Assessment of potential ecological impacts of pink salmon and their capacity for establishment in Ireland

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1 Abstract

The unexpected occurrence of notable numbers of non-native pink salmon in multiple river systems in Ireland in 2017 was unprecedented and reflected similar concurrent events observed in other countries in the North Atlantic region. The establishment capacity of pink salmon here is likely to be primarily determined by the level of propagule pressure experienced over the coming years. Environmental and ecological conditions are considered favourable for establishment. However, the occasional, intermittent presence of individual or very small numbers of vagrant fish in Irish waters is considered unlikely to result in establishment.

There is very limited information available to comprehensively evaluate the potential impacts of pink salmon on native biota and associated ecosystems. Such impacts are likely to be predicated on the frequency of occurrence and associated abundance of pink salmon including their capacity to establish self-sustaining reproducing populations and the resulting abundance of both juveniles and returning adults.

2 Background

Pink salmon is an anadromous migratory species of salmon, 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 is 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 1950s (Gordeeva *et al.* 2015) and self-sustaining populations 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). Subsequent to its introduction to northwest Russia, the species has regularly been recorded in catches in almost all the Atlantic salmon rivers in Northern Norway, notably in the Finnmark region, and in some of the same systems further upstream in Finnish territory (Niemelä *et al.* 2016; Sandlund *et al.* 2018). Incidences of pink salmon encountered outside its native or established range were sporadic until 2017 when an unprecedented increase in their occurrence was concomitantly observed across the North Atlantic region including in the waters of eastern Canada, Iceland, Greenland, western and southern Norway, Britain, Ireland and France (Armstrong *et al.* 2018; ICES, 2018; Mo *et al.* 2018). The reasons for this are currently unclear but it has been postulated that it is associated with a combination of exceptionally high freshwater production of pink salmon in 2016, allied to increased marine survival and altered distribution at sea, all likely influenced by favourable climatic factors (Armstrong *et al.* 2018; Niemelä *et al.* 2016; Mo *et al.* 2018).

Pink salmon typically has a two-year anadromous lifecycle, with spawning occurring on gravel substratum in late- summer to mid-autumn predominantly in the intertidal or lowermost sections of rivers and streams (Heard, 1991). On emergence in the following spring to early summer period, fry usually quickly migrate to the estuarine or coastal environment to further mature before moving off-shore where they over-winter until the following spring or early summer in advance of their return migration to spawn (Heard, 1991). 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) predominate in the introduced range (Gordeeva *et al.* 2015; Niemelä *et al.* 2016).

Pink salmon were first recorded in Ireland in August 1973 when a single specimen was caught by an angler in the River Moy in the north-west of the country (Went, 1974). In the intervening period until 2017, individuals have been infrequently observed in Irish waters and such reports are largely anecdotal and unverified (Minchin, 2006; IFI, 2017). However, in 2017, thirty-six pink salmon were captured in a total of 11 Irish river systems in the period from late June to late September (Millane *et al*. 2019) (Figure 1). The majority were captured in the lower reaches of each system. However, in the River Moy and River Corrib catchments, individual pink salmon were captured a maximum distance of 25 km and 34 km, respectively, upstream of the tidal high-water mark (Millane *et al*. 2019). The latter migration necessitated passage over a weir or through a fish counter and subsequently a 30 km transit through Lough Corrib, a productive freshwater lake and a prime brown trout fishery (Millane *et al*. 2019).

