Introduction to pink salmon in the North Atlantic and Arctic (why are they here and where?)

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Life history

Pink salmon *Oncorhynchus gorbuscha* (Walbaum, 1792) typically have a two-year anadromous lifecycle. Populations principally comprise either *odd*- or *even*-year stocks which can co-exist in the same river systems but are reproductively separate from each other (Heard, 1991). Odd-year stocks (i.e. adults spawning in odd years such as 2021, 2023) predominate in the introduced range (Gordeeva *et al.* 2015; Niemelä *et al.* 2016). Pink salmon generally spawn on gravel substratum in shallow riffles or adjacent areas with a moderate to fast flow of well-aerated water, with spawning occurring in late summer to mid-autumn (Heard, 1991, Alexeev *et al*. 2019; Erkinaro *et al*. 2022) predominantly in the lowermost sections of streams, rivers, their tributaries and the inter-tidal zone (Heard, 1991). They have also been documented to migrate hundreds of kilometres upstream in large river systems to spawning areas (Heard, 1991). This is notably evident in its non-native range in Finland/Norway, where pink salmon have been detected in the upper tributaries of the River Teno/Tana system (Fossøy *et al*. 2022) and observed in the Kola Peninsula region of northwestern Russia (Alexeev *et al*. 2019). Pink salmon are semelparous and die soon after spawning (Cederholm *et al*. 1999).

Pink salmon require good river water quality to successfully reproduce and are comparable to Atlantic salmon in this regard (Heard 1991). Across its range, spawning water temperatures for pink salmon can range from 5ºC to 19ºC but are typically around 10ºC at the onset of spawning (Erkinaro *et al*. 2022 and references therein). Warmer water temperatures within their tolerable range can increase the rate of egg to fry development (Heard 1991; reviewed in Niemelä *et al*. 2016). Fertilized eggs typically develop in the spawning gravels through the winter over a five-to-eight-month period (Heard 1991). On emergence, normally in the following spring to early summer period, fry usually quickly migrate from the river to the estuarine or coastal environment typically in schools but the latter may less so be the case in smaller systems (reviewed in Heard 1991). Migration typically commences when the water temperatures exceed 4 ºC to 5ºC (reviewed in Skóra *et al*. 2023). In coastal environments, pink salmon further mature as post-smolts in nursery areas mainly comprised of irregular shorelines sheltered from strong tidal currents and wind-generated waves before moving further off-shore where they over-winter until the following spring or early summer in advance of their return migration as adults to spawn re-entering freshwater from June to September (Heard, 1991). The schooling behaviour of pink salmon in the open ocean in their native range appears to be limited and unstructured, with any shoals of fish comprised of a low number of individuals unlikely to be commonly associated with their stock of origin (reviewed in Heard 1991).

The most important environmental factors influencing survival in freshwater are density-dependant mortality which may increase as the population level increases, predation pressures and non-biological factors such as river flow and water temperature during the spawning to migration period (reviewed in Heard 1991). Natural marine survival rates from smolt to adult returns are *c*. 4.3% (Heard 1991). Homing to natal rivers is considered to be less precise than in Atlantic salmon stocks (Thedinga *et al*. 2000; Mortensen *et al*. 2002) with straying rates of

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around 10% for wild spawned pink salmon reported from parent systems in its native range (reviewed in Heard 1991). However, higher straying rates may be a notable feature of transplanted populations (Sandlund *et al*. 2019). Straying rates for pink salmon that spawn in intertidal zones are estimated to be higher than those spawning further upstream (Thedinga *et al*. 2000).

Emergent fry do not routinely feed in freshwater but may do so particularly if there is a significant distance of outward migration towards the sea (reviewed in Mo *et al*. 2018; Sandlund *et al*. 2019; reviewed in Lennox *et al*. 2023; Erkinaro *et al*. 2024) or river hydromorphology delays migration (Veselov *et al*. 2016). Freshwater diet principally comprises the larval and pupal stages of dipteran insects but may also include other invertebrates and zooplankton (reviewed in Heard 1991). Diet at sea is variable and mainly comprised of small fish and fish larvae, amphipods, krill and zooplankton and it overlaps with the diet of Atlantic salmon in its introduced range (reviewed in Heard 1991; Diaz Pauli *et al*. 2023). Having entered freshwater as adults, pink salmon do not feed (Heard, 1991; Diaz Pauli *et al*. 2023).

