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Assessment of the risk to Norwegian biodiversity and aquaculture from pink salmon (*Oncorhynchus gorbuscha*)

Scientific Opinion of the Panel on Alien Organisms and Trade in Endangered Species of the Norwegian Scientific Committee for Food and Environment

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Preparation of the opinion

The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) appointed a project group to ansver the mandate. The project group consisted of four VKM members, four external experts and a project leader from the VKM secretariat. Two external referees commented on and reviewed the opinion. The VKM Panel on Alien Organisms and Trade in Endangered Species (CITES) evaluated and approved the final opinion.

Authors of the opinion

Members of the project group that contributed to the drafting of the opinion
In alphabetical order after chair of the project group:

Kjetil Hindar – Chair of the project group and member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian Institute for Nature Research (NINA), Trondheim.

Lars Robert Hole – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) The Norwegian Meteorological Institute, Bergen.

Kyrre Kausrud – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) The Norwegian Veterinary Institute (NVI), Oslo.

Martin Malmstrøm – Member of the project group and project leader in the VKM secretariat. Affiliation: VKM.

Espen Rimstad – Member of the project group and member of the Panel on Animal Health and Welfare in VKM. Affiliation: 1) VKM; 2) Norwegian University of Life Sciences (NMBU), Oslo.

Lucy J. Robertson - Member of the project group and member of the Panel on Biological Hazards in VKM. Affiliation: 1) VKM; 2) Faculty of Veterinary Medicine, Norwegian University of Life Sciences (NMBU), Oslo.

Odd Terje Sandlund – Member of the project group. Affiliation: Norwegian Institute for Nature Research (NINA), Trondheim.

Eva B. Thorstad – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian Institute for Nature Research (NINA), Trondheim.

Gaute Velle – Member of the project group and chair of the panel on Alien Organisms and trade in Endangered Species (CITES) and member of the Scientific Steering Committee in VKM. Affiliation: 1) VKM; 2) NORCE Norwegian Research Centre, Bergen; 3) University of Bergen, Bergen.

Knut Wiik Vollset – Member of the project group. Affiliation: 1) NORCE Norwegian Research Centre, Bergen

Members of the Panel on Alien Organisms and Trade in Endangered Species (CITES) that contributed to the assessment and approval of the opinion

In addition to Kjetil Hindar, Lars Robert Hole, Kyrre Kaursrud, Eva B. Thorstad and Gaute Velle these were (in alphabetical order before chair/vice-chair of the Panel):

Hugo de Boer – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Natural History Museum, Oslo.

Katrine Eldegard – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian University of Life Sciences (NMBU), Ås.

Johanna Järnegren – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian Institute for Nature Research (NINA), Trondheim.

Lawrence Kirkendall – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Department of Biological Sciences, University of Bergen.

Inger Måren – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Department of Biological Sciences, University of Bergen.

Erlend B. Nilsen – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian Institute for Nature Research (NINA), Trondheim.

Eli Rueness – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Centre for Ecological and Evolutionary Synthesis (CEES), Department of Biosciences, University of Oslo.

Anders Nielsen – Vice chair of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian Institute of Bioeconomy Research (NIBIO); 3) Centre for Ecological and Evolutionary Synthesis (CEES), Department of Biosciences, University of Oslo.

Acknowledgment

Competence of VKM experts

Persons working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third-party interests. The Civil Services Act instructions on legal competence apply for all work prepared by VKM.

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Summary

Key words: VKM, risk assessment, Norwegian Scientific Committee for Food and Environment, Norwegian Environment Agency, Norwegian Food Safety Authority

Introduction:

The Norwegian Environment Agency and the Norwegian Food Safety Authority asked the Norwegian Scientific Committee for Food and Environment to assess the risk to Norwegian biodiversity, to the productivity of native salmonid populations, and to aquaculture, from the spread and establishment of pink salmon in Norwegian rivers, and to assess mitigation measures to prevent the spread and establishment of this alien species.

Pink salmon is native to rivers around the northern Pacific Ocean. The species usually has a strict two-year life cycle, with populations spawning in even and odd years being genetically isolated. Fertilized eggs of pink salmon were transferred from Sakhalin Island to Northwest Russia in the late 1950s, and fry were released in rivers draining to the White Sea. The first abundant return to rivers in Northwest Russia, as well as to Norway and other countries in northwestern Europe, was recorded in 1960. Stocking with fish from Sakhalin was terminated in 1979. By then, no self-sustaining populations had been established. From 1985 onwards, stocking in White Sea rivers was resumed with fish from rivers in the more northerly Magadan oblast on the Russian Pacific, resulting in the establishment of reproducing populations. Stocking was continued until 1999, when the last batch of even-year fertilized eggs was imported, and the fry released in spring 2000. Thus, all pink salmon caught after 2001 in the Northeast Atlantic and the Atlantic side of the Arctic Ocean including the Barents Sea, as well as in rivers draining into these seas, are the result of reproduction in the wild.

Pink salmon is now established with abundant and increasing stocks in Northwest Russia and regular occurrence in rivers in eastern Finnmark. Catches of odd-year adult pink salmon in Northwest Russia were usually below 100 tonnes before 2001 and increased to an annual average of 220.5 tonnes during the period 2001-2017. Even-year returns are smaller than odd-year returns both in Northwest Russia and in Norway.

The number of pink salmon recorded in Norwegian rivers peaked in 2017, with a high number of fish in eastern Finnmark, and substantial numbers recorded in rivers all along the coast of Norway and in other European countries. In 2019, the area with abundant returns expanded in comparison with 2017, to include rivers in western Finnmark and Troms. The recorded numbers were perhaps lower in southern Norway in 2017 than in 2019 (full statistics not available when this report was finalised), but also in southern Norway there were more pink salmon in 2019 than in any year before 2017. The large numbers of pink salmon in western Finnmark and Troms in 2019 may indicate an expansion of the area in Norway with abundant odd-year pink salmon returns. In some small rivers in eastern

Finnmark, between 1000 and 1500 pink salmon were fished out by local people in 2019, demonstrating the magnitude of the potential impact in terms of numbers of pink salmon. We cannot rule out that this will not happen over larger parts of Norway in the coming years. The even-year strain of pink salmon only occurs in low numbers in Russian rivers, as well as Norwegian, rivers.

Adult pink salmon enter the rivers from early July, and spawning occurs in August-September. Spawning habitat requirements are like those of native salmonids: Atlantic salmon, brown trout, and Arctic charr. Spawning of pink salmon occurs earlier than the native salmonids, but observations in 2019 indicate a possible overlap with native salmonids in September in northern Norway. Pink salmon eggs hatch in late winter or spring, and the alevins remain in the gravel until most of the yolk sac has been resorbed. Emerging fry are approximately 30 mm in length. Functionally, they are smolt already at this stage, with a silvery colouration and saltwater tolerance. The fry/smolt start feeding on small invertebrates in some rivers, while the fry/smolt migrate without feeding in other rivers. They impact juveniles of native salmonids through competition for food and space and the invertebrate fauna through predation. The impact depends on the duration of their stay. This is assumed to be very short, but some observations indicate that fry/smolt that emerge from spawning redds far upstream may feed and grow to 60-70 mm before entering the sea. Pink salmon smolt may spend some time in estuaries and coastal waters before moving to the open sea. The next approximately 12 months are spent feeding in the open seas before returning to the coast to seek rivers for spawning. Homing is less precise in pink salmon than in other anadromous salmonids. All spawners die shortly after spawning.

Methods

This risk assessment is based on an extensive literature search, contact with scientists in North America, western Europe, Russia, Norway, the county governor in Troms and Finnmark, and local anglers' associations, and other stakeholders in Norway.

We have investigated whether ocean temperatures play an important role in the variation of pink salmon year class abundance, and whether the annual abundance of adult pink salmon is increasing with rising sea temperatures. This is an important aspect of a risk assessment in a 50-yr perspective.

We have used a semi-quantitative risk assessment. The overall risk is the product of the magnitude of the consequences of the event and the likelihood that the event will occur, as judged by the project group experts. The level of confidence in the risk assessment is described, and uncertainties and data gaps identified.

Results

The dynamics and environmental impact of introduced pink salmon in Norwegian rivers, coastal waters, and the ocean, depend on their abundance. In all habitats and for all life

stages, high abundance may have serious repercussions, whereas low numbers may be of little consequence.

An increasing abundance of reproducing pink salmon will likely present hazards to biodiversity and river ecosystems. Establishment of reproducing pink salmon over larger areas in Norway will probably increase the regularity of abundant returns to Norwegian waters. The invertebrate fauna will be negatively affected where large numbers of pink salmon juveniles use it as a food source. This is more likely in long than in short rivers. The river pearl mussel, *Margaritifera margaritifera*, may be particularly vulnerable, as it has a larval stage in juvenile Atlantic salmon or brown trout, but cannot use pink salmon as a host.

Pathogens that may be affected by the increased occurrence of pink salmon in Norway include viruses, bacteria, and parasites (eukaryotic organisms). Very little is known about the susceptibility of pink salmon to viral pathogens. Among 11 viral pathogens assessed, only three or four are known to infect pink salmon.

The project group assesses that the potential impact for aquaculture is moderate if infectious haematopoietic necrosis virus is spread by pink salmon in the marine ecosystems. Salmonid alphavirus (SAV)-infected pink salmon, potentially infected through contact with Atlantic salmon aquaculture, moving from south to north could introduce a risk of spread of this virus and the resulting pancreas disease. The project group assesses that the overall potential impact of SAV for aquaculture in the marine ecosystems is low with medium to low confidence.

The project group assesses that the potential impacts for aquaculture if *Renibacterium salmoninarum* and *Piscirickettsia salmonis* are spread by pink salmon in the marine ecosystems are moderate with low confidence.

The potential negative impact on biodiversity in the marine ecosystems and productivity of native salmonid species is assessed as low to minimal for all viral and bacterial pathogens considered, apart from for *Renibacterium salmoninarum* and viral haemorrhagic septicaemia virus for which the risks were assessed as moderate.

Parasites can potentially represent a major hazard to both wild and farmed salmonids, and we have considered three groups of parasites; (1) those that may impact the health and welfare of native salmonids (in the wild and in aquaculture), (2) zoonotic parasites, and (3) aquatic organisms that have a parasitic stage in their life cycle, but are of relevance and interest in Norwegian ecosystems. The abundance and spread of some of these parasites may be affected by the incursion of pink salmon.

Hybridization between pink salmon (genus *Oncorhynchus*) and native salmonids (genera *Salmo* and *Salvelinus*) has not been documented in the wild. In the laboratory, intergeneric hybridizations between these species have produced only sterile offspring.

Interactions with native salmonids may occur in two ways: through competition for food or through competition for space in the river before spawning and on the spawning grounds. If feeding in the river, pink salmon fry ingest the same prey as native salmonid fry. Thus, competition for food and space may occur if there are high densities of pink salmon for a substantial period. High densities of pink salmon fry may also influence the ability of native salmonid fry to establish territories. On the other hand, emerging pink salmon fry may serve as food for older life stages of native salmonids.

Competition for spawning grounds may be restricted due to pink salmon spawning earlier in the autumn. However, there may be temporal overlap between Arctic charr and pink salmon spawning in northern Norway, and a possible overlap in both time and space with early-spawning brown trout.

High numbers of pink salmon spawners may have a crowding effect on native salmonids before the actual spawning time. Agonistic behaviour, like chasing of up-migrating Atlantic salmon and brown trout by pink salmon, is known to occur. The effect of this aggressive behaviour on the spawning success of native salmonids is not known.

Pink salmon spawners transport organic matter and nutrients from the sea to the rivers. Water quality will be influenced by pink salmon carcasses in rivers after spawning. Decomposition of dead spawners will release organic matter and nutrients (phosphorous and nitrogen) into the water. In nutrient-poor rivers, this will enhance production of algae and zoobenthos, and likely benefit juvenile native salmonids. The impact will likely be negative in more nutrient-rich rivers. Any effect from nutrient input on water quality is likely governed by the number of dead fish, river morphology, and the current nutrient status of the river. Dead and decomposing spawners benefit scavengers of all types and may therefore also affect terrestrial food webs and biodiversity.

In the coastal and marine systems, juvenile and adult pink salmon will constitute a new and additional prey for many predators. Pink salmon in the seas may feed on similar prey as native salmonids, and high densities of pink salmon may negatively affect native salmonids as well as the marine ecosystem, as seen in the North Pacific Ocean.

Hazards for the aquaculture industry are mainly associated with spreading of disease-causing pathogens. This is directly related to the number of pink salmon in the waters around aquaculture installations. The higher the number of pink salmon, the higher is the probability of individuals carrying pathogens that may be transferred to aquaculture fish.

If pink salmon come to dominate the number of salmonids in rivers, this will negatively affect both the economic value of salmon angling, and the value in terms of an important ecosystem service, as catches may be dominated by 1.5 kg fish (that are not fit for human consumption, except early in the season) compared with the larger Atlantic salmon.

Under present climatic conditions, pink salmon may spawn and produce offspring in all rivers along the Norwegian coast. Regular occurrence of the odd-year strain has so far only been

seen in rivers in eastern Finnmark, where we believe self-sustaining populations have been established. The change from 2017 to 2019 may indicate that the area with rivers receiving high numbers is expanding westwards and southwards into Troms. Establishment of self-sustaining populations depend, in general, on a suffiently high survival of offspring after hatching and when they leave the rivers, and during the marine phase.

