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Status and prospects of introduced even-year pink salmon in the North Atlantic and Barents Sea regions

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Pink salmon have a two-year lifecycle, forming distinct odd- and even-year populations, with odd-year cohorts dominating among invasive pink salmon in the North Atlantic and Barents Sea. Here, we summarise current knowledge on the less-studied even-year fish. These remain rare, with typically fewer than 50 individuals observed per river in northern Norway, though Russian total catches have reached up to 11 metric tons in some years. Elsewhere in Europe, records are scarce. We found no long-term trend of increasing even-year abundance. Age analyses provide no indication that even-year fish originate from odd-year individuals deviating from the two-year lifecycle. Some Russian studies suggest genetic constraints may limit the adaptability of even-year fish, but rapid intergenerational increases have been observed. The increase in odd-year abundance after 2017 further highlights the species' capacity for sudden expansion. Continued monitoring is essential to detect early changes, track trends, and inform risk assessments and conservation efforts.

Introduction

Pink salmon (*Oncorhynchus gorbuscha*), native to the North Pacific, have established invasive populations in rivers draining into the North Atlantic Ocean and Barents Sea following repeated, intentional introductions to northwest Russia beginning in the 1950s (Sandlund *et al.* 2019, Alekseev *et al.* 2019, Prusov 2024). Prior to 2017, only low numbers were reported in Norway and other European countries outside Russia. However, in recent years, both the abundance and geographic range of pink salmon have increased substantially, especially in Norway, but also in Iceland and Greenland, and there is a considerable risk of further spread into the Baltic

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Sea (Sandlund *et al.* 2019, Diaz Pauli *et al.* 2023, Staveley *et al.* 2025a,b). In northern Norway, bordering northwest Russia and currently the area with the highest abundance outside of Russia, surveys in 2023 and 2025 recorded thousands to tens of thousands of pink salmon, and in one river nearly 200 000, vastly outnumbering native salmonid species (Anon. 2024, Thorstad *et al.* 2025, Norwegian Environment Agency). Invasive pink salmon pose broad ecological risks through competition with native fish species, disruption of trophic interactions in freshwater, marine and terrestrial ecosystems, nutrient loading from post-spawning carcasses, and the potential spread or amplification of pathogens and parasites that can impact native fish (Hindar *et al.* 2020, Lennox *et al.* 2023).

Pink salmon typically exhibit a strict two-year anadromous life cycle, resulting in genetically and temporally distinct odd- and even-year lineages (Heard 1991). In their native range, both lineages may occur within the same rivers, but their relative abundance vary across rivers, regions, and time periods (Heard 1991). Even-year fish were generally more abundant prior to the mid-1930s, but since then, odd-year lineages have predominated, although shifts in dominance between the two lineages have occurred in some areas (Nagata 2007, Irvine *et al.* 2014, Radchenko *et al.* 2018). In the Great Lakes, where pink salmon were introduced in the 1950s, the population has unexpectedly deviated from the strict two-year life cycle, with individuals returning to spawn at varying ages in both odd and even years (Langan *et al.* 2025).

In the North Atlantic Ocean and Barents Sea regions, odd-year cohorts have so far dominated among introduced pink salmon (Sandlund *et al.* 2019, Diaz Pauli *et al.* 2023) and have drawn most of the attention and concern (Staveley *et al.* 2025a, Thorstad *et al.* 2025). However, the unexpected and rapid increase in odd-year individuals since 2017 underscores the need to closely monitor even-year cohort as well. The aim of this study is threefold: (1) to assess the occurrence and age composition of introduced even-year pink salmon in Norway in fisheries and monitoring programs; (2) to synthesize current knowledge on the introduction of even-year pink salmon in northwest Russia and their occurrence in the North Atlantic regions outside Norway based on published sources; and (3) based on this, evaluate the future prospects of introduced even-year pink salmon in the North Atlantic Ocean and Barents Sea regions and consider implications for management.

Material and methods

Long-term monitoring data on pink salmon are sparse, and data on the even-year population are especially limited. Accordingly, to evaluate the status and future prospects of introduced even-year pink salmon in the North Atlantic and Barents Sea regions, we synthesized available fisheries statistics, our own primary data, and information from scientific publications and publicly available technical reports. To evaluate the occurrence of even-year pink salmon in Norway, we compiled data from catch statistics and snorkeling and video surveys, most collected in recent years. Where possible, we compared the abundance of even- and odd-year pink salmon and contextualized national catch data by contrasting pink salmon abundance with that of Atlantic salmon (*Salmo salar*). Adult pink salmon migrate upstream in Norwegian rivers primarily during July and the first half of August, spawning in August and early September (Sandlund *et al.* 2019; Thorstad *et al.* 2025). The catch and video data correspond to the upstream migration period, whereas snorkeling surveys were conducted toward its end. We also examined whether the occurrence of even-year individuals could reflect deviations from the typical two-year life cycle, based on age determinations from scale readings. Current knowledge on the introduction of even-year pink salmon in northwest Russia and their occurrence elsewhere in the North Atlantic was synthesized from published sources.