Adult pink salmon typically range in length from 45 to 55 cm and migrating fry *c*. 3 cm in length (Heard 1991; Niemelä *et al*. 2016; Muladal *et al*. 2022; Skóra *et al*. 2023). Adults are distinguishable from other native anadromous salmonids by their characteristic large oval black spots on the tail fin, absence of spots on the gill cover, white-coloured mouth with black-rimmed gums and black tongue and relatively smaller fish scales. Both males and females are predominantly silver in appearance in their marine phase with a blueish dorsal hue, a white underbelly and a dark tail fin. On return to freshwater, both males and females notably darken in appearance except for their white belly. Their skin becomes thickened and their scales are absorbed (Heard 1991; Niemelä *et al*. 2016). The males develop a pronounced humped-back and kype with large teeth on both the upper and lower jaws (Heard 1991; Niemelä *et al*. 2016).

Although not common, pink salmon may have some degree of lifecycle plasticity as notably evidenced by the one to three-year lifecycle of the non-native population that established in the Great Lakes of North America (reviewed in Heard 1991; and Crawford 2001) and their non-migration to the sea which highlights their adaptability to new environments (VKM *et al*. 2020). Indeed, established odd-year pink salmon stocks in their introduced range in northwest Russia have been documented to display adaptive changes compared to their source population which includes shifts in genetic character, phenological adaptions, altered morphology, and increased body weight and fecundity (Gordeeva *et al*. 2005; Gordeeva and Salmenkova 2011). There is also some evidence for such genetic-mediated adaptions in the Great Lakes populations despite the limited genetic diversity of the founder stocks (Sparks *et al*. 2023). This demonstrates their capacity for quick acclimatisation and enhanced establishment potential in favourable environments (Niemelä *et al*. 2016; Lennox *et al*. 2023).

Natural and established geographic range

Pink salmon are native to river systems in the northern Pacific Ocean and adjacent regions of the Bering Sea and Arctic Ocean (Page and Burr, 1991). In addition to its native range, pink salmon are established in river systems draining into the Barents Sea and White Sea in the Kola Peninsula region of northwest Russia as a consequence of periodic stocking programmes undertaken there since the mid-1950s (Gordeeva *et al.* 2015; Alexeev *et al*. 2019). Self-sustaining populations of non-anadromous pink salmon have established in the Great Lakes region of North America after their unauthorised introduction into the Lake Superior drainage basin in the 1950s (reviewed in Crawford 2001). In more recent decades, in the North Atlantic region, pink salmon have become established in rivers in northern Norway (notably in Finnmark county) and Finland (Niemelä *et al*. 2016; VKM *et al*. 2020; Erkinaro *et al*. 2022;

Muladal and Fagard 2022); with further successful spawning activity documented or reported in some rivers in Iceland (Skóra *et al*. 2024), Scotland (Armstrong *et al*. 2018; Skóra *et al*. 2023) and southern Norway (ICES 2018), although it is yet to be determined whether such activity has since resulted in the generation of any self-sustaining populations in these locations or if the spawning adults are vagrant fish from elsewhere (Skóra *et al*. 2024). Once established in a river system, pink salmon have the capacity to quickly expand their range within it (reviewed in Sandlund *et al*. 2019).

In northwest Russia, pink salmon fisheries focusing on odd-year stocks have predominantly taken place in the White Sea basin region since the 1960s with annual catches in northwest Russia reported to have exceeding 100 tonnes on four occasions before 2000 and peaking at *c*. 300 tonnes in 2001 (NASCO CNL(24)21 2024; Prusov 2024). From then until 2015, catches ranged from 45 to 118 tonnes and increased from 2013 until 2021 where they exceeded 600 tonnes (Prusov and Zubchenko 2021). In 2023, the harvest was 206 tonnes which represents a 71% reduction on 2021 and a 47% reduction on the preceding five-year mean (NASCO PSWG(24)08; 2024; Prusov 2024).