Abundant returns of pink salmon are correlated with ocean surface temperatures in the North Atlantic Ocean and Barents Sea. Using sea-surface temperature data from 1900 to 2019, we find that the number of pink salmon returning can be relatively well predicted (adjusted $R^2 > 0.5$ for a positive relationship) by sea-surface temperature in the area south of Svalbard and of the cohort size two years previously for all three data sets considered. Hence, the increasing sea surface temperatures and reduced ice cover over the last 20 years may benefit pink salmon in the ocean and be one reason for the increasing number of pink salmon in Northwest Russian and Norwegian waters. However, the average surface temperature of the Arctic Ocean seems to be increasing so rapidly at present that the ecosystem is probably in flux. The effects of this rapid change are unpredictable; however, it is likely that a climate warming over the next 50 years will facilitate the establishment of circumpolar pink salmon populations in Arctic rivers. Whether a warmer climate will benefit pink salmon in all Norwegian rivers remains unclear, as it is considered a cold-water species. However, pink salmon seem to be able to adapt to new conditions over a few generations.

Conclusions

It has already been demonstrated that pink salmon can occur in large numbers and high densities in Norwegian rivers. The impact of pink salmon on biodiversity and ecosystems in Norwegian waters depends on their numbers. This is valid for all aspects of the river systems. A low number of pink salmon are likely of little consequence, whereas abundant spawning pink salmon in a river may have substantial impact on native salmonids, as well as on water quality and biodiversity. Thousands of spawners will possibly produce millions of offspring that may impact small invertebrates and crustaceans negatively and compete with native salmonids for food and space after hatching.

The impact in the sea also depends on the abundance of pink salmon, as they may compete with native salmonids and other species for food as well as have other impacts on the food-web of marine ecosystem.

The likelihood of spreading of disease to native wild fish, as well as to aquaculture fish, is also directly correlated with the number of pink salmon. However, only a few fish may have a serious impact if heavily infested with a pathogen to which native wild fish or aquaculture fish are susceptible, and conditions favour transmission.

The current increasing trend in sea-surface temperatures and reduced ice cover seem to benefit the survival of pink salmon in the sea, and the projected climate change may enhance this. The impact of a warmer climate on the river stages of pink salmon is less clear. The effects of further climate change may introduce unexpected interactions with

pathogens and with other species, as the accelerating change since about 2010 has been moving the Arctic Ocean into previously unobserved temperature regimes.

Feasible measures to reduce the impact of pink salmon in rivers include targeted fishing adapted to local conditions. Experience from 2017 and 2019 shows that such efforts are effective and can decrease or even eliminate the threat of pink salmon to native salmonids and biodiversity in individual rivers, at least in smaller rivers. In order to reduce the number of pink salmon and the recurring returns of pink salmon spawners to Norwegian coastal waters and rivers in general, however, concerted action on a regional, national and international level is required.

Sammendrag på norsk

Nøkkelord: VKM, Vitenskapskomiteen for mat og miljø, risikovurdering, Miljødirektoratet, Mattilsynet

Introduksjon

Miljødirektoratet og Mattilsynet har bedt Vitenskapskomiteen for mat og miljø om å gjøre en risikovurdering av spredning og etablering av pukkellaks i norske vassdrag, med vekt på effekter på biologisk mangfold, produktiviteten av naturlig forekommende laksefiskpopulasjoner, samt akvakultur. Oppdraget omfatter også en vurdering av mulige tiltak for å hindre spredning og etablering av denne fremmede fiskearten.

Pukkellaks forekommer naturlig i elver rundt det nordlige Stillehavet. Arten har en to-årig livssyklus, og bestander som gyter i henholdsvis partalls- og oddetallsår er atskilt fra hverandre og genetisk forskjellige. Befruktet rogn av pukkellaks ble overført fra den russiske øya Sakhalin i Stillehavet til Nordvest-Russland på slutten av 1950-tallet, og yngelen ble sluppet i elver ved Kvitsjøen. Den første tallrike tilbakevandringen av gytemoden fisk til kystfarvann og elver i Russland og i Norge, skjedde i 1960. Ettersom utsettingene ikke førte til at pukkellaks etablerte seg i Nordvest-Russland, ble det slutt på utsetting i 1979. Utsetting ble tatt opp igjen i 1985 med yngel hentet fra Magadan-distriktet lenger nord på den russiske Stillehavskysten. Innhenting og klekking av yngel fra Magadan fortsatte fram til 1999, og den siste yngelen ble satt ut våren 2000. Siden de blir to år gamle, kom voksen pukkellaks fra den siste utsettingen tilbake til elvene i 2001. Det betyr at all pukkellaks som er registrert eller fanget i Europa og i Nordvest-Russland etter 2001, er et resultat av gyting i naturen.

Det er nå tallrike og økende bestander av pukkellaks i elvene i Nordvest-Russland, og pukkellaks har siden 2007 hatt regulær forekomst i elver i Øst-Finnmark, nær grensen til Russland. Det er først og fremst i oddetallsår at de kommer til elvene for å gyte. Antallet pukkellaks i partallsår er lavt både i Russland og Norge. Før 2001 var den registrerte fangsten av pukkellaks i Nordvest-Russland vanligvis mindre enn 100 tonn per år. Fangstene ble mer enn fordoblet i perioden 2001-2017 (gjennomsnittlig 220,5 tonn i oddetallsår, med en topp på 373 tonn i 2017).

I 2017 økte antallet pukkellaks kraftig i elvene i Øst-Finnmark. Det kom også pukkellaks til hele norskekysten og mange andre europeiske land dette året. Foreløpige tall for 2019 viser økte forekomster av pukkellaks i elver i Vest-Finnmark og deler av Troms, og ikke bare i Øst-Finnmark. Dette kan tyde på at området i Norge med tallrik forekomst av pukkellaks utvider seg.

Voksen pukkellaks begynner å gå opp i elvene i juni eller tidlig i juli, og gytingen skjer i august-september. Alle dør etter gyting. De foretrukne gyteplassene ligner på plassene som brukes av laks, sjøaure og sjørøye. Det er antatt at pukkellaksen gyter før de lokale

laksefiskene, men observasjoner fra Nord-Norge i 2019 kan tyde på overlapp i tid med lokale laksefisk som gyter tidlig i september. Rogna til pukkellaks klekkers på senvinteren eller tidlig vår, og yngelen blir i grusen til det meste av den medfødte matpakken (plommesekken) er brukt opp. Når yngelen kommer opp av grusen er den ca. 30 mm lang. Yngelen har blank buk og sider og mørk rygg, og de er allerede i noen grad klare til å takle saltvann. På dette stadiet kalles laksefisk smolt.

Yngelen kan bli i elva i noen dager eller uker og begynne å spise der, men den kan også vandre til sjøen med en gang uten å ta til seg føde i elva. Noen observasjoner tyder på at pukkellaksyngel kan bli i elva til de er 60-70 mm lange. Det kan spesielt gjelde for yngel fra gyteplasser langt opp i elva. Smolt av pukkellaks kan bli i elvemunninger og kystfarvann fra noen dager til uker før de vandrer til havs. De neste ca. 12 månedene tilbringer de i åpent hav før de kommer tilbake til elvene for å gyte. Laksefisk er kjent for å komme tilbake til elva der de ble født og vokste opp når de skal gyte, men pukkellaksen sprer seg mer til andre elver og har mindre presis hjemvandring enn de andre laksefiskene.

Metoder

Risikovurderingen er basert på et omfattende litteratursøk, kontakt med forskere i Nord-Amerika, Vest-Europa, Russland og Norge, med miljøavdelingen hos Fylkesmannen i Troms og Finnmark, og med fiskeforeninger, grunneiere og andre interessenter i Norge.

Vi har testet om overflatetemperaturer i havet spiller en rolle for årlig mengde pukkellaks, og om antall voksen pukkellaks øker med stigende sjøtemperatur. Dette er en viktig del av risikovurderingen i et 50-årsperspektiv.

Vi har gjort en semi-kvantitativ risikovurdering av pukkellaks for biologisk mangfold, bestander av vill laksefisk og akvakultur i Norge. Risiko er fastsatt ut fra hvor stor effekt en hendelse har og sannsynligheten for at hendelsen inntreffer, slik dette er vurdert av eksperter i prosjektgruppen. Styrken på kunnskapen som ligger til grunn for risikovurderingen er angitt og prosjektgruppen har identifisert usikkerhet og kunnskapshull.

Resultater

Bestandsutviklingen og miljøeffektene av pukkellaks i norske elver, kystfarvann og havområder er avhengig av antall individer. I alle habitater og for alle livsstadier vil høye tettheter av pukkellaks mest sannsynlig ha store negative effekter, mens lave tettheter mest sannsynlig vil ha liten betydning.

Et økende antall pukkellaks vil sannsynligvis ha negativ effekt på det biologiske mangfoldet og på akvakultur langs kysten og elveøkosystemene. Etablering av pukkellaks i elver over større områder av Norge vil øke sjansen sannsynligheten for at vi regelmessig får tallrike invasjoner av pukkellaks i norske elver. Bunndyr (små virvelløse dyr) i elvene vil bli mest påvirket der store antall pukkellaksyngel bruker elva som fødeområde. Dette er mer sannsynlig i store vassdrag der pukkellaks kan gyte langt oppe i elva, enn i små, korte, elver.

Elvemusling, *Margaritifera margaritifera*, kan være særlig sårbar art i ferskvann, siden den har et larvestadium på gjellene til ungfisk av laks og/eller aure, men den ikke kan bruke pukkellaks som vertsdyr.

Patogener inkluderer virus, bakterier og parasitter. Man vet svært lite om hvor utsatt pukkellaks er for å bli infisert av virusbårne sykdommer. Av de 11 typene som er vurdert, er det bare tre eller fire som er påvist hos pukkellaks.

Prosjektgruppa vurderer at risikoen for negative effekter på akvakultur er moderat hvis pukkellaks sprer viruset som forårsaker infeksiøs hematopoetisk nekrose i det marine miljøet. Pukkellaks som potensielt kan bli infisert med salmonid alphavirus gjennom kontakt med laks i merder i Sør-Norge, kan spre dette viruset nordover og infisere oppdrettslaks lenger nord. Salmonid alphavirus forårsaker pankreassykdom. Prosjektgruppa vurderer at den totale risikoen av salmonid alphavirus for akvakultur i saltvann er lav, med middels til lav sikkerhet.

Prosjektgruppa mener at hvis bakteriene *Renibacterium salmoninarum* og *Piscirickettsia salmonis* blir spredd med pukkellaks i det marine miljøet, vil den potensielle effekten på akvakultur være middels, med svært lav sikkerhet.

Risikoen for biologisk mangfold forårsaket av patogener i det marine miljøet og for produktiviteten til lokale laksefisker, er anslått til liten eller svært liten. Unntaket er for *Renibacterium salmoninarum* og viral hemoragisk septikemi virus, der risikoen anslås å være middels.

Parasitter kan virke svært negativt på laksefisk både i naturen og i oppdrett. Tre typer parasitter er vurdert: parasitter som påvirker helse og velferd hos laksefisk, parasitter som kan spre seg fra fisk til mennesker, og vannorganismer som har et parasittisk stadium i sin livssyklus og som er av interesse i norske økosystemer. Forekomsten og mengden av noen av disse parasittene kan påvirkes av forekomsten av pukkellaks.

Krysninger (hybridisering) mellom pukkellaks (som tilhører slekta *Oncorhynchus*) og naturlig forekommende laksefisk (som tilhører slektene *Salmo* og *Salvelinus*) har aldri blitt påvist i naturen. I laboratorieforsøk produserer krysning mellom disse slektene bare sterilt avkom.

Laks, sjøaure og sjørøye kan påvirkes gjennom konkurranse om mat og plass mellom yngel av pukkellaks og vill laksefisk, og gjennom konkurranse om gyteplassene. Når yngelen av pukkellaks tar til seg næring i elva, spiser de det samme som yngel av laks, sjøaure og sjørøye. Konkurranse om mat kan derfor forekomme dersom det er høye tettheter av pukkellaksyngel som blir i elva en stund og spiser. Høye tettheter kan også påvirke mulighetene for yngel til innførte arter å etablere revir. På den annen side kan yngel av pukkellaks være bytte for andre laksefisk i eldre livsstadier.

Konkurranse om gyteplassene er trolig begrenset i og med at pukkellaks i stor grad gyter tidligere om høsten enn våre laksefisker. Observasjoner i Finnmark tyder på at overlapp kan forekomme ved sen gyting av pukkellaks og tidlig gyting av lokale laksefisk, særlig sjørøye

og sjøaure. Høye tettheter av gyteklar pukkellaks i stimer kan presse laks, sjøaure og sjørøye vekk fra områdene de normalt oppholder seg i før gyting. Det er kjent at aggressiv atferd fra pukkellaks kan påvirke oppholdssted og atferd til de lokale laksefiskene før gyting, mens effekten på deres gytesuksess er ukjent.