River angling and coastal fishery catches

Information on the number of pink salmon and Atlantic salmon caught in rivers during the sport fishing season, as well as in licensed coastal fisheries using bag nets and bend nets (with only bag nets used after 2021) in Norway, was obtained from Statistics Norway (www.ssb.no). Reporting of all catches in these fisheries is mandatory, however, pink salmon were only included in the catch statistics from 2019 onward. Before pink salmon were incorporated into the catch statistics in 2019, the Norwegian Scientific Advisory Committee for Atlantic Salmon Management opportunistically recorded minimum pink salmon catches through surveys distributed to landowner associations in approximately 200 rivers in 2016 and 2018 (reported in Norwegian Scientific Advisory Committee for Atlantic Salmon Management 2019). In the Neidenelva, located near the Norway–Russia border, river-specific catch statistics for both Atlantic salmon and pink salmon have been collected by Neidenelvens Fiskefellesskap since 2006, which manages fishing activities in the river (data derived from www.laksefisk.no/fangstrapport/). In the Tanaelva and tributaries, pink salmon recordings from 2004 and 2006 have been reported by Niemelä *et al.* (2016) and Erkinaro *et al.* (2026).

Snorkelling counts

Underwater snorkel surveys (also called drift diving, Orell & Erkinaro 2007, Skoglund *et al.* 2021) were conducted by the same experienced team in six rivers and visual counts from the shore in one river (Jakobselva, where the Norway-Russia border, which cannot be crossed, follows the river thalweg) in mid-August of both 2022 and 2024. Observation efficiency during snorkel surveys has been shown to exceed 90% for detection of Atlantic salmon, but is lower under low-visibility conditions and in large rivers, can be lower in fast-flowing rapids than in pools, and also depends on river morphology and other local conditions (Orell & Erkinaro 2007, Skoglund *et al.* 2021). Snorkeling surveys can provide a reliable monitoring tool for pink salmon also in large and deep river systems, when survey design is adapted to river morphology. Rather than requiring complete coverage of the entire river width, sufficient observer effort concentrated in known or annually monitored spawning habitats may provide robust indices of spawning activity and relative abundance. Repeated annual surveys of key spawning areas may therefore offer a practical and efficient alternative for monitoring temporal changes in pink salmon populations in systems where full-river surveys are challenging. The clear-water rivers in our study typically had 6-8 m visibility during counts. Depending on river width, one or two observers drifted downstream, counting visually observed pink salmon. In stretches with a single snorkeller, the second observer monitored from the shore. A few stretches too shallow for snorkelling were assessed solely by visual counts from the shore. Although the surveys did not cover the entire length of each river and therefore represent minimum counts, the same stretches were surveyed at the same time each year, allowing direct comparison between 2022 and 2024.

Video monitoring

In the Kongsfjordelva, annual video monitoring of upstream-migrating pink salmon and Atlantic salmon in the lower river, close to the river mouth, could be conducted from 2011 to 2024. A guiding fence channeled ascending fish into the camera's field of view. The video counting system consisted of a Tronitech camera with a resolution of 720 TV lines and a recorder (model HSC8011F-D Webgate-Petna Brid HD) operating at 20 frames per second and recording continuously (24 h day^{-1}). Video recordings were reviewed retrospectively, typically on a daily basis. This was done manually by fast-forwarding the footage at speeds of up to 16×. The opening through which the fish passed was approximately 4 meters wide (occasionally adjusted to about 3 meters under poor lighting or visibility conditions, etc.). In conditions with poor visibility or lighting, the playback speed was also adjusted and reduced to 8× or 4×. Several tests were conducted to assess whether fish were being missed when the footage was reviewed at higher playback speeds. Video counts were supplemented with data from snorkel surveys and catch records during periods when the video system was not operating and fish may have passed undetected, or when counts were considered unreliable. This was particularly relevant in 2017, when the camera system was not installed due to high water discharge, and in