Introduction history

Pink salmon have been widely transplanted within the bounds of their native range. These efforts typically aimed to enhance natural runs or establish opposite-year populations for commercial fishery purposes but have largely been unsuccessful (reviewed in Heard 1991). Such initiatives to establish pink salmon outside of its natural range for these purposes have also generally been ineffective as self-sustaining populations did not result (reviewed in Heard 1991). These include programmes in eastern North America including in Maine, Hudson Bay and Newfoundland and in the Baltic, Black and Caspian Sea regions of Europe (reviewed in Heard 1991; and in Northern Hemisphere Pink Salmon Expert Group 2023) as well as a minor introduction attempt in southern Norway in 1976 (Sandlund *et al*. 2019). However, significant efforts to introduce pink salmon to northwest Russia, which originally commenced in the mid-1950s and concluded by 2003 (reviewed in Niemelä *et al*. 2016), eventually proved more widely successful when between 1985 and 1998/1999 eyed eggs were periodically transported from further north in the Russian Pacific region (River Ola) than previously the case (Niemelä *et al*. 2016 and references therein; Alexeev *et al*. 2019; NASCO CNL(24)21 2024; Prusov 2024). This has ultimately resulted in more well-established, self-sustaining populations in northwest Russian rivers since that time, predominated by odd-year cohorts (Gordeeva *et al*. 2015). Earlier introductions up to 1979 were considered to have largely failed due to the unsuitability of the more southerly-derived donor stock, from the South Sakhalin and Kuril Islands (Niemelä *et al*. 2016 and references therein; Alexeev *et al*. 2019; NASCO CNL(24)21 2024; Prusov 2024), spawning too late in the season in prohibitively cold temperatures to ensure successful juvenile development (Gordeeva *et al*. 2015). From the 1990s, the stocking of fry in this area of Russia was mainly derived from local catches of odd-year broodstock (Niemelä *et al*. 2016). Attempts to develop large self-sustaining populations of even-year stocks of pink salmon in northwest Russia proved largely unsuccessful despite being sourced from the same far-east area as odd-year stocks (Gordeeva 2005 as cited in Niemelä *et al*. 2016; ICES 2018). This has been attributed to the relatively poorer ability of the even-year cohorts to adapt to their introduced range (Gordeeva 2005 as cited in Niemelä *et al*. 2016) and as such, established even-year stocks in northwest Russia are considered to be modest (Prusov 2024). It is worth noting that since stocking ceased in northwestern Russia, all occurrences of pink salmon in the last two decades or so outside of its native range are wild-spawned (VKM *et al*. 2020).

Spread from introduced range

Until 2017, pink salmon were generally sporadically detected in low or very low abundance in North Atlantic jurisdictions further south and west of its established range (ICES 2022). However, in 2017 pink salmon were widely recorded in unprecedented numbers in the North Atlantic and this has been the case in odd-years since that time (ICES 2018; ICES 2022; ICES 2024). Outside of northwestern Russia, reported numbers of pink salmon in the North Atlantic region have progressively increased in odd-years from 17,148 in 2017, to 20,014 in 2019, 201,694 in 2021 and 575,106 in 2023 (Table 1; ICES 2024). Apart from Norway and northern Finland, during this time, this includes records from Canada, west and east Greenland, Iceland, the Faroes Islands, Ireland, the UK, France, the Netherlands, Germany, Denmark and Sweden (ICES 2022; ICES 2024). Even-year cohorts have typically rarely been observed outside of the introduced range of pink salmon (ICES 2024) but are more regularly recorded in some northernmost Norwegian and Finnish rivers (Niemelä *et al*. 2016; Sandlund *et al*. 2019; ICES 2024). In general, it should be noted that reported numbers of pink salmon are likely to be underestimates as they are largely dependant on the fish being caught or observed. Nevertheless, since 2017, it is clear that there has been a substantial increase in odd-year pink salmon abundance and distribution outside its introduced range in the North Atlantic region.

It is considered likely that the pink salmon vagrants recorded in the North Atlantic ultimately or directly originated from the non-native populations established in northwest Russia. Indeed, Gilbey *et al*. (2022) found that pink salmon sampled from Scottish rivers in 2017 were genetically indistinguishable from White Sea populations. In addition, recent specimens from eastern Canada were found to be genetically similar to Norwegian samples (Northern Hemisphere Pink Salmon Expert Group 2023).