Gytefisk av pukkellaks transporterer organisk materiale og næringssalter fra havet og opp i elvene, siden alle dør etter gyting. Elvas vannkvalitet vil bli påvirket av den døde gytefisken når den går i oppløsning. Dette vil frigi organisk materiale og næringssalter (fosfor og nitrogen) til vannet. I næringsfattige elver kan dette øke produksjonen av alger og bunndyr og dermed forbedre mattilbudet for andre laksefisk. I næringsrike elver kan råtnende pukkellaks føre til for høye nivåer av organiske stoffer og næringssalter. Effekten av dette avhenger av mengden av død fisk, elveløpets utforming og hydrologi, og vannets innhold av næringssalter.

Om høsten vil råtnende gytefisk tilføre næringsstoffer som kan øke mengden bunndyr. Gyteklar pukkellaks er bytte for både pattedyr og fugl, og utgytt og død fisk spises av åtseletere av alle slag. Dette kan også påvirke næringsnett og biologisk mangfold på land.

I kystsonen og i havet vil pukkellaks være et nytt bytte for mange predatorer. I sjøen spiser pukkellaks de samme byttedyrene som andre laksefisk, og ved svært store tettheter av pukkellaks kan dette virke negativt på andre laksefisk så vel som på det marine økosystemet, slik det er påvist i det nordlige Stillehavet.

Eventuelle negative effekter på fiskeoppdrett i sjøen har sammenheng med spredning av sykdomsorganismer og parasitter. Dette har en direkte sammenheng med tettheten av pukkellaks rundt merdene. Jo høyere tetthet av pukkellaks nær oppdrettsmerdene, desto større er muligheten for at det finnes individer med sykdom som kan overføres til oppdrettsfisken.

Hvis det blir en stor andel pukkellaks i lakseelvene, vil dette virke negativt på verdien av laksefisket. Fangstene vil kunne bli dominert av relativt små fisk (ca. 1,5 kg) som allerede tidlig i sesongen vil være uegnet som mat for mennesker.

Med dagens klimaforhold vil pukkellaks kunne gyte og få fram avkom i alle lakseelvene langs Norges kyst. Regulær og tallrik forekomst av oddetalls pukkellaks har hittil bare vært observert i elver i Øst-Finnmark, men utvidelsen i 2019 til at området med tallrike bestander også omfatter Vest-Finnmark og deler av Troms, tyder på at det er mulighet for videre ekspansjon.

Den økende havtemperaturen og reduksjonen i isdekket i Barents- og Nordishavet gjennom de siste 20 årene kan være gunstig for pukkellaks og være en årsak til det økende antallet i norske og russiske elver. Tallrik forekomst av pukkellaks i nordnorske og russiske elver er korrelert med temperaturen i overflatevannet i havet mellom Finnmark og Svalbard. Ut fra havtemperaturen og antall pukkellaks registrert to år tidligere, kan vi relativt sikkert forutsi antallet pukkellaks som kommer til elvene. Temperaturen i disse havområdene har økt så

raskt de siste årene at hele økosystemet trolig er i endring. Det er vanskelig å forutsi effektene av dette, men når det gjelder pukkellaks vil temperaturøkning trolig gjøre det lettere for arten å etablere bestander i elvene i Nord-Norge, i alle fall i et 50-års perspektiv. Hvorvidt et varmere klima vil være til fordel for pukkellaks i alle norske elver er usikkert, da arten er ansett å være en kaldtvannsart. Pukkellaks ser imidlertid ut til å være i stand til å tilpasse seg nye forhold ganske raskt.

Konklusjoner

Det har allerede vist seg at pukkellaks kan forekomme i store antall og tettheter i norske elver. Påvirkningen av pukkellaks på biologisk mangfold og økosystemer i norske elver avhenger av antall pukkellaks. Noen få pukkellaks vil trolig ha liten betydning, mens tusenvis av gytefisk vil ha stor effekt på naturlig forekommende laksefisk så vel som vannkvalitet og biologisk mangfold. Tusenvis av gytende pukkellaks vil produsere millioner av yngel som kan konkurrere med yngel av annen laksefisk om mat og plass, og redusere antallet av små bunndyr og krepsdyr gjennom beiting.

Effektene i kystfarvann og havet vil også henge sammen med antallet pukkellaks, gjennom konkurranse med annen anadrom laksefisk og endringer i næringsnettet.

Risikoen for at pukkellaks skal spre sykdomsorganismer til vill laksefisk så vel som oppdrettsfisk, er også direkte korrelert med antallet pukkellaks. Imidlertid kan også et fåtall pukkellaks få stor betydning dersom de er infisert av patogener som vill- eller oppdrettsfisk er mottakelige for, og forholdene ellers favoriserer smitteoverføring.

Dagens utvikling med varmere havvann og redusert isdekket areal i havet, ser ut til å være til fordel for pukkellaksens overlevelse i sjøen. En videre utvikling mot et varmere klima vil trolig forsterke denne tendensen. Virkningen av varmere klima på de stadiene i livssyklus som foregår i elvene er mindre klar. Et varmere klima kan føre til uventete interaksjoner med sykdomsorganismer og andre organismer, siden de raske klimaendringene rundt 2010 har ført til forhold i de nordlige havområdene som tidligere ikke har vært observert.

Tiltak for å redusere effektene av pukkellaks i elvene omfatter målrettet utfisking med metoder tilpasset lokale forhold. Erfaringer fra mindre elver i Finnmark i 2017 og 2019 viser at utfisking kan redusere, og i enkelte tilfeller fjerne, trusselen fra pukkellaks mot andre laksefisk og biologisk mangfold i elvene. For generelt å redusere antallet pukkellaks og gjentagende invasjoner av gytefisk til norske kystfarvann og elver, er det imidlertid nødvendig med samordnete tiltak på regionalt, nasjonalt og internasjonalt plan.

Glossary

Alevin: Growth stage in a salmon life cycle that occurs after hatching from the egg and when the yolk sac is still present.

Anadromous: Fish that migrate from the sea and into freshwater to spawn.

Ecosystem services: The benefits that humans freely gain from the natural environment.

Eutrophication: When a body of water becomes overly enriched with minerals and nutrients causing an excessive biological productivity.

Eutrophic water: Water body with high levels of biological productivity caused by being overrich in nutrient constituents, especially nitrogen and phosphorus.

Fecundity: The potential for reproduction of an organism or a population.

Fry: Growth stage in a salmon life cycle that occurs when the yolk sac has been absorbed and the fish start independent.

Invasive species: A species that is not native to a location (has been introduced) and that tends to spread to a degree believed to cause damage to the environment, human economy, or human health.

Iteroparous: A species that potentially can have multiple reproductive cycles over the course of its lifetime.

Kype: The hook shape on the jaw of a fish that develops during the spawning period.

Mesotrophic water: Water body with an intermediate level of productivity due to a moderate level of nutrients.

North Atlantic: For the purpose of this report, the term "North Atlantic" or "North Atlantic Ocean" is used as a short-hand term to mean the Norwegian Sea, the Barents Sea, and the Greenland Sea, roughly from 40° W to 50° E, and from 60° N to 85° N.

Oligotrophic water: Water body with relatively low productivity, due to the low nutrient content.

Phenology: the timing of events in a plant or animal life cycle and how these are influenced by environmental variables.

Redd: A nest made in the gravel where female salmon deposit their eggs.

Semelparous: A species characterized by a single reproductive episode before death.

Smolt: Life stage in a salmon that occurs when the fish adapt for life in sea water. Many physiological changes occur in the fish during the smolt stage.

Substratum: The river bed. The organic and minerogenic makeup is important for salmon.

Background as provided by the Norwegian Environment Agency and Norwegian Food Safety Authority

Pink salmon (*Oncorhynchus gorbuscha*) is an anadromous salmonid with a natural distribution in the Northern Pacific Ocean, from the Sacramento River in California and northwards to Makenzie River in Canada. On the Asian-Pacific Coast, there are natural populations of pink salmon from the Jena and Lena rivers in Arctic Russia in the north, to North Korea in the south. Pink salmon was for the first time introduced to western parts (White Sea and Barents Sea) of Russia in 1956, in four rivers. The species spread rapidly, and in 1960 more than 76,000 individuals were recorded in 23 rivers within Russian territories. During the summer and spring periods of 1960, pink salmon were also caught over a large area of the North Atlantic. In Norway, the species was registered as far south as Jæren, and a total of 20-25 tonnes was caught in Norway, mainly in Finnmark.

Between 1961 and early 2000, there were only a few registered observations of pink salmon in Norway. Since then there has been a gradual increase, with most of the observations coming from Finnmark. In 2007-2008, the first registered spawning of pink salmon was recorded in River Jakobselv in East Finnmark.

By 2017, the species had spread further south into the Atlantic than had previously been recorded for this species. Pink salmon was found in large quantities all along the Norwegian coast, but also in large parts of continental Europe. Spawning individuals have been recorded in many rivers in eastern Finnmark, but whether these represent self-sustaining populations remains unknown. Because of this increase in migrating pink salmon, a registration scheme was initiated and a total of 6,170 pink salmon were caught and registered in 2017. An additional 5,285 individuals were recorded from direct observations and cameras in fish ladders during the same year.

Over the last few decades, there has been a significant increase in farming of Atlantic salmon (*Salmo salar*) outside the Kola Peninsula, and, based on this, a great concern is that migrating pink salmon may introduce parasites and infectious diseases from these farms to Norwegian territories, including aquaculture and populations of wild Atlantic salmon.

Pink salmon has a two-year life cycle, and the smolt migrate to sea shortly after hatching in the spring. Direct competition for food with Atlantic salmon and trout has thus not been expected. However, recent research from Russia suggests that the migrating smolt scavenge the riverbed for food on their way to the sea. It is therefore unclear which consequences an increased population of pink salmon will have on native species.

Pink salmon is assessed as having "high ecological risk" on the Norwegian Biodiversity Information Centre's list of alien species. Both in Norway and in other countries, several different methods (snorkeling, harpooning, and net fishing) have been tested in order to stop the pink salmon from migrating up the rivers, and thus prevent further spread and establishment. However, the efficiency of these methods as well as their impact on native species remain unknown.

Terms of reference as provided by the Norwegian Environment Agency and Norwegian Food Safety Authority

The Norwegian Environment Agency and the Norwegian Food Safety Authority requests the Norwegian Scientific Committee for Food and Environment to:

1) Identify potential hazards associated with increasing amounts of pink salmon (regardless of establishment) in Norwegian waters.

2) Identify areas and habitats that are best suited for, and thus most vulnerable to, spread and establishment of pink salmon

   a. under current climate conditions.
   b. during the next 50 years (given different scenarios for climate change).

3) Assess the consequences of spread, and potential establishment, of pink salmon in Norwegian rivers on

   a. biodiversity in Norway.
   b. aquaculture species (i.e., Atlantic salmon).
   c. productivity of native salmonid populations.

4) Assess the likelihood of pink salmon to

   a. regularly spread to Norwegian waters.
   b. establish self-sustaining populations in Norway.
   c. introduce pathogenic agents to wild and farmed fish in Norway.
   d. have other negative impacts on biodiversity in Norway (identified under ToR #1).

5) Characterize the risk of negative impact from spread, and potentially establishment, of pink salmon in Norway for

   a. biodiversity in Norway.
   b. aquaculture species (i.e., Atlantic salmon).
   c. productivity of native salmonid populations.

6) Assess various mitigation measures to prevent spread and establishment of pink salmon in Norway, including the risk of negative impacts on native species associated with these measures.

The Norwegian Environment Agency asks that the time frame for the risk assessment of adverse effects on biodiversity should be 50 years, or five generations for species with a generation time of more than 10 years. This is in accordance with the time perspective considered by the Norwegian Biodiversity Information Centre.

If there is data to suggest density-dependent factors, that is that the species only becomes a problem when it reaches a particular population size or density, this should be included in the assessment.

Biodiversity is defined as "ecosystem and species variability and intra-species genetic variability, and the ecological relationships between ecosystem components" (Section 3, letter c in the Nature Diversity Act). The species' ability to survive in Norwegian climate, the possible impact on ecosystems and other species, in addition to the risk associated with hitchhiking organisms, should be present as part of the risk assessment for adverse effects on biodiversity.

Known effects on ecosystem services should be mentioned in the report, even though this is not part of the risk assessment for biodiversity and aquaculture.

1 Introduction

1.1 Invasive fish species

1.1.1 Problems related to invasive non-native fish

The introduction of non-native species is generally considered one of the major threats to native biodiversity and ecosystem services (Rahel 2002; Pejchar and Mooney 2009). This is also the case for non-native fish. Introductions happen when species are moved outside of their natural distribution area by humans (Falk-Petersen et al. 2006). This may happen accidentally or with the purpose of establishing new populations. Purposeful introductions are commonly motivated by economy, subsistence, or recreation, and have occurred throughout human history (Williamson 1996; Olden et al. 2011). The most serious impact of species introductions is often associated with the ability of the introduced alien species to spread and establish in more localities than the original target release area(s). This so-called secondary spreading is perhaps the greatest challenge for management, because it becomes impossible to contain unwanted species that have a strong dispersal capacity.

