The pink salmon invasion: a Norwegian perspective

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Introduction

In the period 1956-1979, more than 220 million of pink salmon (*Oncorhynchus gorbuscha*) eggs from the southern part of Sakhalin Island in the Pacific Ocean were transported to the northwestern part of Russia (Gordeeva *et al*., 2015). The hatched fry were stocked to several rivers draining to the White Sea and Barents Sea, which is part of the Arctic Ocean, bordering on the North Atlantic Ocean (Fig. 1). These introductions resulted in large catches of adult pink salmon during the 1970s, especially in the White Sea (Niemelä *et al*., 2016). However, self-reproducing populations were likely not established, perhaps because the pink salmon were not adapted to the local climatic conditions and timing of spawning. Low water temperatures during the autumn may have caused mortality of the developing embryos (Gordeeva *et al*., 2015). The more northerly-located River Ola (close to Magadan) in Russia was chosen as the donor population for all subsequent ova introductions. Introductions during the 1980s resulted in self-reproducing populations of the odd-year brood line; which indicated that the River Ola population was better adapted to the hydrothermal regimes in the recipient rivers (Gordeeva *et al*., 2015). During the 1990s, stocked fry in Russian rivers were mostly based on eggs from local catches of odd-year spawners in the White Sea area (Niemelä *et al*., 2016).

According to Niemelä *et al*., (2016), the translocation of pink salmon eggs from the Pacific Ocean ended in 1998, while releases of fry from local catches ended in 2000. Consequently, catches later than 2001 in the White Sea, Barents Sea and North Atlantic Ocean and rivers draining to these areas originate from self-reproducing populations, mainly in rivers draining to the White Sea (Niemelä *et al*., 2016). This successful translocation of pink salmon to create a self-sustaining population represented a distance of over 5600 km as the crow flies. By far, odd-year spawners dominate the established populations (Gordeeva & Salmenkova, 2011). Several introductions of an even-year brood line from Ola River did not provide perceptible results, but still, low numbers of pink salmon enter the rivers in even-years (Gordeeva *et al*., 2015).

Observation of pink salmon in Norwegian rivers

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The stockings of pink salmon fry in rivers in the Kola Peninsula in the late 1950s resulted in the first large invasion to Norway in 1960. Pink salmon invaded more than 40 of the northernmost Norwegian rivers, but individual fish were recorded as far south as Bergen, some 2500 km from the stocked rivers in Russia (Berg, 1961). Between 1960 and 1979, high numbers of pink salmon occurred simultaneously in Norwegian and Russian rivers in years after stockings of millions of fry. Successful spawning was observed in Norwegian rivers (Bjerknes, 1977). In recent years, spawning pink salmon have been observed in six rivers, and migrating smolts the following spring in two rivers (Hesthagen & Sandlund, 2016). Since the beginning of 2000s, after the stockings ceased, variable numbers from a few to hundreds of pink salmon have been visually observed in the rivers most years, but clearly in higher numbers in odd years.

The 2017 invasion

During 2017, adult pink salmon were observed in at least 272 Norwegian rivers from the Russian border in the northeast to the Swedish border in the southeast, spanning 13 degrees latitude. Thousands of adult pink salmon ascended the rivers, and more than 3400 pink salmon were reported as caught in the rivers as bycatch during routine recreational angling for Atlantic salmon (*Salmo salar*), anadromous brown trout (*S. trutta*, hereafter termed sea trout) and anadromous Arctic charr (*Salvelinus alpinus*). More than 2400 adults were deliberately killed as mitigation measures by harpooning, gill netting etc. mostly in the north-easternmost Norwegian rivers. Where possible, pink salmon observed in fish ladders were collected and killed. In addition, an unknown number was caught in the sea. Still, numerous spawners were visually observed in many rivers from July to mid-September. Where spawning activity was observed, spawning mostly took place in the lowermost parts of the rivers. However, in some rivers, spawned individuals were found tens of km upstream from the outlet. It seems that the number of adult pink salmon entering Norwegian rivers have exceeded 10 thousand.