Northern North-east Atlantic Commission area

As a likely consequence of the stocking activities in northwest Russia, the first records of pink salmon in Norwegian rivers were in 1960 (reviewed in Sandlund *et al*., 2019; and in Diaz Pauli *et al*. 2023) when large numbers of pink salmon were observed in rivers in northernmost Norway and individual fish were encountered as far south as Bergen (reviewed in Mo *et al*. 2018). The following two decades recorded high numbers of pink salmon in both northern Norwegian and northwestern Russian rivers notably odd-year returns in the years after stocking (Niemelä *et al*. 2016 and references therein; Mo *et al*. 2018). Despite the cessation of odd-year stocking by 2001, pink salmon continued to be recorded in Norwegian rivers in variable numbers and again this was notably higher in odd-years (Mo *et al*. 2018). Indeed, observations since 1976 show that pink salmon have been recorded in a wide geographic range of Norwegian rivers from north to south in variable abundance and are distributed across the whole latitudinal range of the Norwegian Sea on its eastern side towards the Norwegian coast (Diaz Pauli *et al*. 2023). Pink salmon were not detected in southernmost Norway until 1997 with annual occurrences here reported in most years, particularly odd-years, since 2015 (Diaz Pauli *et al*. 2023). Records of pink salmon have increased in Norway annually in odd-years since 2015 and have dramatically increased since 2017 (Diaz Pauli *et al*. 2023; ICES 2024; Table 1). This is reflected in odd-year annual catches (comprising river removals, river angling and coastal fisheries) which progressively increased from 11,654 in 2017, to 14,633 in 2019, to 151,437 in 2021 and 361,548 in 2023 (Table 1; ICES 2024; NASCO CNL(24)35 2024). The vast majority of pink salmon in Norway are recorded in Finnmark, and to a lesser extent, Troms counties which adjoin northwest Russia (Sandlund *et al*., 2019; Diaz Pauli *et al*. 2023; Frøiland and Høstmark 2024). In many waterways there, pink salmon are reportedly outnumbering Atlantic salmon, with the species recorded in at least 41 waterways in this region (Muladal and Fagard 2022).

Since the 1960s up until 2017, there have been variable occurrences of pink salmon in the River Teno/Tana which is a cross-jurisdictional river system between Norway and Finland and has its sea point in northeasternmost Norway adjacent to northwestern Russia. Since 2017 estimated abundances range from *c*. 5,000 in 2017 and 2019 to *c*. 50,000 in 2021 and 170,000 in 2023 (Table 1; Erkinaro *et al*. 2023; ICES 2024). Large-scale spawning was first evident in this system in 2021 (Erkinaro *et al*. 2022 and references therein) and the species has now colonised the main stem and tributaries, including three notable headwaters in the upper catchment as well as an increasing number of the smaller tributaries there (Erkinaro *et al*. 2023).

Pink salmon were first observed in Icelandic fisheries in 1960–1961 (n=22) and were not reported in any notable abundance since then until 2017 when 52 fish were recorded (Þórðardóttir and Guðbergsson 2022; reviewed in Skóra *et al*. 2023). In the following odd-years *c*. 340 and 492 pink salmon were reported in 2021 and 2023, respectively (Þórðardóttir and Guðbergsson 2022; ICES 2024). In Sweden, pink salmon were first recorded in 2017 (n=44; ICES 2018; ICES 2024). In 2021, 70 pink salmon were reported from six rivers with relatively lower numbers recorded in 2019 (n=5) and 2023 (n=13) (Staveley and Ahlbeck Bergendahl 2022; ICES 2024). Very low numbers of pink salmon have been reported in Denmark and the Faroe Islands in some odd-years since 2017 (Table 1; ICES 2024).

Southern North-east Atlantic Commission area

Until 2017, pink salmon have been infrequently recorded in very low abundance in the southern North-east Atlantic Commission (NEAC) area (ICES 2022). After the first record of pink salmon in UK (Scotland) in 1960, low numbers of pink salmon were intermittently documented in Scotland up until 2016 with a total of 15–16 fish recorded from 12 locations (reviewed in Armstrong *et al*. 2018; Bean 2023). Prior to 2017, pink salmon have only rarely been observed in Ireland with the only confirmed record from the River Moy in 1973 and sparse anecdotal reports of individual fish besides this (reviewed in Millane *et al*. 2019a). This is also the case in UK (England and Wales) with only occasional reports since the 1960s (ICES 2018). Since 2017, all three jurisdictions have documented an unprecedented increase in odd-year pink salmon abundance with occurrences in multiple rivers and/or from interceptions in coastal fisheries (Table 1; Armstrong *et al*. 2018; Bean 2023; Millane and McCormick 2023; ICES 2024). In Ireland, pink salmon have now been recorded in 15 rivers; in UK (Scotland) in at least 23 separate catchments (Bean 2023); and in UK (England & Wales) the species has been recorded in a few catchments with records predominantly from northeastern coastal net fisheries (NASCO CNL(23)61 2023). A notable relative increase in occurrence of pink salmon in preceding odd-years was anticipated in these jurisdictions in 2023 and potentially elsewhere in Southern NEAC, but based on reported records this did not materialise (Table 1; ICES 2024).