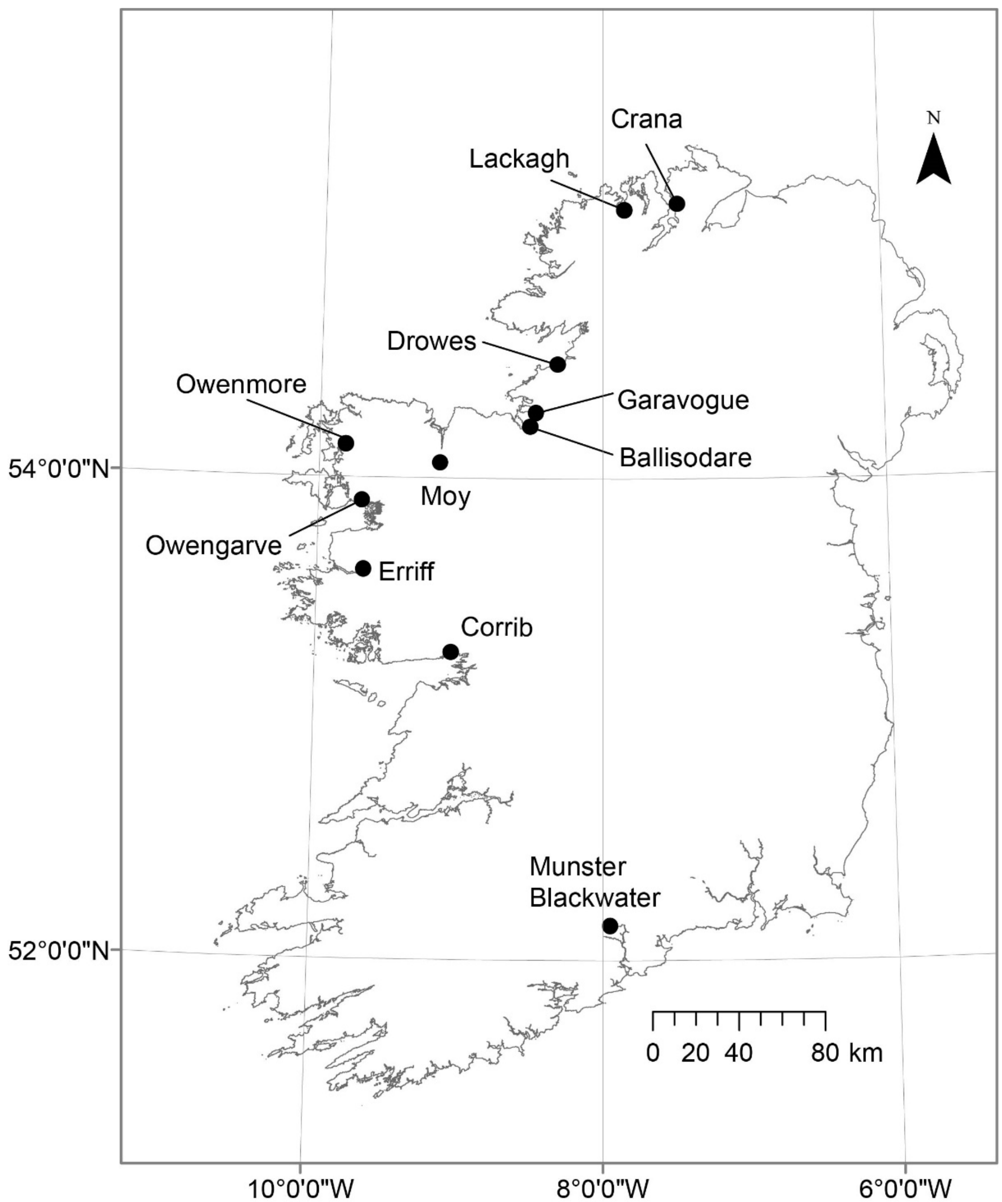

Figure 1 Irish river systems where pink salmon were recorded in 2017 (adapted from Millane *et al*. 2019).

3 Establishment capacity of pink salmon in Ireland

It remains uncertain whether the unprecedented occurrence of pink salmon in multiple Irish river systems in summer 2017, as observed elsewhere in the North Atlantic region, was an exceptional event or if it represents the initial phase of a range expansion (ICES, 2018). Only 36 fish were captured in Ireland (Millane *et al.* 2019), but it is likely that more individuals were present in these 11 rivers and other systems given that the median angling exploitation rate on native Atlantic salmon stocks is estimated at 10.8 % (Millane *et al.* 2017).

The risk of pink salmon becoming established in Irish waters will most likely relate to the level of propagule pressure experienced in Ireland over the coming years rather than the periodic presence of small numbers of vagrant fish (Millane *et al.* 2019). Repeated stocking programmes in rivers in northwestern Russia since the 1950s until 2001 are thought to have resulted in the initial expansion to and the apparent establishment of self-sustaining pink salmon populations in northernmost Norway (Niemelä *et al.* 2016; Sandlund *et al.* 2018). Despite their persistent presence there since the 1960s, this is not known to have resulted in such populations establishing further south in Norway to date (Sandlund *et al.* 2018). This suggests a low risk of establishment of the species in Ireland at present (Millane *et al.* 2019). Nevertheless, the well-established range of pink salmon in north-western Russia and northern Norway is considered to represent a "permanent, but variable propagule pressure on rivers in Norway as well as in the rest of north-western Europe" (Sandlund *et al.* 2018).

An increasing frequency of climatic conditions (e.g. more optimum river temperatures for hatching and smolt migration) which favour the development and survival of pink salmon is likely to increase the risk of establishment in Ireland and neighbouring jurisdictions (Millane *et al.* 2019). Ecologically, the Irish climate is already well within the tolerable range (reviewed in Heard, 1991 and Copp, 2017) for the species to reside and reproduce (Millane *et al.* 2019). Indeed, successful early stage development from fertilised eggs deposited in 2017 in neighbouring Scottish rivers has been observed *in situ*, and under laboratory conditions mimicking a range of natural river temperatures that occur there (Armstrong *et al.* 2018). In addition, existing knowledge of physical and physico-chemical habitat requirements (Heard, 1991) clearly indicate that there is ample availability of such estuarine and freshwater habitat in Ireland to facilitate successful establishment (Millane *et al.* 2019). Although the species typically spawns in the lower reaches of river systems, migration to spawning grounds hundreds of km upstream through freshwater has been documented (Heard, 1991). Despite pink salmon being considered less proficient than *S. salar* in ascending migratory impediments (Heard, 1991), one fish captured in 2017 did negotiate a substantial weir in the lower River Corrib to migrate further upstream (Millane *et al.* 2019).