August 2021, when pink salmon spawning activity and extensive bidirectional fish movement in front of the camera reduced count reliability. The 2017 estimate of pink salmon abundance was based on snorkel surveys covering the entire river on 10 August, supplemented by reported angling catches. Some late-arriving pink salmon may not have been included an the estimate. In 2023 and 2024, a bank-to-bank trap (picket weir; Thorstad *et al.* 2025) was installed at the same location as the previous video monitoring system, with the aim of removing all pink salmon entering the river before spawning. The camera was integrated into the trap system, and in 2024, pink salmon recorded by the camera during periods when the trap was not operating were added to the trap counts. Regular snorkel surveys were conducted each year to verify the reliability of the camera monitoring and efficiency of trap catches, and to assess whether any fish remained in the river mouth downstream of the camera and trap location. The bank-to-bank trap proved efficient in catching fish that attempted to pass. A few individuals have been observed to spawn downstream of the trap location in odd years, but not in even years.

Video monitoring was also carried out in four rivers in northeastern Norway in 2024 using Mohn Technology's autonomous Fish Research System (FRS) camera, commissioned by the County Governor of Troms and Finnmark. In two of the rivers, Neidenelva and Vestre Jakobselv, the camera was installed in fishways, and in two of the rivers, Karpelva and Vesterelva, the guiding fences were used to channel ascending fish into the camera's field of view. Pink salmon counts were obtained from the County Governor's website (https://www.statsforvalteren.no/nb/troms-finnmark/miljo-klima/fiskeforvaltning/pukkellaks/kartlegginger-og-overvaking/).

All video-monitored rivers are at 70°N, where bright nights from the midnight sun during the pink salmon migration allow continuous monitoring.

Age of even-year salmon

From 2000 to 2024, scales from 21 adult pink salmon were collected by fishers in even years (samples from 0–5 fish each year), from 17 different rivers and two coastal areas. The age of the fish was determined through scale analysis. Scale impressions were prepared by pressing scales onto cellulose acetate slides using a roller. Growth patterns, visible as dark concentric circuli, were examined with a microfiche reader. Fish age was determined from seasonal growth bands, with narrow circuli indicating winter growth and wider spacing indicating summer growth.

Literature searches

Current knowledge on the introduction of even-year pink salmon in northwest Russia and their occurrence in North Atlantic regions outside Norway was synthesized from published sources. We drew on our collection of scientific publications and technical reports compiled over nearly a decade on the pink salmon invasion in the Barents Sea and North Atlantic, as well as literature identified by Staveley *et al.* (2025a). To ensure comprehensive coverage, we conducted literature searches in the Web of Science Core Collection on 20 February 2026. A search covering 1945–2025 using the terms "pink salmon AND Russia AND (even-year OR even year)"returned 35 records. A second search using "pink salmon AND (invasive OR alien OR non-native OR introduced) AND (even-year OR even year)" yielded eight records. A final search for 2025–2026 publications using "pink salmon" returned 94 records. Screening titles and abstracts confirmed that all relevant publications had already been included in our compiled material.

Occurrence and age composition of even-year pink salmon in Norway

River angling and coastal fishery catches

In even years during 2020–2024, a total of 219–436 pink salmon were reported caught each year in the river and coastal fisheries

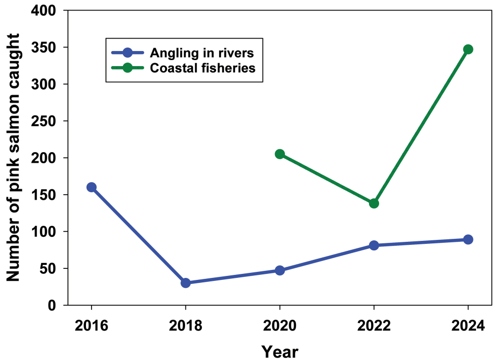

Fig 1. Number of even-year pink salmon caught in rivers and coastal fisheries in Norway, based on catch statistics for 2020–2024 (Statistics Norway). Data from 2016 and 2018 were collected opportunistically from a subset of rivers (Norwegian Scientific Advisory Committee for Atlantic Salmon Management 2019), and therefore likely underestimate catches compared to the 2020–2024 catch statistics.

(47–89 pink salmon in rivers and 138–347 in coastal fisheries, Fig. 1). Most even-year pink salmon were caught in the northernmost counties Troms and Finnmark (84–90% of the river catches and 95–99% of the coastal catches), which are located near the Russian border, showing a geographic pattern similar to that of odd-year catches (Staveley *et al.* 2025a). The remaining catches were reported from the counties Nordland, Trøndelag, Møre and Romsdal, and Vestland, while no catches were reported from the southernmost counties of the country.