Although very low numbers of pink salmon have been recorded in France, Germany, the Netherlands and UK (Northern Ireland) since 2017 relative to other Southern NEAC jurisdictions (Table 1; ICES 2024), these observations further highlight the widespread presence of this non-native species in the Southern NEAC area of the Northeast Atlantic in recent years.

North American Commission area

Pink salmon stocks remain well-established in the Laurentian Great Lakes since their introduction. Since 2017, pink salmon have been sparsely recorded in low numbers in odd-years in eastern Canada, notably in Newfoundland and Labrador and Quebec (Table 1; ICES 2024; NASCO CNL(24)21 2024). Previous stocking in Newfoundland in the 1950s and 1960s did not ultimately result in self-sustaining populations (reviewed in Heard 1991). There are no reported incidents of pink salmon in US Atlantic waters in recent times (ICES 2024; NASCO CNL(24)21 2024) with the stocks introduced to the State of Maine in the 1900–1920s believed to have disappeared by the late 1920s (Heard 1991).

Table 1: *Numbers of pink salmon reported to ICES in NASCO commission areas (2017-2023). These numbers are from catches, removals, counts or observations (reproduced from ICES 2024).*

Country/Jurisdiction	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Canada	4		5		14		3
Denmark	10				8		4
Faroe Islands	1		6		7		
Finland*	5000		5000		49500	20	170000
France	3				4		
Germany	3		1		1		2
Greenland	6	4	78		62		1021
Iceland	79	1	251		340	5	492
Ireland	36		11		45		1
The Netherlands	3				6		
Norway	11654		14633	254	151437	219	361,548***
Russia (north-west)**	220000		223529		352941		
Sweden	44		5		70		13
UK (England and Wales)	208	1	3		26		2
UK (Northern Ireland)	2		3		3		2
UK (Scotland)	131		18		171	1	47

* Figures for Finland are for the River Tana/Teno.

** Russian numbers estimated from t 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). Data from 2022 and 2023 are not available.

*** a provisional figure of 403,519 reported in ICES 2024; amended to 361,548 as in NASCO CNL(24)35 (2024).

East and West Greenland

Pink salmon were first observed in Greenland in 1969 (reviewed in Nielsen *et al*. 2020) and have been documented in at least 22 locations there since 2013 with the vast majority of specimens encountered since 2017 (Nielsen *et al*. 2020). There was a notable increase in reports in 2023 (n=1,021) compared to preceding odd-years when between 62 and 78 pink salmon were recorded (Table 1; ICES 2024). The majority of records are from western and southern Greenland (Nielsen *et al*. 2020). However, in the relatively more isolated areas of south-east Greenland, pink salmon have also been observed in the lower reaches of some rivers and specimens encountered in adjacent near-shore areas (G. Wightman, N. Jepsen and K. Aarestrup pers. comm.)

High Arctic region

Pink salmon commonly occur in Svalbard in both the marine and freshwater environments having been first recorded there in 1961 (Bengtsson *et al*. 2023 and references therein). However, they have no current potential to spawn there as the rivers run dry or freeze in the autumn and winter (Bengtsson *et al*. 2023). In the eastern Canadian Arctic between 2017 and 2019, individual pink salmon have been documented at three locations (McNicholl *et al*. 2021). In addition, since 2011, some westward expansion of pink salmon from its native range has been documented in the Russian Arctic, where further expansion is likely constrained by prohibitive climatic conditions with the Taymyr Peninsula considered to separate native and introduced ranges (reviewed in Northern Hemisphere Pink Salmon Expert Group 2023).

