon abundance (Table 1) and the expansion of the species across Norwegian rivers (Figs. 1 and 2) is a result of the increase in mitigation measure efforts (as explained above). Within the same timeframe, however, the reported catches of pink salmon in the coastal licenced bag- and bend-net fishing in Norway showed a similar increase (Table 1) as in the rivers, despite a large decrease in fishing effort (ICES 2024). For example, the number of bag-nets in use in 2021 and 2023 were 53% and 59% fewer, respectively, compared to 2019 (when reporting of pink salmon became mandatory in this fishery), while the use of bend-nets was banned in 2022 (ICES 2024). We are therefore confident that the observed increase in pink salmon abundance in Norwegian rivers (and across the other Nordic countries) is real. However, exactly how much of the river specific increase in abundance from one year to the next is due to increased fishing effort is not known.

There is a connection between an area with a high abundance of pink salmon and the stepwise expansion of increased abundance in adjacent, nearby areas along the Norwegian coast (Fig. 2). This allows speculation on the possible expansion of the pink salmon distribution to new areas, for example to the Baltic Sea. There are historic records of releases of juvenile pink salmon in the coastal areas of the former Soviet Union in the Baltic Sea in the 1970s and 1980s and subsequent catches of returning adult fish (Kudersky 2005). However, natural reproduction of pink salmon in the Baltic Sea basin was not observed, nor have pink salmon observations been recorded during the present increase in the Atlantic area since 2017. Environmental conditions in the brackish water Baltic Sea could be suitable for supporting pink salmon, but may, however, be dependent on resources such as food availability. Pink salmon has been successfully introduced to other brackish water areas (e.g. White Sea) and even in freshwater systems (Laurentian Great Lakes; Emery 1981) and due to the anadromous life history of this salmonid there seems no apparent reason why pink salmon could not establish in the Baltic Sea region. In addition, recent analysis of the development of thermal suitability of marine areas in the Atlantic Ocean and nearby seas suggest possibilities for future expansion of the species to the Baltic Sea (Dunmall *et al.* 2025). However, pink salmon abundances in areas close to the Baltic Sea (i.e. western Sweden, Denmark) have so far remained low with no increasing trend (Fig. 1, Table 1).

Despite the massive invasion of pink salmon in northern Norway and Finland and the risk of further spread in the Nordic region, the knowledge of impact on other salmonids and ecosystems is still very poor. Even though pink salmon has been present in the region since at least 1960 (Sandlund *et al.* 2019), we found only three studies that were published in peer-reviewed international scientific journals before 2018 (Berg 1961; Bjerknes 1977; Bjerknes and Vaag 1980). Ecological impacts from pink salmon during the marine phase in their native Pacific range have been comprehensively reviewed by Ruggerone *et al.* (2023) to which some processes, such as changes in food web structure and adaptation to climate change, could be relevant in the Atlantic area. During their relatively short time in freshwater, non-native pink salmon could compete with native brown trout, Arctic char and Atlantic salmon. Potential threats to native salmonids from pink salmon are (Thorstad *et al.* 2024): 1) Competition for space, out crowding and aggressive attacks from adult pink salmon during the upstream migration and spawning — which may lead to migration delays and altered behaviour and distribution of native salmonids. 2) Competition for food and space between juveniles, which could cause reduced growth and survival. 3) Deteriorated water quality due to decomposition of dead pink salmon after

spawning. The impact of pink salmon on Atlantic salmon in rivers depends on their abundance and thousands of pink salmon will likely have a large impact (Hindar *et al.* 2020). Recent studies from the native Pacific range also indicate that pink salmon can negatively affect the spawning distribution and productivity of Chinook salmon (*Oncorhynchus tshawytscha*) (Ruggerone *et al.* 2025) and reduce sea survival of steelhead trout (anadromous rainbow trout, *Oncorhynchus mykiss*) through interspecific competition at sea (Ohlberger *et al.* 2025). Examples from other non-native salmonid species also document potential negative impacts on other native salmonid species (Taniguchi *et al.* 2000; Houde *et al.* 2015).

The dramatic increase of pink salmon abundance from 2017 has resulted in an increase in published studies, but most studies have so far been focused on mapping numbers and distribution, studying pink salmon biology and life history, summarising knowledge, and examining risks and consequences. Hence, there is a huge knowledge gap, hampering the understanding of the consequences of the invasion on other species, ecosystems, ecosystem services and aquaculture. The rapid increase in studies after 2017 may indicate there will be a further increase in studies in the coming years, but still the overall number of studies is low. We acknowledge that there is more knowledge on pink salmon than included here, such as in technical reports and university theses. However, to our knowledge, the result of this overview of scientific publications gives a representative impression of the current situation.

The main categories of global information gaps on invasive pink salmon are its invasion potential, interactions between pink salmon and native species, and the effects of current mitigation efforts (Dunmall *et al.* 2025), which also applies to the Nordic region. Specifically for the Nordic region, there are knowledge gaps related to homing *versus* straying in pink salmon, impacts of potential competition between pink salmon and native salmonids both at juvenile and adult life stages in rivers, and to potential crowding when pink salmon outnumber native species. There are also knowledge gaps related to impacts of deteriorated water quality in rivers due to decomposition of dead pink salmon after spawning, as well as possible impacts of large numbers of dead pink salmon on terrestrial ecosystems. Pink salmon may also influence other species than salmonids in estuaries, fjords and marine areas of the Barents Sea, Atlantic Ocean and the Baltic Sea, regarding which we have very little knowledge. Strengthening of the knowledge base is needed to guide management responses to different scenarios in terms of the spread and abundance of pink salmon in different areas.

Since the recent dramatic development in distribution and abundance of pink salmon has taken place in such a short period of time, and future predictions are uncertain, updating impact and risk assessments is recommended. Moreover, several countries and jurisdictions in the Nordic region, have not yet produced any risk assessments evaluating the potential impact of the invasive pink salmon to their national waters, ecosystems and native species. As the difference in pink salmon distribution and management actions has varied greatly between the Nordic countries, this highlights the need for adaptive management and for countries where pink salmon has not yet become overly numerous to be vigilant in monitoring programs and mitigation measures.

Conclusion

Based on the increased abundance of pink salmon in all the Nordic countries since 2017, and an expansion of the area with very high abundances of pink salmon in northern Norway, we conclude that pink salmon has the potential to establish in large numbers in some rivers in all the Nordic countries within the next years or decades. Despite the massive invasion of pink salmon, and the risk of further spread within the Nordic region, the knowledge of impact on native salmonids and Nordic ecosystems is still very poor. This huge knowledge gap hampers the understanding of the consequences of the invasion on other species, ecosystems, ecosystem services and aquaculture. Consequently, the knowledge base for management and mitigation measures is poor which underscores the need

for increased research efforts to assess potential risks and to inform effective management strategies for aquatic ecosystems. In addition, most of the Nordic countries seem not to have developed management plans to meet a potential increase in abundance of pink salmon.

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