The catches of pink salmon in even years were substantially lower than in odd years within the same fisheries and time period (2021: approx.. 10 500 pink salmon in rivers, 38 930 in coastal fisheries, 2023: 13 348 in rivers, 98 770 in coastal fisheries, fangstrapp.no, Statistics Norway). Likewise, the number of different rivers with reported catch of pink salmon was low in even years (27–33 rivers) compared to odd years (232 rivers in 2021 and 164 rivers in 2023).

Catches of pink salmon in even years were also very low compared to annual catches of Atlantic salmon in the same fisheries (even years 2020–2024: 45 190–123 344 Atlantic salmon caught in rivers including caught and released salmon, 20 171–53 400 Atlantic salmon caught in coastal fisheries). In contrast, the abundance of pink salmon in odd years by far outnumber Atlantic salmon (Thorstad *et al.* 2025).

Information on fishing effort is generally lacking; however, restrictions have been implemented in response to declining Atlantic salmon populations. As a result, fishing effort in both riverine and coastal fisheries has been reduced between 2019 and 2024. Hence, the increased catches of even-year pink salmon from 2020 to 2024 occurred despite a reduced catch effort. It should be noted that due to the large mesh sizes used, the smallest pink salmon (< 45 cm) are rarely caught in the coastal fisheries (Havn *et al.* 2023).

Before pink salmon were included in the catch statistics in 2019, the Norwegian Scientific Advisory Committee for Atlantic Salmon Management recorded catch of at least 160 pink salmon in 2016 and 30 pink salmon in 2018 (Fig. 1). However, because these data were collected from surveys covering only a subset of rivers, they likely underestimate catches and are not directly comparable to the catch statistics compiled since 2019. The higher catches in 2016 likely reflect a greater abundance of pink salmon that year compared to subsequent years, consistent with findings from the Norwegian river Neidenelva and northwest Russia presented below.

Pink salmon were also caught in Norwegian rivers during even years prior to 2016, as shown by catch statistics from the rivers Neidenelva and Tanaelva. In the Neidenelva, near the Norway-Russia border, no pink salmon were recorded in 2006. However, from 2008 to 2024, small numbers were caught in every even year, averaging 10 individuals annually (range 1–38, Fig. 2). The highest even-year catch occurred in 2016. Overall, there was no significant increase in even-year catches over the period 2006–2024 (linear regression, $r^2 = 0.078$, $p = 0.43$, $n = 10$, df = 8). In contrast, odd-year cohorts showed a markedly different pattern (Fig. 2); catches remained low between 2007 and 2015 (average: 20 individuals per year; range: 6–61), followed by a sharp increase from 188 pink salmon in 2017 to 2 299 in 2023, indicating an exponential growth.

Between 2004 and 2014, pink salmon were caught in the Tanaelva during every even year,

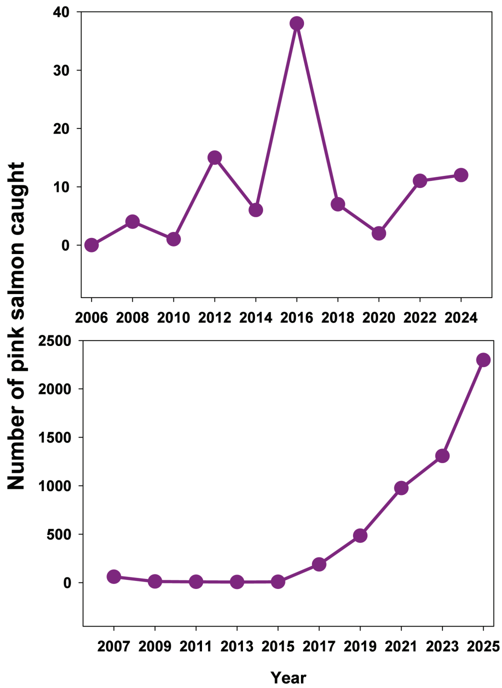

Fig 2. Angling catches of pink salmon in the river Neidenelva, Norway, during even (upper panel) and odd (lower panel) years from 2006 to 2025. Note the different scales on the y-axes of the two panels. Data source: https://www.laksefisk.no/fangstrapport/.

with an average of ten individuals per year (range: 1–25, Niemelä *et al.* 2016). In contrast, odd-year catches were consistently higher: from 2005 to 2015, an average of 46 individuals were recorded annually, ranging from six to 126 (Niemelä *et al.* 2016). Erkinaro *et al.* (2006) summarized total records of pink salmon in tributaries to the Tanaelva for 2006–2024, reporting a mean of eight individuals per even year (range: 1–19), with the highest numbers observed in 2024, 2018 and 2016, and e-dna detections of pink salmon in a few localities in 2022 and 2024. Over the same time period, the number of pink salmon entering the watershed increased sharply, from about 5 000 pink salmon in 2017 to about 180 000 in 2023 (Erkinaro *et al.* 2026).