The reason for the abundant pink salmon invasion in 2017 is unknown. A combination of successful spawning in Russian as well as some Northern Norwegian rivers in 2015, favourable river temperatures for hatching and smolt migration, and favourable conditions for pink salmon in the sea may be the explanation. A few individual pink salmon were recorded in some southern Norwegian rivers in 2015. Hence, we cannot exclude the possibility that spawning occurred in some of these rivers, but since these were single observations in only a few rivers, it is unlikely that it resulted in the significant production of pink salmon that was recorded in 2017. Catches of pink salmon in Norwegian rivers except those in Finnmark County, close to the Russian border, have been few in the years before 2015, with reports of only single individuals in some rivers. Because pink salmon have not been included in official catch statistics, reported numbers in 2017 and earlier years are

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underestimates. However, based on frequent contact with local managers and fishers in Atlantic salmon rivers, we believe that the low numbers of pink salmon reported from rivers south of Finnmark County in 2015 and earlier years reflect that they occurred in only low numbers.

Norwegian management authorities were unprepared for the situation that emerged in 2017. Mitigation measures were not organised on a national or regional level, and for each river mitigation depended on personal and voluntary initiatives. In Norway, pink salmon is listed as an unwanted invasive species, so local activities arose spontaneously to catch and kill pink salmon and in most cases were approved by the authorities.

Pink salmon influences on native salmonids

There is limited knowledge on the interactions between pink salmon and the native anadromous salmonids in Norwegian rivers. The native species (Atlantic salmon, sea trout and Arctic charr) all spawn in late autumn (September-November), the eggs hatch in the spring, and in the majority of Norwegian rivers the juveniles of the three salmonid species spend 2-5 years in the rivers before they become smolts and migrate to the sea. Pink salmon also spawn in the late summer and early autumn (August-September), but they emerge from the gravel already silvery smolts and ready to migrate to the ocean early next year.

Pink salmon and the native anadromous salmonids use similar spawning areas. Competition at the spawning sites will depend on the timing of arrival and spawning by the various species. The main spawning of pink salmon in Norwegian rivers in 2017 occurred from 10 August and during the first half of September, based on observations of ovulated females, spawning activity and spawned fish (reports to us from local people). Late pink salmon spawning might have occurred at the same time as early sea trout spawning and possibly Arctic charr, but likely a few weeks before the Atlantic salmon spawning. Direct interactions during spawning between pink salmon and the native anadromous salmonids were therefore unlikely to happen. Large numbers of pink salmon may still have negative consequences by disturbing wild anadromous salmonids on their spawning areas prior to spawning. Even though pink salmon die after spawning, they can protect their spawning redds for some time after they have spawned (Smirnov 1975 and McNeil 1962, referred by Heard 1991), and it is unknown to what extent this may influence the other salmonids.

If the pink salmon juveniles migrate to sea before they start feeding, the interaction with other fishes in the river during this stage will be minimal. However, Smirnov and Kamyshnaya (1965) (referred by Heard, 1991) and Gordeeva & Salmenkova (2005) reported that pink salmon fry in the Kola Peninsula rivers remained feeding somewhat longer in streams after emergence than in other areas. If pink salmon juveniles remain for a few

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weeks feeding in the rivers before migrating to sea, competition may be intense between pink salmon and fry of native anadromous salmonids during a short, but important, period for survival of the native species. However, if the small (3-4 cm) pink salmon fry remain in the river for an extended period, they will also constitute a potential prey for other fish in the river, including juvenile Atlantic salmon and brown trout which reside in the rivers for 1-3 years,

Another expressed fear associated with the introduction of pink salmon ova from the Pacific to the Atlantic is the risk for introduction of pathogens, mainly viruses. However, there are surprisingly few studies of this. To our knowledge, there has been only one study of virus in pink salmon from rivers in Northern Norway. Skjåvik (2008) examined pink salmon caught in the rivers Tana and Neiden in Finnmark County, for the presence of infectious haematopoietic necrosis virus, infectious pancreatic necrosis virus and infectious salmon anemia virus. None of these viruses were found in any of the examined 74 fish.