There are some well-documented examples of invasion of non-native fish among salmonids, and some of these species have been spread over most of the world, such as brown trout (*Salmo trutta*) (MacCrimmon and Marshall 1968) and several Pacific salmon (*Oncorhynchus*) species (Crawford and Muir 2008). When established with viable populations, these species can migrate to new water bodies, resulting in secondary spread. The impacts of the establishment of non-native fish species on the recipient ecosystem are associated with predation, competition, hybridization, and transfer of disease agents.

1.1.2 Invasive fish in Norway

The Norwegian fauna of native freshwater fish includes 32 species. An additional 11 non-native fish species have established regularly reproducing populations (Hesthagen and Sandlund 2007) (see Appendix II). Most of the non-native species exist in few localities, and only tench (*Tinca tinca*) and brook trout (*Salvelinus fontinalis*) have established populations in more than 50 localities.

This may have changed with the 2017 invasion of pink salmon (*Oncorhynchus gorbuscha*), although the status of pink salmon in terms of established populations has been uncertain. Most non-native fish species are restricted to the southern part of the country, and it may be that the Norwegian climate is a challenge to many of the fish species imported from abroad (Hesthagen and Sandlund 2007). To date, pink salmon occur regularly and are most abundant in northern rivers, indicating that a cold climate is suitable for this species.

1.2 Biology and ecology of pink salmon

1.2.1 Taxonomy

Pink (or humpback) salmon (*Oncorhynchus gorbuscha,* Walbaum, 1792) is one of six species of so-called Pacific salmon in the genus *Oncorhynchus* within the Salmonidae family of fish (Scott and Crossman 1973, Radchenko et al. 2018). All *Oncorhynchus* species spawn in freshwater, and, in most populations, they migrate to sea as juveniles, where they feed and grow until they return to freshwater to spawn.

1.2.2 Morphology and coloration

Early in the summer, when pink salmon return from the ocean and are captured in sea fisheries or in the rivers, they are silver in colour (Figure 1.2.2-1) and typically 1.3 to 1.9 kg in weight (sizes of those reported caught in Norway have varied between 360 g and 4 kg). Like Atlantic salmon, brown trout, and Arctic charr, pink salmon have an adipose fin (a small fin on the back between the dorsal fin and the tail).

Figure 1.2.2-1: Pink salmon from early in the season. Photo: Håvard Vistnes

In appearance, pink salmon are closer to Arctic charr than Atlantic salmon and brown trout, primarily because the scales on the body are very small compared with those of Atlantic salmon and brown trout of the same size. Males and females appear relatively similar early in the season. One trait that distinguishes pink salmon from all native salmonids in Norway, is the long base of the anal fin. The large oval black spots on the tail of pink salmon are characteristic (Figure 1.2.2-2) and larger than the black spots that may be found on the tail of brown trout. The mouth of a pink salmon is white, but the gums and tongue are black (Figure 1.2.2-3), unlike those of Atlantic salmon, brown trout, and Arctic charr.

Figure 1.2.2-2: Tail fin of pink salmon with characteristic black spots. Photo: Håvard Vistnes.

Figure 1.2.2-3: The gums and tongue of pink salmon are black, unlike those of Atlantic salmon, Arctic charr, and brown trout. Photo: Håvard Vistnes.

Later in the summer, after entering the rivers, the males change colour, from brown to black on their back, with a bright white belly. The males start to develop a large hump on their back (hence the name humpback salmon, pukkellaks in Norwegian), and a hooked jaw called a kype (Figures 1.2.2-4 and 1.2.2-5). The male in the photo below, caught in the last part of July, has started to develop the hump and kype but is not fully developed for spawning (Figure 1.2.2-4).

Figure 1.2.2-4: Male pink salmon from summer (caught 24 July 2017). Morphological changes have started. Photo: Ola Ugedal

Figure 1.2.2-5: Pink salmon males caught in a river in mid-August, close to spawning. Photo: Daniel Tengs.

Females also change colour after entering the rivers and close to spawning, but, unlike the males, they do not develop a hump and kype. The females develop a bright white belly, and the rest of the body becomes olive green, with dusky bars or patches that can be lavender or dark gold (Figure 1.2.2-6).

Figure 1.2.2-6: Female pink salmon that has just spawned (August). Photo: Kim Andre S. Herstad

1.2.3 Life cycle

Pink salmon have a two-year life cycle. Fish that spawn in the autumn of odd years produce offspring that hatch in spring, leave the river and come back after one winter at sea to spawn in odd years, whereas the offspring of fish that spawn in even years, spawn in even years (Figure 1.2.3-1). This has resulted in the evolution of odd-year and even-year broodlines (Quinn 2005). The two broodlines are reproductively isolated from each other, but show limited genetic differences (Olsen et al. 1998; Churikov and Gharrett 2002; Hawkins et

al. 2002, Tarpey et al. 2018), not exceeding the general level of inter-population differences in salmonids (Althukov et al. 2000). However, following introduction of pink salmon into the Great Lakes, North America, some populations have established a three-year life cycle (Kwain and Lawrie 1981, Kwain 1987; Kennedy et al. 2005), which shows the ability of pink salmon to adapt its life history and ecology to local conditions.
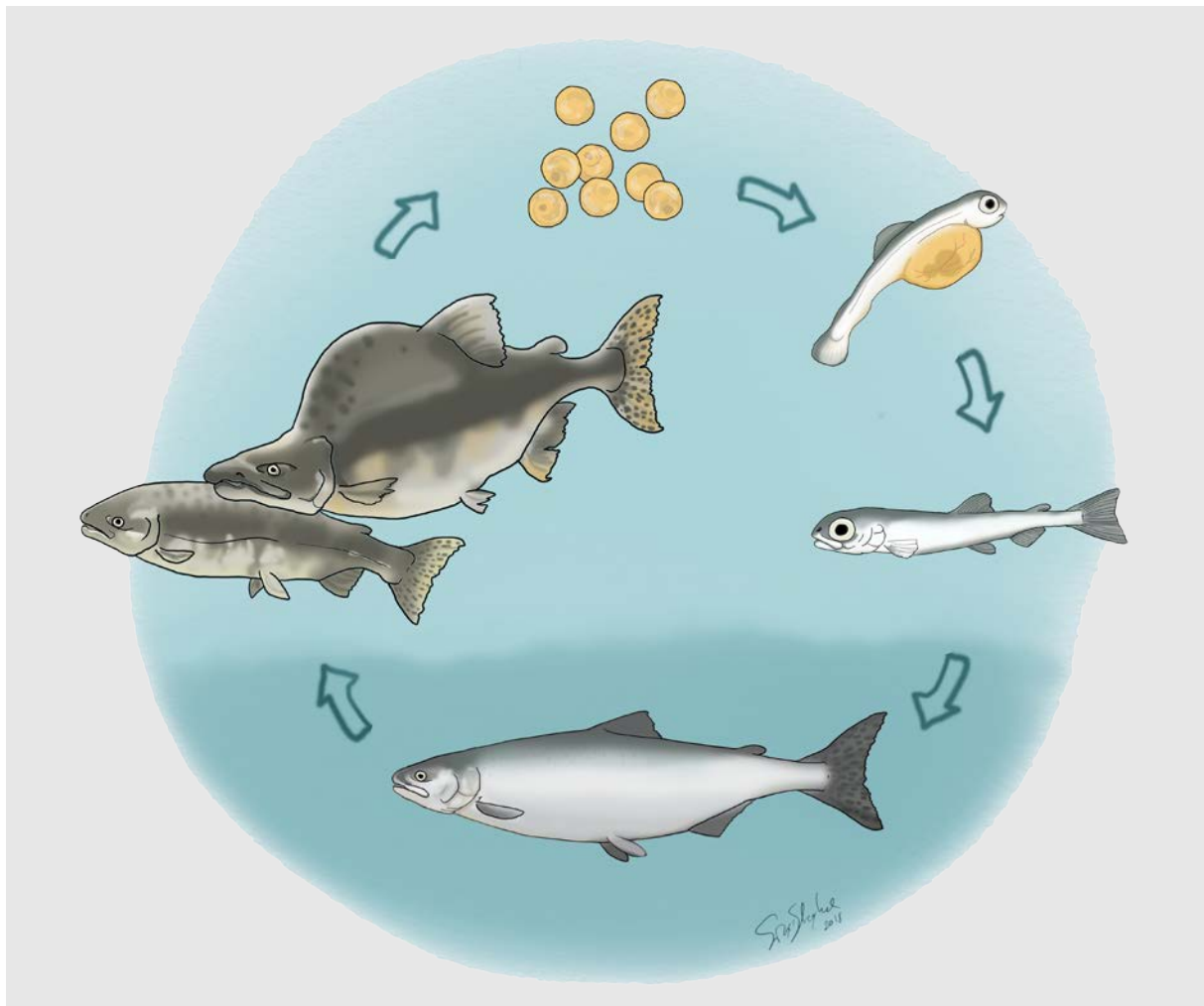
Figure 1.2.3-1: Life cycle of pink salmon. Drawing by Sigrid Skoglund, NINA.

In most rivers in the native range of pink salmon, both even-year and odd-year broodlines occur (Gordeeva and Salmenkova 2011). Overall, within the native range in the Pacific, it appears that the odd-year broodline is most abundant in southern areas, while the even-year broodline is most abundant in the north (Irvine et al. 2014), although this may change over time (Irvine and Fukuwaka 2011, Ruggerone and Irvine 2018).

Pink salmon is the species within the *Oncorhynchus* genus that spends the least part of their life cycle in freshwater. The adults enter the river in June – September, a few weeks before spawning, which occurs between mid-July and late October (Scott and Crossman 1973; Dyagilev and Markevich 1979; Heard 1991). The preferred spawning sites have coarse gravel with a flow through of well-aerated water, which is the same as that for Atlantic salmon

(*Salmo salar*) and anadromous brown trout (also termed sea trout, *S. trutta*). Both the main river and tributaries may be used for spawning, which commonly occurs in the lower 50 km of the rivers and may occur in the tidal zone (Heard 1991). In large rivers, spawning may be as much as hundreds of kilometres upstream (Ishida 1966; Basham and Gilbreath 1978; Chereshnev et al. 2002). In the River Tana, on the border between Norway and Finland, pink salmon have been caught more than 200 km from the sea (Niemelä et al. 2016).

Females dig nests (called redds) in the gravel in the riverbed and lay 1200–1900 eggs depending on her size (Heard 1991). Eggs are usually 6 mm in diameter (Figure 1.2.3-2) Pink salmon aggressively defend their spawning sites before, during, and for a few days, after spawning, before they die.

Figure 1.2.3-2: Pink salmon eggs in river. Photo: Tore Wiers

The fertilized eggs hatch into alevins (fish larvae) with large yolk sacs during winter or early spring depending on river temperature. The alevins spend some time in the gravel until the yolk sac has been absorbed, when they swim up and start external feeding as fry. Swim-up commonly occurs in March-May (Heard 1991; Quinn 2005). They are 30-32 mm long upon swim-up and already saltwater tolerant (Gallagher et al. 2013), and many migrate directly to sea. The time spent by pink salmon fry in freshwater before migrating to the sea, may be up to several weeks (Veselov et al. 2016; Robins et al. 2005). This likely depends on local

feeding conditions and on the distance from the spawning site to the estuary. The outmigrating life stage is called a smolt and smolt are typically 30-40 mm in length.

The smolt may spend a variable period in the estuaries, and even up to a few months in coastal waters, before moving to the ocean, where they stay for one winter before returning as adults (Heard 1991; Moore et al. 2016; Radchenko et al. 2018). Thus, within the two-year life cycle, the time spent in freshwater includes some weeks before and after spawning, egg incubation through the first winter, and some days or weeks after hatching and emergence.

1.2.4 Freshwater ecology

For the pink salmon fry, there is a rapid transition from nutrition based on yolk to feeding on small aquatic organisms. Small invertebrates (copepods and early instar chironomid larvae) may be eaten while some yolk remains (Veselov et al. 2016; Sandlund et al. 2019).

The importance of feeding in freshwater seems to vary between and within rivers. In some Alaskan rivers, Bayley (1975) found prey in only 4% of fry in the gravel and none in downstream-migrating fry. Other studies have also reported that pink salmon apparently eat little - or nothing - during seaward migration in short streams (Kazarnovskii 1962; Kobayashi 1968; Levanidov and Levanidova, 1957; Bailey et al., 1975). Pink salmon smolts in the Indera River on the Kola Peninsula started feeding during their seaward migration. Here, two size groups of smolts were found; smolts with normal size (84% had commenced feeding) and smolts with large size (100% had commenced feeding) (Veselov et al. 2016). The large-sized smolts had a large stomach fullness index, and fed on larger invertebrates (e.g., larvae and pupae of Chironomidae and Simuliidae) than they did at swim-up (Veselov et al. 2016).

Smolts are more likely to feed while migrating long distances in freshwater (Levanidov and Levanidova 1957; McDonald 1960; Veselov et al. 2016). They can also spend time in lakes during migration and feed there. For example, fry were observed to spend 1–3 months in Lake Aleknagik in Alaska, where they experienced growth rates similar to those recorded in near-shore marine waters (Rogers and Burgner, 1967; Robins et al. 2005). Such episodes, where fry grow during seaward migration through lakes, are not common because pink salmon rarely spawn above lakes (Robins et al. 2005).