Snorkelling counts

During underwater snorkel surveys in six rivers and visual counts from the shore in one river, between zero and 50 pink salmon were recorded annually in each river in 2022 and 2024 (Table 1). In five rivers, the number of pink salmon observed was higher in 2024 than in 2022, in one river, the number was lower, and in one river, no pink salmon were recorded in either year.

Video monitoring

In Kongsfjordelva, the 11 individuals recorded in 2024 represent the highest number documented in any even year since monitoring began; however, six individuals were also recorded in both 2014 and 2020 (Fig. 3), and no significant trend in even-year catches was detected over the period 2012–2024 (linear regression, $r^2 = 0.043$, $P = 0.65$, $n = 7$, df = 5). In contrast, the numbers recorded in odd years began to increase in 2017, reaching nearly 6 000 individuals in 2023 (Fig. 3).

Table 1. Number of pink salmon observed during snorkel surveys and visual counts on selected stretches of seven rivers in 2022 and 2024.

River	Date 2022	Date 2024	Number of pink salmon 2022	Number of pink salmon 2024
Vestre Jakobselva	18 August	20 August	3	12
Vesterelva	17 August	17 August	13	10
Bergebyelva	18 August	20 August	0	11
Nyelva	4 August	17 August	0	0
Neidenelva	16 August	19 August	8	50
Karpelva	16 August	18 August	0	4
Jakobselva	15 August	18 August	20	22
Total			44	109

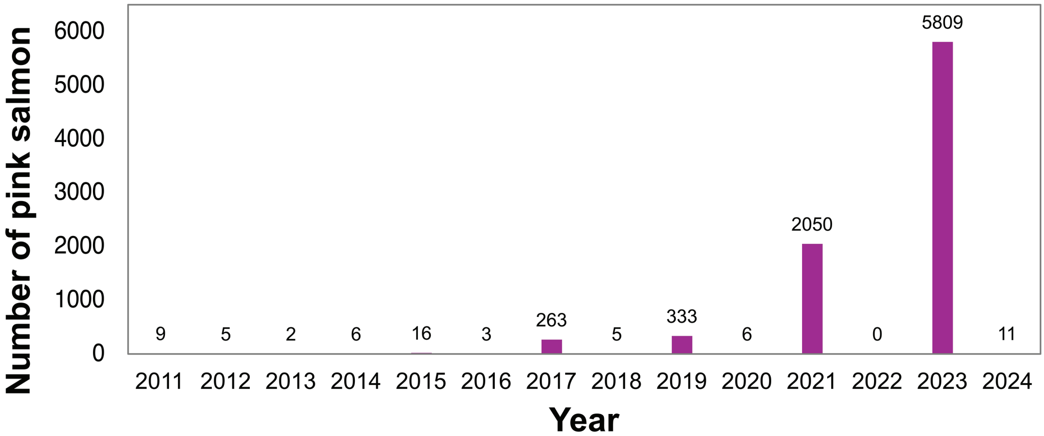

Fig 3. Annual counts of pink salmon entering the Kongsfjordelva in even and odd years, based on video monitoring supplemented by snorkelling counts and catch records from 2011 to 2024.

In four other rivers in northeastern Norway with video monitoring in 2024, between zero and 50 pink salmon were observed per river (Table 2). In the Neidenelva and Vestre Jakobselva, these counts underestimated actual pink salmon abundance, because snorkelling surveys showed that most individuals were located downstream, between the river mouths and the camera location. In contrast, in Vesterelva and Karpelva, nearly all pink salmon entering the rivers were likely recorded by the video monitoring. Of the four rivers, only the Neidenelva had prior video data, with five individuals recorded in 2018, none in 2020, and four in 2022. In addition, a local organization conducted video monitoring in Repparfjordelva and recorded six pink salmon in 2024.

Table 2. Number of pink salmon recorded by video monitoring in four Norwegian rivers in the Varangerfjord in Finnmark in 2024 (based on Mohn Technology's Fish Research System (FRS) camera, data obtained from www.statsforvalteren.no/nb/troms-finnmark/miljo-klima/fiskeforvaltning/pukkellaks/kartlegginger-og-overvaking/).