Parasitological studies have shown that Atlantic and pink salmon have similar parasitic helminths and nematodes in the alimentary tract (Ieshko *et al*., 2016). As these parasites are transmitted via the food web, the two species seem to eat the same food at sea. However, it is not known whether they may compete for food with Atlantic salmon at sea where they stay in the same ocean areas.

All pink salmon die after spawning. The decomposing carcasses constitute a significant supply of nutrient to the rivers (Nelson & Reynolds, 2015). This will also be the case in Norwegian rivers if regular spawning by pink salmon is the result of the recent development. Many Norwegian rivers are typically nutrient-poor, but how a significant nutrient supply from pink salmon carcasses may potentially affect the balance of the existing nutrient and energy budgets, and thus the effect on the river ecosystem, is not known.

Large numbers of pink salmon in rivers with Atlantic salmon may also have another negative consequence, although not biological. Sports fishing for large Atlantic salmon is important for the local economy along many rivers. If the catches constitute mainly small pink salmon, the perceived value of the sport fishers may be reduced, as well as the income for local stakeholders.

Future perspectives

The previous peak in pink salmon numbers in Norwegian rivers occurred in 2007. However, numbers then remained low until the new peak in 2017. Thus, it is difficult to know if the high numbers in 2017 signifies a more stable and abundant occurrence in Norwegian rivers south of the rivers of Finnmark County.

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One scenario is that the pink salmon invasion in 2017 indicates that the odd-year broodline has become better adapted to the ecological and physical conditions in rivers in the North Atlantic. While invasions before 2000 mainly were due to the high number of stocked fry in Russian rivers, the invasion in 2017 stem from self-reproducing pink salmon populations in Russian, and possibly some Norwegian rivers close to the Russian border. However, the paucity of abundant odd-year invasions may indicate that there is no successful continuous natural reproduction combined with favourable conditions for survival and growth in the sea. The warming of the northern ocean areas due to climate change may be beneficial for pink salmon (Karpevich *et al*., 1991 in Gordeeva & Salmenkova, 2011).

The ability of pink salmon to adapt to the hydrothermal conditions in rivers southwards along the Norwegian coast is unknown. Northern Norway is more similar in climate to Ola River than southern Norway. If White Sea rivers are too cold for pink salmon from Sakhalin and almost too cold for pink salmon from Ola river (cf. Gordeeva & Salmenkova, 2011), western and southern Norway should be too warm, being considerably warmer than southern Sakhalin.

However, with the more or less continuous, although variable, supply of pink salmon spawners, it may only be a matter of time before a stable, higher abundance of pink salmon becomes established in rivers connected to the northeast Atlantic Ocean. In any case, with the dire lack of knowledge on essential aspects such as the phenology of pink salmon spawning, the survival of pink fry, smolts and sub-adults in estuaries and the sea, and the interactions between pink salmon and native salmonids in the rivers, the invasion of pink salmon in Norwegian rivers should cause concern. The Atlantic salmon populations in many Norwegian rivers have declined significantly the last decades due to a number of other negative impacts (Forseth *et al*., 2017). The invasion of self-reproduced pink salmon in the North Atlantic in 2017 indicates a great risk of pink salmon being established in more rivers and over a larger area around the North Atlantic Ocean. This would be an additional negative pressure on Atlantic salmon. If an establishment of pink salmon reduces the abundance of Atlantic salmon parr, this may also adversely affect the endangered freshwater pearl mussel (*Margaritifera margaritifera*) in those rivers where the parasitic glochidia are host specific to and dependent on Atlantic salmon parr to complete its lifecycle.

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