Fry densities of 0.1 to 589 per square meter (average 250) have been observed in stream sections consistently favoured by spawning salmon (Bailey 1975). The survival of pink salmon fry depends on their growth rate and ability to escape from predators and detrimental environmental conditions. The availability of hiding space in the gravel, which depends on substrate quality, may also impact juvenile survival and densities. It is believed that swim-up and timing of seaward migration are synchronized among fry and adapted to coincide with algal blooms and food development in saltwater (Alexandersdottir and Mathisen 1983).

A major part of the juvenile downstream movement is nocturnal, and the degree of migration in daylight increases with travel distance (McDonald 1960). It seems that greater

turbidity, and the accompanying decrease in light, enhances movement during the day. The downstream migrants prefer the swiftest-flowing part of the river section and move downstream passively in the current, by actively swimming with the current, or by a combination of both (McDonald 1960).

In freshwater, the eggs and juveniles of pink salmon may be eaten by other salmonid fishes, as well as by sculpins, birds, and small mammals.

1.2.5 Marine ecology

In the estuary, pink salmon feed heavily on pelagic zooplankton (especially cladocerans, decapod zoeae, larvaceans, and invertebrate eggs), and less on benthic and intertidal forms (Bailey 1975; Kaczynski et al. 1973). The number of prey items consumed is temperature-dependent and can range from around 130 specimens per day per fish at 8.5 °C to 550 items per day at 12.8 °C (Bailey 1975). The prey size increases with increasing pink salmon size (Radchenko et al. 2018), and the growth rate in the estuary and first months at sea is extraordinarily high.

The diet in the open seas may be quite similar to the marine diet of Atlantic salmon, consisting of marine zooplankton, squid, and a variety of fish. Salmonid fish appear to be gape-limited, opportunistic predators (Dixon et al. 2017; Radchenko et al. 2018; Rikardsen and Dempson 2011) and the size of their prey increases as they grow. Pink salmon migrate long distances in the ocean and may be found throughout the Pacific Ocean north of 40 ºN. At sea, pink salmon are preyed upon by marine mammals, and, to a lesser extent, by larger fish (Scott and Crossman 1973).

During their return migration to the coastal areas and rivers, the fish become sexually mature and, at some point, cease feeding. Nevertheless, pink salmon can still be caught by anglers during and after the ascent into rivers.

1.2.6 Vector for nutrients

Pink salmon acquire more than 95% of their body mass at sea (Groot and Margolis 1991) and utilize all resources into maximizing their single reproduction. Consequently, pink salmon transport nutrients from the marine environment to inland spawning areas, where they die and release nutrients as the carcasses decompose. Alternatively, if the dying fish or carcasses are eaten by other animals, the nutrients enter aquatic or terrestrial ecosystems, depending on the predatory or scavenging animal.

1.2.7 Native distribution

Pink salmon has a wide native range in the northern Pacific (Figure 1.2.7-1). It previously occurred in rivers from the Sacramento River, California (38° N latitude) and Korea (37° N) in the south, to the northern tip of Alaska (71° N) and the river Lena in Siberia (73° N) in the

north (Heard 1991). However, the most abundant populations are found in the northern part of this area, from Alaska to Puget Sound (48° N) and from Siberia to southern Sakhalin (40° N) (Ruggerone and Irvine 2018). It appears that the number of populations and their abundance are decreasing in the south, while the northern distribution is expanding (Radchenko et al. 2018).

In most rivers in the native range, both odd- and even-year broodlines occur (Gordeeva and Salmenkova 2011). Overall, within the native range in the Pacific, the relative abundance of the two broodlines varies among regions (Irvine et al. 2014), although the odd-year broodline has generally been most abundant. Presently, the odd-year dominance seems to be increasing in the northern Pacific. The changes may be associated with climate change as well as large-scale stocking with hatchery produced fish (Irvine and Fukuwaka 2011; Ruggerone and Irvine 2018).

Figure 1.2.7-1 The native distribution of pink salmon shown by the coastline being marked orange. Source: Adapted from Augerot (2005). Illustration by Kari Sivertsen, NINA.

1.2.8 Introduction to Northwest Russia

The first introduction of pink salmon occurred in the Russian Barents region in 1956–1957. Fertilized eggs from the southern part of Sakhalin (48° N) on the Russian Pacific were transferred to local hatcheries in the White Sea drainage (64° N). In the spring of 1957, 3.5 million fry were released into rivers directly after their yolk sacs had been resorbed (Azbelev 1960; Azbelev et al. 1962; Bakshtansky 1970; Zubchenko et al. 2004). A similar operation was repeated with 6.2 million fry in 1957-1958. However, these two stocking events produced no recaptures of returning adult fish. Therefore, in the spring of 1959, the alevins were kept in hatcheries until they had commenced external feeding, and 15 million fry of the even-year broodline (expected to return for spawning in 1960) were released. In 1960, more

than 76,000 returning adults were caught in Russian waters (Zubchenko et al. 2004), and an estimated catch of 20-25 tonnes (approx. 13,000-17,000 fish) was recorded in Norwegian waters (Berg 1961, 1977; Rasmussen 1961). In most following years until 1979, a variable number of pink salmon fry originating in Sakhalin were stocked in White Sea rivers (Zubchenko et al. 2004; Gordeeva and Salmenkova 2011). There were abundant returns of adult fish in most odd years (i.e., of the odd-year broodline).

The aim of establishing permanent self-sustaining populations was not achieved during this period (Gordeeva et al. 2006), although reproduction was observed in Russian rivers in some years associated with North Atlantic warming (Karpevich et al. 1991). The stocking programme with eggs from Sakhalin was terminated in 1979, and it was assumed that the reason for not attaining natural reproduction was that the stocking material originated from rivers in a warmer climatic region (Gordeeva and Salmenkova 2011). The timing of spawning migration and spawning in salmonids are, to a large extent, inherited traits (McGregor et al. 1998, Carlson and Seamons 2008). It has therefore been suggested that the southern fish would probably spawn too late, resulting in disturbances in the early embryo development during cooling in early winter (Gordeeva and Salmenkova 2011). This might result in hatching at an unsuitable time in the spring (Markevich et al. 1978; Agapov 1986).

During 1960-1980, returning adult pink salmon were recorded over a large area, from the Kara Sea in the east, to Iceland, Scotland, England, and Denmark (Mills 1991). In 1961, pink salmon were recorded in the seas around Spitsbergen (approx. 77° N latitude; Berg 1977), and the species is now commonly observed in that area.

After a six-year break, stocking activity in Northwest Russia was resumed in 1985, when eggs of odd-year pink salmon were imported from the River Ola, Magadan oblast, at nearly 60° N latitude on the Russian Pacific. After hatching, fry were released in 1986, with adult fish returning in 1987. Import of eggs was repeated in 1989, with odd-year fry being released in early 1990. These introductions resulted in successful natural reproduction by odd-year pink salmon in White Sea rivers. Even-year eggs from the Magadan region were imported in 1986 and released in 1987, resulting in a single return in 1988, but apparently no natural reproduction. When the import of even-year eggs was repeated in 1998, and the fry released in 1999, it resulted in a catch of 8,100 adult fish in 2000, and a limited natural reproduction, with 1,100 adult fish caught in 2002. Low numbers of even-year fish were also caught in later years. Thus, the stocking programme based on broodstock from the Magadan region, which started in 1985 and ended in 1999, resulted in local self-reproducing populations in the White Sea area, with odd-year stocks being more abundant than even-year stocks. Consequently, all pink salmon caught after 2001 in the northeast Atlantic Ocean and Atlantic side of the Arctic Ocean including the Barents Sea, and in rivers draining into these areas, are due to reproduction in the wild.

Catches of odd-year adult pink salmon in Northwest Russia were usually below 100 tonnes before 2001 and have increased in recent years. For the period 2001-2017, mean annual catches of odd-year pink salmon in Russian waters were 220.5 tonnes (99.5-373.4 tonnes;

the highest amount in 2017, numbers from 2019 not available yet when this report was finalized). The mean weight of pink salmon in the White Sea rivers has increased from 1.3 to 1.9 kg over the last 11 years (A. Veselov, unpublished data). If we assume a mean weight of 1.5 kg, the mean odd-year catch in 2001-2017 corresponds to 147,000 fish per year, with a maximum of nearly 250,000 fish in 2017. The high variation in adult returns may be due to a sub-optimal environment in some years (Gordeeva and Salmenkova 2011).

Despite the substantial decline in catches of even-year fish since 2000, there is a variable, and small catch of even-year fish in Russian rivers (between 30 kg and 11 tonnes). There is also a small and regular even-year pink salmon occurrence in Norwegian rivers. This indicates that in these non-native stocks, the even-year broodline is less productive in the wild than the odd-year broodline. According to Gordeeva et al. (2015) and Gordeeva (2017), the reason may be that while the odd-year broodline was able to respond to the severe natural selection pressure in the new environment more quickly than the even-year fish.

1.2.9 Pink salmon in Norway

The successful return of adult fish from the Russian stocking of pink salmon fry in the spring of 1959 also resulted in the first record of pink salmon in Norway in 1960 (Berg 1977). This is possibly the most abundant return of even-year pink salmon ever recorded in Norwegian waters. Almost all subsequent peak years have been odd-year fish (Table 1.2.9-1). The geographical distribution of the 1960 catches indicates quite poor homing in this group of fish (see also Ogura and Ishida 1995). The Norwegian catch was 20-25 tonnes (Berg 1977), corresponding to approximately 13,000-17,000 fish, while that year's Russian catch was 76,300 fish (Zubchenko et al. 2004). Several spawning fish were observed in at least 15 rivers in Finnmark (around 69° N), and pink salmon were caught as far south as Bergen (60° N; Berg 1961). During 1960-1975, abundant returns to Russian waters were accompanied by relatively large catches and numerous observations in Norwegian waters (Berg 1977; Zubchenko et al. 2004, Sandlund et al. 2019).

Limited experiments on production of pink salmon in hatcheries in Norway were carried out between 1963 and 1975, with the intention of testing the species for net pen production (Berg 1977). We know of only one occasion of pink salmon stocking in Norway, in the River Søgneelva at 58 °N in 1976 (Anon. 1978), resulting in no known recaptures.

The large increase in pink salmon numbers in Norwegian rivers in 2017, and equally high numbers in 2019 (Table 1.2.9-1), is not due to released fish and must be the result of natural reproduction in rivers in Northwest Russia and likely, also from pink salmon spawning in rivers in eastern Finnmark (Sandlund et al. 2019). In 2017, pink salmon were registered in *c.* 200 salmon rivers in Norway, and in many other rivers in Europe (Figure 1.2.9-1). Moreover, pink salmon were caught as far away as Iceland, Greenland, and Newfoundland, Canada.

Table 1.2 9-1: Detailed observations on the occurrence of pink salmon events in Norway. Shaded lines indicate years when pink salmon were relatively abundant. After Sandlund et al. (2019) for the years 1960-2017. and with new information for the years 2018-2019 (Muladal 2018; Anon. 2019; Berntsen et al. 2019).

Year	Comment	Reference
1960	Catch: 20-25 tonnes, observed in 40 rivers, spawning in Northern Norway	Berg 1977
1961	Lower catch, spawning. Catches in Svalbard	Berg 1977
1962-64	Very low numbers (4-30 reported)	Berg 1977
1965	> 20 tonnes, abundant in eastern Finnmark. Svalbard	Berg 1977
1966-70	Very low numbers (0-30 reported)	Berg 1977
1971	20-25 tonnes, abundant in eastern Finnmark. Svalbard	Berg 1977
1972	Low numbers	Berg 1977
1973	> 25 tonnes, spawning observed south to Trøndelag (63 °N)	Berg 1977
	"huge numbers" in Tana	Niemelä et al. 2016
1974	Low numbers, spawning in eastern Finnmark	Berg 1977
1975	20-25 tonnes, obs. in many rivers eastern Finnmark	Berg 1977
	> 4.5 tonnes in Tana	Niemelä et al. 2016
1976	Low numbers, single indindividuals observed south to Mandal (58 °N)	Berg 1977
	> 500 kg in Tana	Niemelä et al. 2016
	Migrating fry in rivers in Finnmark	Bjerknes 1977, Bjerknes and Vaag 1980
1977	1.3 tonnes in Tana	Niemelä et al. 2016
1978-80	Low numbers in Tana (9-370 kg)	Niemelä et al. 2016
1981-82	Zero catches in Tana	Niemelä et al. 2016
1983-88	< 1,000 kg marine catches, no reports from rivers	Jensen et al. 2013
1989	> 2.5 tonnes marine catches, some in rivers	Jensen et al. 2013
1990	< 300 kg marine catches, a few in rivers	Jensen et al. 2013
1991	> 2.5 tonnes marine catches, > 500 kg in rivers	Jensen et al. 2013
	Highest catch since 1977 in Tana	Sandlund et al. 2019
1992	Lower than 1990	Jensen et al. 2013
	Very low in Tana	Sandlund et al. 2019
1993-99	Tana: 1993-99: relatively high in odd years, low in even years	Sandlund et al. 2019
2000-03	Tana: 2000-03: all years higher than 1999	Sandlund et al. 2019