River	Monitoring period	No. pink salmon
Vestre Jakobselva	23 Jun.–26 Sep.	14
Vesterelva	17 Jun.–25 Sep.	34
Neidenelva	12 Jun–27 Sep.	0
Karpelva	15 Jun–10 Sep.	50

Age of even-year salmon

From scale analyses, all individuals sampled in even years (n = 21, from 17 different rivers and two coastal areas) had spent one winter at sea, consistent with the typical two-year life cycle of pink salmon. Analyses of scales from 536 pink salmon collected in Northern and Middle Norway in odd years (2019, 2021 and 2023) in previous studies also indicate that the invasive population in this region follows a strict two-year life cycle, as all individuals had spent one winter at sea, and none were offspring of fish that had spawned in even years (Paulsen *et al.* 2022, Nes 2025, Simmons *et al.* 2025).

Current knowledge on the introduction of even-year pink salmon in northwest Russia and their occurrence in the Barens Sea and North Atlantic Ocean regions

Introduction and occurrence of even-year pink salmon in northwest Russia

First period of introductions 1957–1979

Fertilized eggs were transported from the southern part of Sakhalin Island to local hatcheries in the White Sea area, and fry were released into rivers in northwest Russia starting in 1957. Fry were stocked almost annually until 1979. During this period, pink salmon were also recorded in Norway and other European countries, appearing in relatively low numbers during both odd and even years (Sandlund *et al.* 2019). The odd-year brood line was believed to have a selective advantage, as it spawned earlier than the even-year line, improving egg survival following autumn temperature drops (Dyagilev and Markevich 1979, cited in Gordeeva *et al.* 2003). However, efforts to establish self-sustaining populations of either brood line in northwest Russia were unsuccessful, likely because the fish originated from rivers located too far south and were poorly adapted to the colder northern climate (Gordeeva *et al.* 2003, 2006, Alekseev *et al.* 2019). As a result, the Russian stocking program was discontinued in 1979 (Gordeeva *et al.* 2003, 2006) and returns of pink salmon to rivers in the region dropped to near zero in subsequent years, both odd and even years, without further releases (Gordeeva and Salmenkova 2005, Alekseev *et al.* 2019).

Second period of introductions 1984–2003

Stocking efforts for odd-year pink salmon in northwest Russia resumed in 1985, using eggs sourced from a more northerly Pacific population in the Magadan region. These eggs were incubated in local hatcheries, and the resulting fry were released into White Sea rivers (Gordeeva *et al.* 2003, 2006). This led to successful natural reproduction and the establishment of self-sustaining odd-year populations in the region, suggesting that fish from Magadan were better adapted to the colder northern conditions than the previously used Sakhalin broodstock (Gordeeva *et al.* 2003, 2006). This population has since spread to Norway and other European countries (Sandlund *et al.* 2019).

At the same time, four translocations of even-year-broodlines from the same river in the Magadan region, using eggs collected in 1984, 1986, 1996 and 1998, were ultimately unsuccessful, despite the transfer of large numbers of eggs and favourable rearing conditions at several hatcheries (Gordeeva and Salmenkova 2011). The first three translocations did not result in any significant returns of adult fish, except a small return in 1986, and no recorded returns were observed between 1988 and 1998 (Gordeeva and Salmenkova 2011, Alekseev *et al.* 2019, Prusov 2024). The final translocation, based on eggs collected in 1998, produced a relatively large return in the first generation (spawners in 2000), but abundance declined sharply in the second generation and pink salmon nearly disappeared from even-year runs thereafter (Gordeeva and Salmenkova 2011). Goordeeva and Salmenkova (2011) concluded that, unlike the odd-year broodline, the even-year line failed to establish in northwest Russia, likely due to limited genetic variation, which constrained its adaptive plasticity and colonization potential.

Niemelä *et al.* (2016) mention that some fry of even-year pink salmon were released in northwest Russia in 2001 and 2003, but we have not found mention of this in any other sources. Spawners from releases of fry in 2001 and 2003, if any, would be expected to return in 2002 and 2004 (see catch data below).

Catches of even-year pink salmon after the second period of introductions

The relatively large return of even-year pink salmon in the first generation following the releases based on eggs collected in 1998 is also reported by Prusov (2024), with recorded catches in northwest Russia reaching 11 metric tons in 2000. However, catches declined sharply in subsequent even years, dropping to 1.4 metric tons in 2002 and 1.2 metric tons in 2004. From 2006–2012, catches remained very low (0.8, 0.5, 0, and 0.2 metric tons, respectively, Prusov 2024), supporting the conclusion by Gordeeva and Salmenkova (2011) that the attempted establishment of an even-year broodline once again largely failed.