Potential reasons for increased abundance and distribution in the North Atlantic since 2017

It is difficult to comprehensively establish the causative factors which resulted in the dramatic increase in pink salmon abundance and their wide geographic occurrence as observed in the North Atlantic region in odd-years since 2017. However, more favourable warmer water temperatures experienced in recent years in both the freshwater and marine environments in its northernmost established non-native range is considered to be one of the main drivers of the increased abundance observed (VKM *et al*. 2020; Paulsen *et al*. 2022; Lennox *et al*. 2023; Northern Hemisphere Pink Salmon Expert Group 2023). In this region, increasing sea surface temperatures have been associated with an increased abundance of adult returns (VKM *et al*. 2020). In freshwater, increased temperatures have been reported to result in higher growth and smolt survival (reviewed in Veselov *et al*. 2016; and Farley *et al*. 2020) and a warmer receiving marine environment for smolts and post-smolts is considered to enhance survival prospects (Mo *et al*. 2018; Farley *et al*. 2020; Kaustad 2021). It is notable that in its native range, the abundance of juvenile pink salmon in summer is known to be highly correlated to the harvest of adults in the following year (Miller *et al.* 2022) and increases in odd-year cohorts in recent decades have been associated with increasing sea temperatures there (Irvine *et al*. 2014).

Homing instinct to natal rivers in at least some introduced stocks is considered to be less precise than native stocks which may facilitate increased vagrancy potential over a wide geographical range (reviewed in Niemelä *et al*. 2016; and in Lennox *et al*. 2023). However, despite stocks in northwestern Russia considered mainly to return to natal rivers, even with low straying rates, high abundances of pink salmon in a given year may result in the straying of significant numbers of individual fish (Sandlund *et al*. 2019). It has been speculated that straying to Greenland and to jurisdictions in the southern NEAC area from northwesternmost Europe could be promoted by vagrants following the course of typical ocean circulation patterns used by Atlantic salmon (Diaz Pauli *et al*. 2023). It has been further speculated that if homing has inherited features, transplanted stocks would be more susceptible to straying (VKM *et al*. 2020).

Future prospects for establishment and occurrence outside of established introduced range

The future prospects of pink salmon establishment and occurrence outside of its currently colonised range in northwesternmost Europe are difficult to determine (Lennox *et al*. 2023; Northern Hemisphere Pink Salmon Expert Group 2023). Climatic factors are likely to be key determinants influencing the abundance of pink salmon here in upcoming decades and consequently affect their capacity for further spread south and west in the wider North Atlantic region (Niemelä *et al*. 2016; VKM *et al*. 2020). Sustained periods of more favourable water temperatures both in the freshwater and marine environments, particularly during the smolt emigration and post-smolt periods, are likely to increase pink salmon survival and as such increase the propagule pressure experienced elsewhere, enhancing the potential for further self-sustaining populations to establish (Mo *et al*. 2018; Sandlund *et al*. 2019; Farley *et al*. 2020; Kaustad 2021). This is particularly important for jurisdictions more distant from the current range of colonisation (Millane *et al*. 2019b; Skóra *et al*. 2023). However, this has more immediate concerns for proximal areas to its current non-native established range, particularly further south in Norway, increasing the importance of effective control measures to inhibit further spread. With the climatically-induced increase in water temperatures already observed in northernmost latitudes likely to continue, it is anticipated that pink salmon will become a northern circumpolar species (VKM *et al*. 2020). Successful reproduction has already been documented in some rivers outside of its established northwesternmost range in Europe, which demonstrates that rivers in many jurisdictions throughout the North Atlantic capable of supporting the biological requirements for pink salmon spawning and juvenile development are therefore potentially susceptible to colonisation. Indeed, modelling thermal preferences may be particularly important to better ascertain the likely spread of pink salmon both in the North Atlantic and Arctic regions (Northern Hemisphere Pink Salmon Expert Group 2023). In addition, the documented ability of pink salmon to rapidly adapt and acclimatise to new areas of introduction is likely to enable their capacity for further establishment (Lennox *et al*. 2023). However, such range expansion cannot be assessed in isolation as climate warming, particularly in more northern latitudes, may result in gross ecosystem changes with novel predator pressures emerging or other currently unknown factors potentially tempering any expansion that may otherwise occur (Lennox *et al*. 2023). Further curtailment of pink salmon establishment in more southerly latitudes is also possible as river temperatures may increase above its current reproductive capability (VKM *et al*. 2020).

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