2004	Tana: low	Sandlund et al. 2019
2005	Tana: high	
2006	Tana: low	
2007	Tana: high, Neiden: high	
2008-16	Tana and Neiden: low catches	Sandlund et al. 2019
2017	Very high catches in Tana, Neiden and the rest of Norway	Sandlund et al. 2019
2018	Low catches in entire Norway. Reports of total 30 pink salmon captured in 14 different rivers, and in addition 14 pink salmon recorded during snorkelling surveys in 16 rivers in Finnmark.	Anon. 2019; Muladal 2018
2019	High catches in Norway. Preliminary report indicates higher numbers of pink salmon in Finnmark and Troms than in 2017, and perhaps lower numbers in southern Norway although higher than any year before 2017. The full catch statistics were not available when this report was finalized.	Berntsen et al. 2019

In late 2019, a summary of the numbers of pink salmon seen by divers who counted wild Atlantic salmon and escaped farmed Atlantic salmon in a series of surveyed rivers in Finnmark, showed that about 4270 pink salmon were observed (Naturtjenester i Nord, unpublished results referred to by the County Governor of Troms and Finnmark). At the same time, about 1180 Atlantic salmon, 710 anadromous brown trout, and 240 anadromous Arctic charr were observed. These were observations made after the fishing season (It should be noted that such snapshot observations do not necessarily reflect the true relationship between the species' abundance in the rivers).
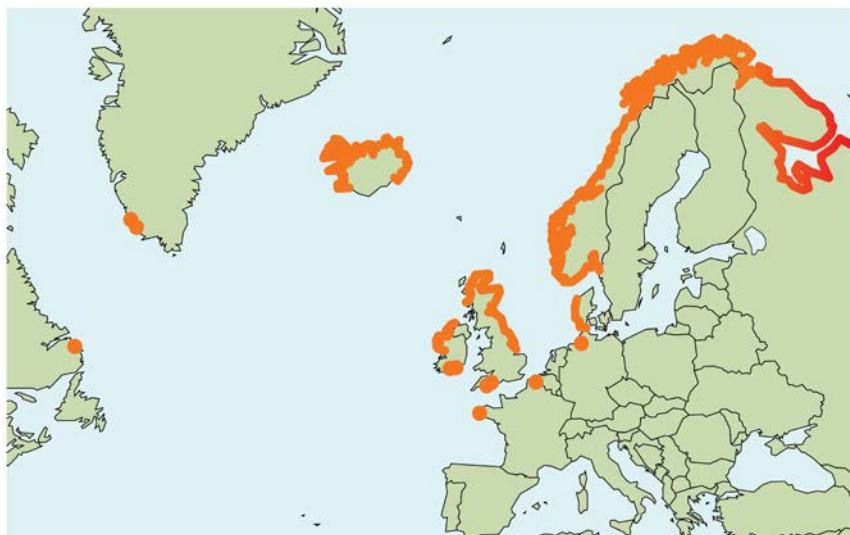
Figure 1.2.9-1 Distribution of pink salmon catches in Atlantic and Barents drainages in 2017. Red areas mark the main introduction area in Northwest Russia (White Sea and Barents Sea rivers), whereas orange colour marks catch along the North Atlantic coastline, as collated by Eva Thorstad (unpublished). Pink salmon were also caught on Spitsbergen Island by experimental trapping, north of the map area. Illustration by Kari Sivertsen, NINA.

In individual rivers, the highest recorded catches were reported from the large Tana river system in 2019 (Berntsen et al. 2019), as in previous years. Two small streams, River

Karpelva and River Klokkerelva in eastern Finnmark, each had more than 1300 pink salmon removed by traps and netting during the summer of 2019.

Official angling catch data in the rivers for 2019 are not yet available. In coastal fisheries in 2019 (bag nets and bend nets), 10.5 tonnes of pink salmon were reported caught (9.6 tonnes in Finnmark and 0.6 tonnes in Troms, with the most southernmost catch reported from Rogaland) (Statistics Norway https://www.ssb.no/jord-skog-jakt-og-fiskeri/artikler-og-publikasjoner/over-10-tonn-uonska-laks-fiska).

1.2.10   Influence of climate

Arctic ecology is always subject to strong influences by weather and climate fluctuations, and, with ongoing climate change, the whole system must be expected to change rapidly and somewhat unpredictably. Our climate data show that a large increase in sea-surface temperatures (SST) and decrease in ice cover are taking place, with observations during recent years moving further and further away from the historically normal range of variation (see Figures 1.2.10-1 to 1.2.10-3).

Climate effects in the oceanic part of the salmonid life cycle are likely to be mediated through direct effects of temperature on metabolism, growth and immune system, as well as indirect effects of temperature on food abundance, pathogen dynamics, and predator and competitor species. Together, these factors determine survival and reproductive potential. Climate also affects reproduction and survival during the freshwater phases. Water temperature and discharge may affect timing of spawning, hatching and emergence, growth, timing of migrations, physiological processes, food availability and impact of pathogens.
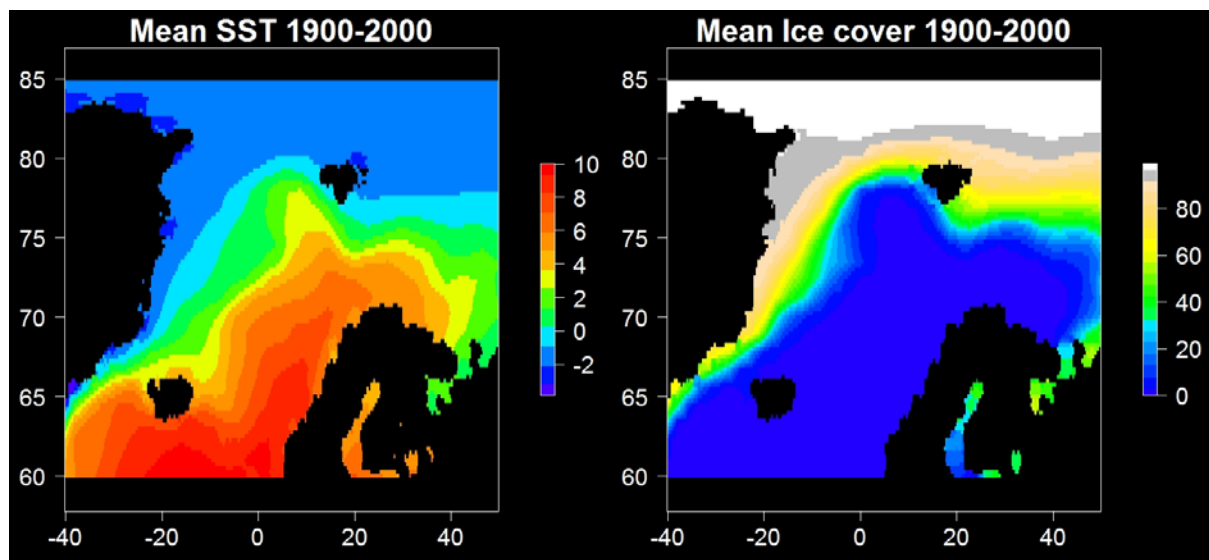
Figure 1.2.10-1: Mean sea surface temperature (SST, left panel) and ice cover (right panel) in the North Atlantic Ocean during 1900-2000. The Greenland coast effectively forms a western border of the data, which are otherwise bounded by the Scandinavian Peninsula and 45 degrees longitude to the east. Iceland (lower left) and Svalbard (upper right) are visible as islands (see Glossary).
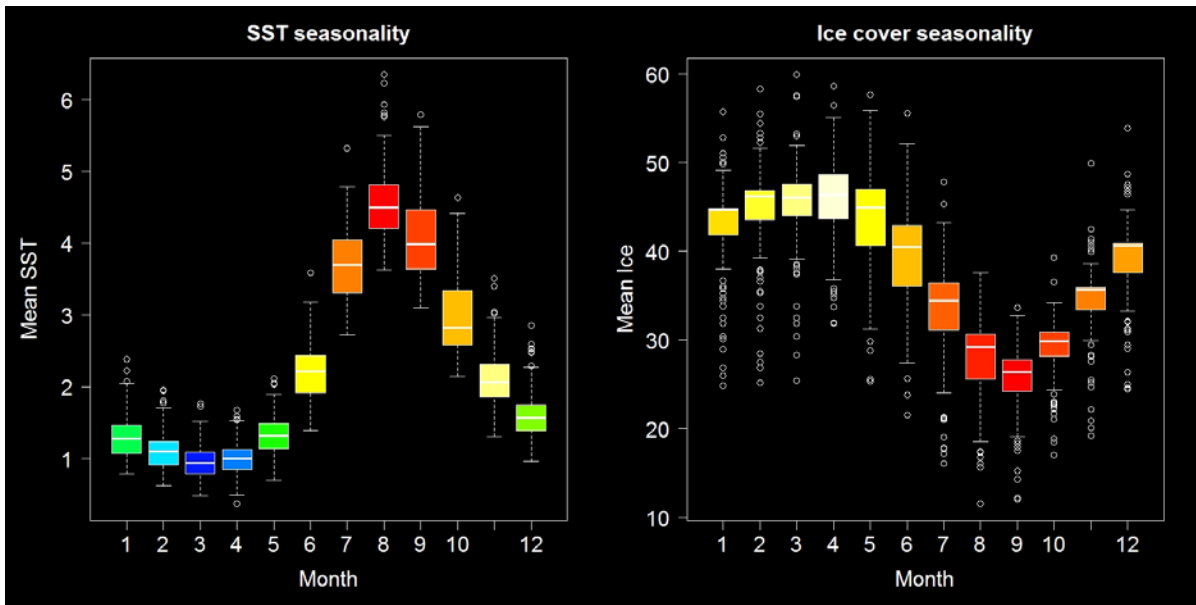
Figure 1.2.10-2: Seasonality in sea surface temperature (SST) given as °C and ice cover given as % of the area in the data area (see Figure 1.2.10-1). Sea surface temperatures tend to be below freezing for large parts of the year until summer thaw reduces average ice cover to just above 40% in July. The coloured boxes represent 50% of observations, with the dividing line marking the median value. Lines stretch out to whiskers extending up to 1.5 times the interquartile range from the box to the furthest data point within that distance. Outliers beyond that are represented individually as points.
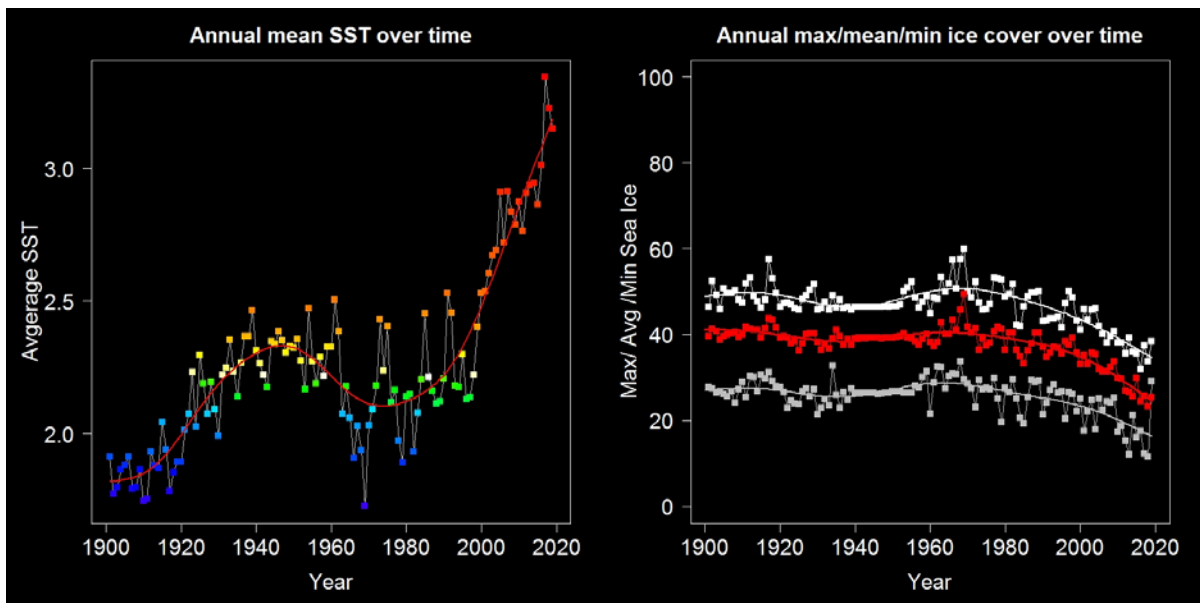
Figure 1.2.10-3: Temporal trends in sea surface temperature (SST) given as °C and ice cover given as % of the area in the data area (see Figure 1.2.10-1). Some ice-cover data are lacking for the 1940s, but coverage is good for our data period, as well as back to the year 1900. Note, the fast increase in SST (left), and the corresponding decrease in ice cover (right), for maximum, minimum, and average annual ice cover.

1.2.11   Previous risk assessments of pink salmon

Pink salmon were evaluated by The Norwegian Biodiversity Information Centre in 2018 and categorized as a species of "high risk" regarding the potential for negative impacts on biodiversity in Norway (Artsdatabanken 2018). This categorization was primarily based on the potential of pink salmon for rapid spreading and establishing distant populations.