Surprisingly, even-year catches increased again in 2014, reaching a record 11.1 metric tons, followed by a decline in subsequent years to 8.3, 4.3, and 0.9 metric tons in 2016, 2018, and 2020, respectively (Prusov 2024). In 2022, catches rose once more to 5.0 metric tons, and preliminary data from 2024 suggest a similar level, although exact figures are not provided and are only available in graphical form (Zelenina *et al.* 2025). Given the very low catches between 2008 and 2012, the sudden peak in 2014 and the rebound from 2020 to 2022 are unexpected. The peaks in 2014 and 2022, followed by declines, resemble the pattern observed after the 1998 egg translocation.

Overall, an analysis of long-term catch data reported by Prusov (2024) shows no significant increase in catches of even-year salmon in northwest Russia during 1994–2022 (linear regression, $r^2 = 0.094$, $p = 0.27$, $n = 15$, df = 13), although four of the five highest catches occurred during the last ten years of the time series. In northwest Russia, similar to Norway, the abundance of pink salmon in odd years have by far outnumbered catches in even years. During 2000-2023, the catches of pink salmon in odd years was average 263 metric tons (range 98–716), and in even years average 3.7 metric tons (range 0–11.1 metric ton) (Prusov 2024). Catches of native Atlantic salmon have consistently outnumbered those of even-year pink salmon, whereas since 2001, catches of odd-year pink salmon have greatly exceeded those of Atlantic salmon in northwest Russia (Prusov 2024, Zelenina *et al.* 2025).

Even-year pink salmon in the North Atlantic area beyond Norway

In areas of the North Atlantic outside Norway, very few pink salmon have been recorded during even years. April *et al.* (2023) reported only a single occurrence of an even-year pink salmon in this region between 2017 and 2021, from England and Wales. No even-year pink salmon have been recorded in Sweden (Staveley and Bergendahl, 2022). In Finland, a few pink salmon have been recorded in the river Tanaelva (Teno in Finnish) every even year since 1998, similar to the Norwegian side of the river (Niemelä *et al.* 2016). In Scotland, two individuals were recorded in 2022 and seven in 2024 (Fisheries Management Scotland, https://fms.scot/pink-salmon-in-scotland/). In Iceland, even-year pink salmon have also been observed, but with fewer than ten individuals reported in each of the years 2014, 2016, and 2020 (Þórðardóttir and Guðbergsson, 2021). In Greenland, four individuals were recorded in 2018, but none in 2020 (Nielsen *et al.* 2020, 2024). Additionally, oceanic catches of even-year pink salmon have been documented off the Arctic archipelago of Svalbard in 2016 (Bengtsson *et al.* 2023). In line with observations from Russia and Norway, these records consistently demonstrate a low abundance of pink salmon in even years relative to the markedly higher occurrences recorded during odd years since 2017 in the same regions.

Future prospects of the even-year population and implications for management

When discussing the future prospects for even-year pink salmon, one must take into account current abundance, long-term trends, and their introduction history. Drawing on the data and syntheses presented above, we address these aspects and their implications below.

Overall, the abundance of pink salmon in the Atlantic Ocean and Barents Sea regions remains low, based on assessments of Norwegian data and published reports from northwest Russia and other countries bordering the North Atlantic. Even-year pink salmon are scarce compared to odd-year fish, and their abundance is also low relative to native Atlantic salmon. In contrast, odd-year pink salmon now outnumbers Atlantic salmon in many areas.

Between 2020 and 2024, the typical abundance of even-year pink salmon in Norwegian rivers was fewer than 50 individuals per river, although numbers were likely higher in some years and rivers. A risk assessment concluded that the impact of pink salmon on biodiversity and ecosystems in Norwegian waters depends on their abundance. When numbers are low, the presence of pink salmon is likely to have little effect, whereas high numbers may have substantial impacts on native salmonids, water quality, and biodiversity (Hindar *et al.* 2020). According to this assessment, the current situation indicates a low to moderate risk to biodiversity and ecosystems from the even-year population, in contrast to the high or very high risk associated with the odd-year population. However, if the even-year population increases in the coming years, the likelihood of negative impacts would rise accordingly. The present low abundance does not warrant large-scale mitigation measures such as the bank-to-bank trapping carried out in odd years (Thorstad *et al.* 2025). Still, in rivers where pink salmon can be removed before spawning through harpooning, selective local nets, or targeted removal at fishways, even-year runs can be kept as low as possible.