4 Potential ecological impacts of pink salmon in Ireland

In general, the long-term negative impacts of pink salmon on native Irish species and ecosystems will most likely be predicated on notable factors such as their frequency of occurrence and associated abundance, their capacity to establish self-sustaining reproducing populations and the resulting abundance of both juveniles and returning adults. There is a paucity of information in the literature to comprehensively evaluate the potential impacts of pink salmon on native biota, notably native salmonid and estuarine and coastal marine fish species and associated ecosystems. A non-native species risk screening exercise by Invasive Species Ireland (2010) considered pink salmon to be of 'medium risk' as its "impact on conservation goals remains uncertain due to lack of data showing impact or lack of impact."

There is no direct overlap in the late summer-autumn spawning period of pink salmon (Heard, 1991) and either Atlantic salmon and brown / sea trout which spawn in wintertime in Ireland (Elliot and Elliot, 2010) or indeed other potentially co-existing diadromous fish species such as twaite shad, sea lamprey and smelt which spawn in late spring to early summer (King *et al.* 2011). Documentary evidence is lacking to date which shows any specific negative interactions between Atlantic salmon in their spawning areas and pink salmon (ICES 2013, Copp, 2017). Nevertheless, the return run of pink salmon does occur within the return run periods of both Atlantic salmon and anadromous trout. Therefore, pink salmon may co-habitat the same sections of rivers or estuaries with native salmonids and other conservationally-important diadromous fish species during this time. Indeed, during their spawning period, non-native pink salmon have been reported to display aggressive behaviour towards native fish (Armstrong *et al.* 2018; Kaliuzin 2003 as cited in Sandlund *et al.* 2018); and push out Atlantic salmon from holding pools to more atypical habitat in smaller channels when large numbers of pink salmon are present (Zubchenko *et al.* 2004 as cited in ICES, 2013).

As pink salmon is semelparous (i.e. dies after spawning; Cederholm *et al.* 1999), the presence of large numbers of decaying carcasses after spawning, particularly in smaller river systems, may have potential impacts on the functioning of recipient ecosystems. Some resident animal and plant species are likely to be favoured through increased nutrient input and consequential production with others suffering directly from reduced water quality and indirectly from habitat modification (Armstrong *et al.* 2018; Mo *et al.* 2018). Any pink salmon-mediated reduction of native salmonid abundance may threaten the sustainability of endangered freshwater pearl mussel populations as this species relies on resident salmonids to successfully complete its lifecycle (Mo *et al.* 2018; Zyuganov and Veselov, 2015 as cited in Sandlund *et al.* 2018).

Having entered freshwater, adult pink salmon do not feed (Heard, 1991) and therefore, will not compete with native species for food resources. Such competition between co-occurring pink salmon fry, native freshwater species and native juvenile salmonids is unlikely to be significant in the lower reaches of river systems where pink salmon fry, once emerged, are known to quickly migrate from the river towards the sea (Heard,1991; ICES 2013). There exists potential for some level of food resource competition where high densities of pink salmon emerge further upstream in river systems and thus reside longer in freshwater (reviewed in Mo *et al.* 2018; Sandlund *et al.* 2018). Pink salmon may also act as a novel food source for native salmonids (Mo *et al.* 2018; Sandlund *et al.* 2018). In northwest Russia, Atlantic salmon smolts have been reported to prey on pink salmon juveniles (Bakshtanskii 1964 as cited in Rasputina *et al.* 2016), and fry and parr have been documented to preferentially consume pink salmon eggs (Rasputina *et al.* 2016).

Knowledge to assess the potential ecological impacts of pink salmon while resident in non-native coastal ecosystems and off-shore is limited (Sandlund *et al.* 2018). However, in its native range, the common prey resources of resident seabirds, other species of salmon, and other pelagic marine species may be suppressed in years when pink salmon are present in high abundance (Ruggerone and Irvine, 2018; Springer *et. al*. 2018). Furthermore, juvenile pink salmon in the coastal environment have been associated with the suppression of marine macro-zooplankton through predation which resulted in a concomitant increase in phytoplankton abundance (Shiomoto *et al.* 1997). Alternatively, juveniles could represent a novel and abundant prey item for some native fish, and piscivorous bird and mammal species in this ecosystem.

5 Conclusion

The unprecedented occurrence of pink salmon throughout the North Atlantic region, including Ireland, in summer 2017, means that particular vigilance is required to monitor for this non-native species in Irish waters in upcoming odd years (Millane *et al*. 2019). Based on current knowledge of its life history, summer 2019 will provide the first indication of whether the increased occurrence as evident in 2017 was an exceptional event or more characteristic of an emerging trend (Millane *et al*. 2019). Liaison with international colleagues prior to and during the likely pink salmon freshwater incursion window in future years in both even- and odd-years will allow for an early warning mechanism for Ireland (Millane *et al*. 2019).

6 Acknowledgements

Karen Kelly and Seán Rooney (IFI) are acknowledged for providing some information associated with ecological impacts. The sections concerning background information and establishment are adapted from Millane *et al*. 2019 (*Journal of Fish Biology*). The section on potential ecological impacts is adapted from additional material submitted with but not published in Millane *et al*. 2019 for brevity. Therefore, the input of two anonymous reviewers are gratefully acknowledged for their contribution to this particular section.

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