The Norwegian Scientific Advisory Committee for Atlantic Salmon Management (Vitenskapelig råd for lakseforvaltning) assessed the threats from pink salmon to Atlantic salmon in their annual evaluation of threats to Norwegian Atlantic salmon (Anon. 2019). They concluded that escaped farmed salmon, salmon lice (*Lepeophtheirus salmonis*), and infections related to salmon farming are the greatest anthropogenic threats to Norwegian wild salmon. They further concluded that hydropower production, other habitat alterations, and introduced pink salmon are also major threats to wild salmon. They emphasized that, for pink salmon, the knowledge of the magnitude of impact and future development is poor.

Pink salmon was assessed in 2017 by Gordon Copp at the Centre for Environment, Fisheries & Aquaculture Science (Cefas), using the Great Britain Non-native Species Rapid Risk Assessment (GB-NRRA) methodology (Copp 2017). Using Great Britain as the assessment area, it was assessed that entry and establishment were very likely (with high confidence), and that the potential for spread was high (also with high confidence). The overall estimated severity of impact was assessed as moderate (with low confidence). In sum, pink salmon was assessed to pose a high risk, with medium confidence, in terms of negative impact on biodiversity in Great Britain. The assessment states that "based on the available information, it is impossible to estimate the magnitude and extent of any impacts".

The conclusion of a recent full risk assessment for the GB-NRRA, led by Ian Cowx (Cowx 2018), is that the risk is moderate with medium confidence. Here it was commented that "Information is lacking on the species' impacts and/or interactions with native salmonids.", and "The greatest concern is that if future invading pink salmon spawn later in the year then the current assessment would require a drastic re-evaluation, since this might result in a spring emigration of pink salmon, which would increase the chances of subsequent survival at sea and increased likelihood of populations becoming established."

The Fish Invasiveness Screening Kit (FISK) has been used several times in different assessment areas around the world to evaluate the invasiveness of pink salmon (Vilizzi et al. 2019). These screenings categorize the invasive potential of pink salmon to be "moderate" to "high".

In sum, previous risk assessments and risk-ranking procedures suggest that pink salmon poses a high risk to native biodiversity and highlight the invasion potential of the species. However, assessing the magnitude of impact with strong confidence seems difficult, as long-term studies on the effects of pink salmon in European environments are lacking.

2 Methodology and data

2.1 Methodology for risk assessment

We have used a semi-quantitative risk assessment approach. The overall risk is the product of the magnitude of the consequences of the event and the likelihood that the event will occur, as judged by the project-group experts.

The resulting risks are presented in figures such as that of Figure 2.1-1.
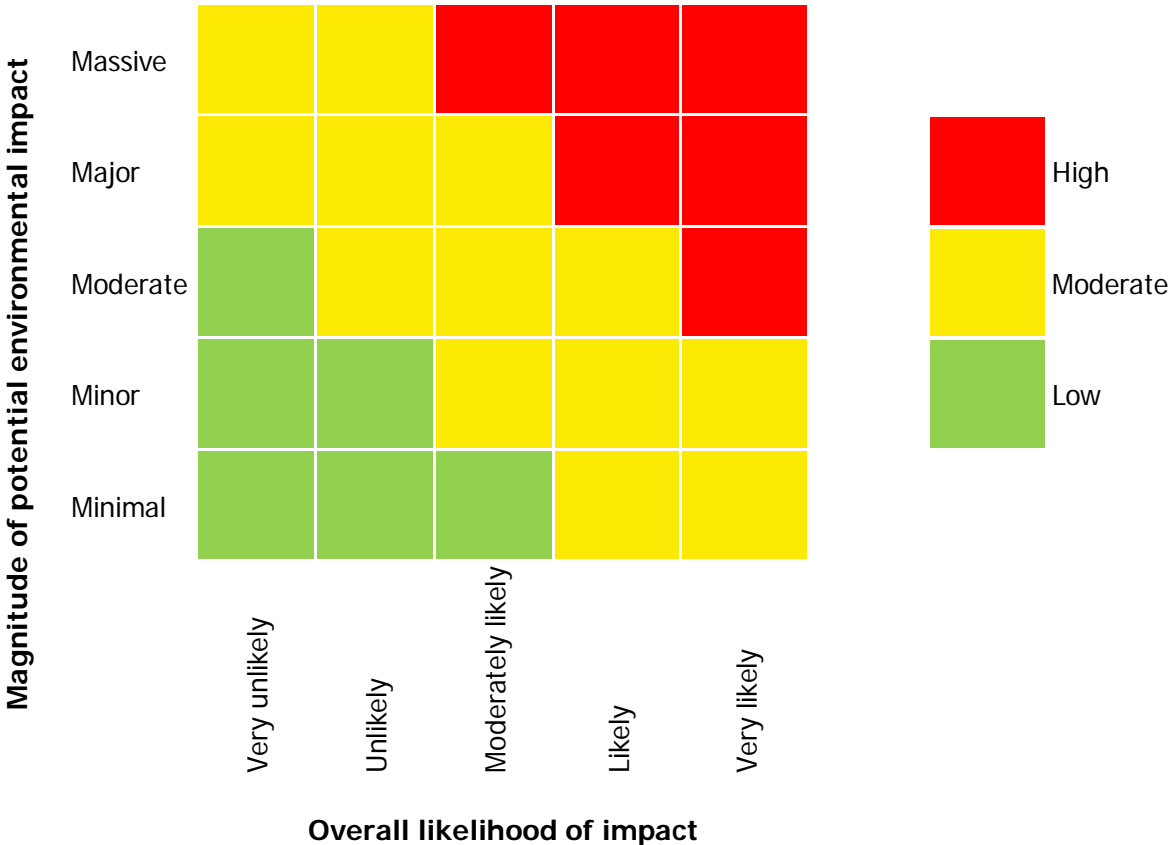
Figure 2.1-1: The conclusion of the risk assessments (low, moderate, or high) is based on the overall likelihood of the impact and the magnitude of the potential consequences of that impact on Norwegian biodiversity.

In order to provide clear justification of why a rating is given in the risk assessment, the project group used ratings and adapted versions of the descriptors from Appendix E in (EFSA Panel on Plant Health (PLH) 2015). A description of the ratings used can be found in Tables 2.1-1–2.1-3 below.

Table 2.1-1 Ratings used for the assessment of the magnitude of the impact.

Rating	Descriptors
Minimal	No known impact on local biodiversity
Minor	Potential impact on local biodiversity, but only occasional deaths of individuals
Moderate	Impact may cause moderate reduction in viability and adaptability of native populations
Major	Impact may cause severe reductions in local populations with consequences for local biodiversity and ecosystem functions and services
Massive	Impact may cause severe reductions in local biodiversity (local extinctions), with severe consequences for ecosystem functions and services

Table 2.1-2 Ratings used for the likelihood of impact.

Rating	Descriptors
Very unlikely	Negative consequences would be expected to occur with a likelihood of 0-5%
Unlikely	Negative consequences would be expected to occur with a likelihood of 5-10%
Moderately likely	Negative consequences would be expected to occur with a likelihood of 10-50%
Likely	Negative consequences would be expected to occur with a likelihood of 50-75%
Very likely	Negative consequences would be expected to occur with a likelihood of 75-100%

Table 2.1-3 Ratings used for describing the level of confidence.

Rating	Descriptors
Very low	There are no published data on the topic. Only expert judgement used.
Low	Available information on the topic is limited, and mostly expert judgements are used.
Medium	Some published information exists on the topic, but expert judgements are still used.
High	There is sufficient published information, and expert judgements are in concurrence.
Very high	The topic is very well debated in peer-reviewed journals, and international reports. Expert judgements are in concurrence.

2.2 Literature search

This report owes a lot to the work by Niemelä et al. (2016), who described the status of pink salmon in northwestern Russia and how they spread to watercourses in northern Finland and Norway. Sandlund et al. (2019) built on this and included detailed information on the 2017 invasion of pink salmon in Norway and elsewhere in Europe (Sandlund et al. 2019).

Both publications relied on extensive collaboration with scientists from Russia, who contributed with their expertise and experience on the ecology and fisheries of pink salmon in northwestern Russia. This contact has also resulted in the Russian literature being available, which would otherwise not have been accessible to us.

Ecological effects of pink salmon were also searched for in the scientific literature (Google Scholar and Web of Science) using relevant search terms: pink salmon AND effects OR impact OR influence AND terrestrial ecosystems OR ocean ecosystems OR river ecosystems

OR estuary AND/OR feeding behaviour OR prey OR vegetation OR predators OR water quality. The literature cited in the papers and its citations were also searched.

A formal literature search was carried out by the Norwegian Institute of Public Health. The searches were specifically targeted for various pathogens, i.e., bacteria, viruses, and parasites. These searches (described in Appendix Ia, Ib, and Ic) returned 18 relevant articles about bacterial pathogens, 7 articles on viral pathogens, and 134 articles on parasites in relation to pink salmon. All articles were screened and their relevance to the terms of reference was considered.

2.3 Other literature

The 2017 invasion of pink salmon in Europe led to several international meetings during the following months. A meeting between Norwegian and Russian scientists was organized by the County Governor of Finnmark and held in Pasvik, Norway, in February 2018. This meeting provided exchange of information that is not readily available in international publications or in the written literature. Reports from the talks and presentations given at the meeting can be found at https://www.fylkesmannen.no/troms-finnmark/miljo-klima/internasjonalt-samarbeid/pukkellaks-i-finnmark/.

In September 2017, a European meeting took place in Edinburgh, Scotland. At this meeting, reports of the 2017 pink-salmon invasion were given by representatives from several European countries. Moreover, video recordings of upstream swimming and spawning behaviour and preliminary data from excavations of redds were presented, and contacts established with several European researchers.

Apart from the recent literature assessed during the above meetings, we searched for grey literature in Norway. Finally, we used several books on salmon ecology (Scott and Crossman 1973, Radchenko et al. 2018, Quinn 2005, Hendry and Stearns 2003, Groot and Margolis 1991).

2.4 Data and models

Two modelling projects were carried out by members of the expert group during the work for this report. The first model forms a test of hypotheses put forward by Russian scientists that climate change related to sea-surface temperatures (SST) plays an important role in determining the survival and return rate of a pink-salmon year class. The rationale for this hypothesis is that pink salmon from the Sakhalin Island were not successful in establishing self-sustaining populations in northwestern Russia, whereas the 1985 year-class of pink salmon from the Magadan oblast was successful and (for odd-year transplants) eventually seems to have adapted to the environmental conditions of the Barents- and White Sea drainages (Gordeeva and Salmenkova 2011). We thus tested whether there was a detectable climate influence on the annual abundance of adult pink salmon, using SST and sea ice data, as this is an important aspect of a risk assessment in a warming climate.

The second model is a preliminary analysis of characteristics of the rivers that are associated with high catches of pink salmon. Our approach was based on models for river characteristics that have been developed to explain why escaped farmed salmon are more numerous in some rivers than in others (Hindar et al. 2018; Diserud et al. 2019a; 2019b). The rationale was that pink salmon are essentially homeless in rivers in Norway, and that they may end up in the same rivers that attract escaped farmed salmon. The dependent variable is catches of pink salmon by rod or by other methods in each river in 2017 and 2019 (Berntsen et al. 2019).

The explanatory variables tested were water discharge, number of Atlantic salmon caught (2006-2018), spawning target (number and kg of females necessary to fulfill each river's carrying capacity), distance of the river mouth from the Russian border (i.e., Grense Jakobselv), distance of the river mouth from the coastline (a line drawn between islands and mainland on the outer coast, termed 'grunnlinje' in Norwegian), river wetted area, degree of hydropower regulation, and proportion and number of escaped farmed salmon in the catches.

The 2019-data are still preliminary and both the estimates and deductions from using them must be treated with caution. Apart from the preliminary data assembled from Norwegian rivers by Berntsen et al. (2019), we have received preliminary data from Finland 2019 from Natural Resources Institute Finland (unpublished data) for the Finnish stretches of the border rivers Tana/Teno and Neiden/Näätämö). Official numbers of pink salmon caught in 2019 will not be available until early 2020.

2.4.1 Data used in modelling

Temporal data on the catches of pink salmon in River Tana and River Neiden in Norway/Finland were collated from Niemelä et al. (2016) and Berntsen et al. (2019). The data starts in 1974 for Tana and 2007 for Neiden.

Temporal catches and fry imports/release from northwestern Russia 1960-2003 were collated from Zubchenko et al. (2004) by Niemelä et al. (2016) and Russian information given to ICES WGNAS and in the Nor-Rus meeting in Pasvik.

Appendix III is based on Niemelä et al. (2016), Henrik Berntsen (report to Environment Agency October 2019), ICES (2013 and 2018), and Russian figures presented at the workshop on pink salmon in Pasvik, February 2018.

The central data column is collated by Sandlund et al. (2019), given a qualitative score of 0, 1 or 2 denoting little to no returning pink salmon, moderately many, and peak year respectively. The classification starts in 1959 and is tentative for 2019 at the time of writing.

2.4.2 Climate data

The climate data used in the modelling were provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). These include monthly data of SST and sea-ice concentration (SIC). For the period 1979-present (the satellite era), we downloaded ERA5 reanalysis data for the area of interest. The data cover the Earth on a ~30km grid. For the period 1900-1978, we used the ERA20C reanalysis on a 125 km grid, which was produced with the Integrated Forecast System of the ECMWF. SIC and SST data from the pre-satellite era are subject to great uncertainty. For convenience, the ERA20C data were interpolated to the ERA5 grid.