Norwegian data indicate that the number of even-year pink salmon was higher in 2024 than in 2020. However, the limited availability of long-term datasets makes it difficult to assess broader temporal patterns. Available data suggest that catches of even-year pink salmon peaked around 2014 and 2016 in both northwest Russia and Norway, with lower catches recorded in more recent years. Statistical analyses reveal no significant long-term increase in even-year pink salmon abundance in Russia or in two monitored rivers in northern Norway. Instead, the Russian data show intermittent periods of increase followed by subsequent declines.

The even-year pink salmon in northwest Russia mainly originate from releases of a single source population from the Magadan region (Gordeva *et al.* 2003, Gordeeva and Salmenkova 2011, Zelenina *et al.* 2025). While several releases during the 1980s appear to have been unsuccessful, a release based on eggs from spawners collected in 1998 resulted in relatively high returns in 2000. However, this did not seem to lead to the establishment of a self-sustaining population, as catches declined sharply in subsequent years (Gordeeva and Salmenkova 2011), until a sudden increase was observed in 2014 (Prusov 2024, Zelenina *et al.* 2025).

Russian publications prior to the 2014 increase attributed the failure of the even-year lineage, despite three attempts in the 1980s and one in 1998, to genetic constraints. In contrast to the odd-year broodline, which rapidly adapted to the strong natural selection pressures in the new environment, the even-year fish appeared to lack sufficient genetic variation to do so (e.g. Gordeeva and Salmenkova 2005, 2011, Gordeeva *et al.* 2015, Zelenina *et al.* 2025). The peaks in 2014 and 2022, followed by declines, resemble the pattern observed after 1998. We have found no information indicating new hatchery releases in Russia during this period that could account for these increases. This suggests two possible explanations: either the recent fluctuations reflect undocumented hatchery releases, or the even-year pink salmon may have established a weakly self-sustaining, but fluctuating, population as a delayed result of the 1998 release.

Deviations from the typical two-year life cycle are uncommon in pink salmon. However, in the Great Lakes, where pink salmon were introduced in the 1950s, the population has developed life history modifications, with individuals that spend two or even three winters in the lakes, instead of one, now occurring frequently (Langan *et al.* 2025). This age variation has transformed the originally odd-year population into one that includes spawners in both odd and even years. In contrast, age analyses of invasive pink salmon from the Barents Sea and North Atlantic population described here provide no evidence that even-year pink salmon in Norway originate from odd-year individuals that have deviated from the typical two-year life cycle. Rather, they appear to be descendants of even-year fish introduced in northwest Russia. However, Zelenina *et al.* (2025) detected a particular haplotype shared between odd- and even-year spawners in northwest Russia, leading them to conclude that some genetic exchange has occurred between the two lineages, suggesting rare instances of deviation from the two-year life cycle. Changes in the life history of pink salmon in the Great Lakes demonstrate that deviations from the two-year life cycle can occur rapidly in introduced environments.

To conclude, the abundance of even-year pink salmon is still very low, with no clear indication of a long-term increasing trend. However, Russian catch data show that abundance can increase dramatically from one even year to the next, and four of the five highest recorded catches occurred within the last ten years. In Norway, the abundance of pink salmon seemed higher in 2024 than in 2020. The sharp rise observed in the odd-year population between 2015 and 2017 further highlights the unpredictable nature of this invasive species in the region, with potential for sudden and substantial population growth. Although even-year pink salmon are currently scarce, these populations could establish and expand rapidly, as occurred with the odd-year lineage after 2017. Continued monitoring is therefore essential to detect early signs of population growth and to support proactive management before control becomes more difficult. Without consistent surveillance, even-year populations may be underreported or misclassified as sporadic rather than establishing. Long-term datasets are critical for understanding temporal trends and informing scientific publications, ecological risk assessments, and conservation strategies. We therefore recommend that the monitoring described here be maintained and further developed, incorporating catch statistics, video counts, snorkelling surveys, and age analyses. Catch statistics are useful because they cover many rivers across the North Atlantic but in several places their value is limited by fishing restrictions and closures resulting from reduced Atlantic salmon populations. In addition, catch rates of pink salmon are poorly known, making it difficult to assess how well catches reflect abundance. Video counts provide reliable season-long data but are relatively resource-intensive and require suitable monitoring sites. Snorkel surveys can be a cost-effective method for obtaining snapshot data but can also be designed to provide comparable data between years in both small and large rivers. Covering entire watersheds by snorkelling is challenging in long or remote rivers. eDNA surveys can detect the presence of pink salmon but currently do not provide reliable estimates of abundance. Therefore, monitoring should continue to combine complementary methods adapted to the characteristics and conditions of each river.

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