Further details on the data applied can be found at
https://www.ecmwf.int/en/forecasts/datasets/browse-reanalysis-datasets

3 Potential hazards to biodiversity and native salmonids

3.1 Changes in the ecosystems

3.1.1 River ecosystems

3.1.1.1 HAZARD IDENTIFICATION

Information about effects from pink salmon on the invertebrate fauna and food web in rivers is generally lacking. The invertebrate fauna is negatively affected if large numbers of pink salmon use it as food source. This depends on the duration of the period that fry spend in freshwater after their yolk sac has been resorbed and external feeding has commenced. Time spent in the river depends on the migration distance, speed of the current, and potential migration through lakes (Robins et al. 2005; Veselov et al. 2016). Active swimming only increases the migration speed by about 0.032 m/s since the expected swimming speed is about 1 body length/s (Ware 1978). Thus, it is likely that pink-salmon fry feed more in long rivers during their seaward migration, suggesting more negative effects on the invertebrate fauna, on native salmonids, and on birds like the white-throated dipper (*Cinclus cinclus*).

Pink salmon cannot replace juvenile Atlantic salmon or brown trout as hosts for the parasitic larvae stage (glochidia) of the freshwater pearl mussel (*Margaritifera margaritifera*), which is a Red-Listed species. Thus, establishment of pink salmon at the expense of native salmonids could weaken recruitment and, in a long term, reduce local freshwater pearl mussel populations (Veselov and Zyuganov 2016).

As invertebrates perform important ecosystem functions, such as filtering of water, litter breakdown, and nutrient spiralling, negative effects on the invertebrate fauna can have profound impacts on the ecosystem (Ferreira et al. 2006).

In a preliminary survey from the rivers Ekso and Jølstra in Norway, pink salmon fry had eaten chironomid larvae, and copepods were also present in the stomachs from Jølstra (Sandlund et al. 2019).

The river ecosystem is also influenced by pink salmon due to invertebrates, fish (juvenile salmonids, sculpins), birds, and small mammals preying on pink salmon eggs and fry (Rasputina et al. 2016). Moreover, rotting carcasses of pink salmon in the river after spawning may affect both aquatic and terrestrial ecosystems.

3.1.1.2 HAZARD CHARACTERIZATION

Biodiversity will be negatively affected if the establishment of pink salmon causes a decline, or even extirpation, of local populations of native salmonids or invertebrates.

The project group assesses that the potential negative consequences on biodiversity in the river ecosystems are:

For streams where the freshwater pearl mussel is present: **Major** with **medium confidence.**

For streams with low densities of pink salmon: **minor** with **medium confidence**.

For streams with moderate densities of pink salmon: **moderate** with **medium confidence**.

3.1.1.3 LIKELIHOOD

Food webs in the river ecosystem are potentially affected by cascading effects caused by eutrophication, interactions with native salmonids, and predation of invertebrates. In addition, pink salmon may replace the obligate hosts for the freshwater pearl mussel (i.e., juvenile Atlantic salmon and/or brown trout), thereby causing a decline, or even extirpation, of mussel populations. Overall, the project group assesses that it is **likely**, with **medium confidence,** that pink salmon will alter food webs in river ecosystems.

3.1.1.4 RISK CHARACTERIZATION

In terms of risk characterization, the project group concluded that the risk of negative impacts on biodiversity in terms of changes to the river ecosystems are:

- **High** for streams where the freshwater pearl mussel is present
- **Moderate** (bordering low) for streams with low densities of pink salmon
- **Moderate** (bordering high) for streams with high densities of pink salmon

The overall **confidence** is **medium** for these risk characterizations.

3.1.2 Water quality

3.1.2.1 HAZARD IDENTIFICATION

The nutrient release from rotting salmon carcasses in rivers can be significant. For example, spawning sockeye transported more than 2 million kg of organic matter and 5000 kg of phosphorus annually to the Karluk Lake system in Alaska (Juday et al. 1932). Phosphorus is the key nutrient that limits primary production in pristine rivers, where natural concentrations of phosphorus can be below detection level (tot-P about 1 µg/l) (Dodds and Whiles 2010). A sudden increase in nutrients can lead to increased growth and change in the

species composition and diversity of plants, algae, and cyanobacteria (Correll 1998, Veraart et al. 2008). The input of nutrients from carcasses can also cause a five-fold increase in biomass and abundance of macroinvertebrates, causing juvenile fish to grow faster (Mclennan et al. 2019; Naiman et al. 2002). Such processes are especially important in nutrient-poor systems, while carcasses may have little effect on primary production (chlorophyll *a*) in nutrient-rich streams (Rand et al. 2011; Guyette et al. 2014). Juvenile salmonids can also consume eggs or carcass flesh from spawners (Naiman et al. 2002).

Carcasses that are flushed to the estuary can provide food for marine animals, such as crabs, sculpins, cod, and other marine fishes. The density and diversity of birds in estuaries and along streams in the North Pacific Rim are positively related to the spawning salmon biomass (Christie and Reimchen 2008; Field and Reynolds 2011).

Salmon also gather organic contaminants and heavy metals from a wide area in the ocean and concentrate these in a restricted area in the river where they accumulate (Ewald et al. 1998). However, the concentration of contaminants is low in pelagic fish in the northern Atlantic Ocean, such as cod and Atlantic salmon (https://sjomatdata.hi.no/#/seafood). This suggests a similarly low concentration of contaminants in pink salmon.

3.1.2.2 HAZARD CHARACTERIZATION

If phosphorus (tot-P) makes up 0.5% of the body mass (Gende et al. 2002), 1000 fish with an average weight of 2 kg will add 10 kg of tot-P to a river. In nutrient-poor rivers (oligotrophic) with a moderate to high discharge (>50 m^3/s), a low addition of nutrients and organic matter will increase the productivity with few, if any, negative effects for the river ecosystem (see conceptual model of freshwater eutrophication in Correll 1998, p. 262). However, the species composition of algae may still change (Veraart et al. 2008). We can also expect a subsidy-stress relationship between nutrients and invertebrate taxon richness, and community biomass, where the richness and biomass increase as a response to low to moderate levels of nutrient enrichment, but decrease at high levels of nutrient enrichment (King et al. 2007; Ouyang et al. 2018). Water quality will deteriorate at high densities of pink salmon carcasses, and especially in rivers with an intermediate (mesotrophic) or high (eutrophic) nutrient content. Mesotrophic and eutrophic rivers are typically situated in areas with agriculture and receive nutrient-rich runoff that includes fertilizers and soils. Effects on the nutrient status of rivers caused by pink salmon carcasses will vary according to:

1) The density of pink salmon, with higher densities causing nutrient pollution and a higher risk of negative effects.
2) The current nutrient status of the site, including the types of nutrient that currently limit the primary productivity of algae and macrophytes at the site.
3) The river water discharge, where effects will be less distinct in rivers with a high discharge. Here, nutrients are transported from the source, and diluted and distributed over a large area downstream. The nutrients are likely flushed to sea in short rivers with a high discharge.

4) Morphological characteristics, such as river length, gradient, the presence of lakes and large pools, content of particles, light regimes, and local climates (Faafeng et al. 1990). Effects will be most distinct in long rivers with a low discharge.

5) The food chain of the ecosystem. For example, if there are large numbers of fish (including pink salmon fry) that feed on invertebrates, the number of grazers will decrease. This may result in a higher algal biomass.

6) Expected climate change, where increased run-off, warmer temperatures, and longer growing season (Hanssen-Bauer et al. 2015, Karlsson et al. 2009), will reinforce the negative consequences of man-made eutrophication and make it more difficult to improve the water quality (Moss et al. 2011).

7) The number of consecutive years with pink salmon spawners, where longer periods imply more distinct effects.

In sum, predictions on the potential effects on water quality from an introduction of pink salmon should be based on scenarios with all the above-mentioned factors. We have given some simplified scenarios of effects based on water discharge, water nutrient content, and density of pink salmon (Table 3.1.2.2-1). The **confidences** are **low**, because there are many uncertainties when the scenarios are simplified.

Table 3.1.2.2-1: Summary of effects as a function of density of pink salmon spawners, water discharge (m³/s), and trophic state: oligotrophic streams have ca 5 µg, mesotrophic streams ca 20 µg phosphorous/ l. All confidences are low.

Stream type	Water discharge 10 m³/s		Water discharge 50 m³/s	
Spawning fish	Low density	High density	Low density	High density
Oligotrophic	Minor	Major	Minimal	Moderate
Mesotrophic	Moderate	Massve	Minor	Major

3.1.2.3 LIKELIHOOD

Nutrient release from pink salmon carcasses may potentially lead to eutrophication and reduced water quality. The project group assesses that all scenarios of consequences given in Table 3.1.2.2-1 are **likely**, with **medium confidence**.

3.1.2.4 RISK CHARACTERIZATION

The overall risk of negative effects on biodiversity stemming from reduced water quality caused by pink salmon quality is summarized in Table 3.1.2.4-1.

Table 3.1.2.4-1 Risk characterization with regards to water quality reduction.

Stream type	Streamflow 10 m³/s		Streamflow 50 m³/s	
Spawning fish	Low density	high density	Low density	High density
Oligotrophic	Moderate	High	Moderate	Moderate
Mesotrophic	Moderate	High	Moderate	High

The overall **confidence** in this risk characterization is **medium to low**.

3.1.3 In marine ecosystems

3.1.3.1 HAZARD IDENTIFICATION

The identified hazards in the marine ecosystems are: (1) the top-down and bottom-up trophic cascade effects mediated by predation by large abundances of pink salmon, and (2) potential impacts of carcasses of adults flushed into the local estuarine ecosystem. Cascade effects may occur throughout the marine ecosystem, from the fjord to the open ocean.

Trophic cascades due to pink salmon have been observed in the Pacific Ocean. For example, in the North Pacific Ocean and Bering Sea, climate change was associated with growth of many wild Pacific salmon stocks in the 1980s and 1990s. Competition among salmon for prey in the sea resulted in reduced growth and survival, in addition to delayed maturation (Debertin et al. 2016). Due to the characteristic biennial life cycle of pink salmon, scientists have demonstrated that years with large abundances of pink salmon correspond with years with low abundance of their prey and decreased growth and survival of other salmon species (Bugaev et al. 2001; Ruggerone et al. 2003; Ruggerone and Connors 2015), indicating a density-dependent competition where abundance of pink salmon is an important factor in the marine ecosystem. Another example is that the predation pressure from Kamchatka pink salmon resulted in a trophic cascade in the Bering Sea, where pink salmon were feeding on large copepods, and the copepods were feeding on large diatoms. During odd years, when the abundance of pink salmon was high, the abundance of large copepods was low, and the abundance of large diatoms high (Batten and Ruggerone 2018). The opposite pattern occurred during even years. Such trophic effects can reduce the abundance of key prey species for whales and, consequently, have a negative influence on the birth and survival of whales (Ruggerone et al. 2019).

The great abundance of pink salmon in the Bering Sea during odd years may also negatively influence the body mass and liver mass of seabirds (Springer and van Vliet 2014). Here, pink salmon consume enough food in a period that overlaps with the seabirds' breeding season to have a negative influence on the breeding success of birds, such as kittiwakes (*Rissa* spp.) and puffins (*Fratercula* spp.). The scale of ecosystem impacts linked to pink salmon is also exemplified by short-tailed shearwaters (*Ardenna tenuirostris)*, which are common seabirds that migrate annually between the South and North Pacific Ocean. Their food sources overlap with pink salmon in the north, and the impact of competition influences the frequency and magnitude of mass mortalities of shearwaters in the south (Springer et al. 2018).

The average number of prey consumed per pink salmon per day in estuaries has been measured (see section 1.2.5), suggesting that the carrying capacity of an estuary can be estimated if the density of potential prey is known. Large numbers of pink salmon juveniles will likely have negative consequences on food webs in an estuary due to their high consumption rate.

Carcasses of adults that are flushed from rivers can provide energy to the food web in the estuary. We know little about this impact, but shallow coastal systems exhibit increased algal growth in response to nutrient enrichment (Kinney and Roman 1998).

3.1.3.2 HAZARD CHARACTERIZATION

Data concerning effects on marine food webs in the North Atlantic region are scarce, but considerable information is available on the effects from pink salmon in the North Pacific Ocean and Bering Sea. It should be noted that the abundance of pink salmon can be very high along the North Pacific Rim. Information on effects should probably only be extrapolated from the North Pacific Rim to the North Atlantic region when the densities of pink salmon in the regions are similar.

In sum, the project group assesses that the potential negative consequences for biodiversity in the marine ecosystems are **moderate**, with **low confidence.**

3.1.3.3 LIKELIHOOD

It is unknown whether pink salmon will impact marine ecosystems in the North Atlantic Ocean, Barents Sea, and White Sea. Given that effects in the North Pacific region are density-dependent, impacts on marine ecosystems in the North Atlantic region probably also depend on densities of pink salmon.

Overall, the project group assesses that it is **likely**, with **low confidence,** that pink salmon will alter marine food webs. Such alterations are likely to require an abundant stock of pink salmon in the North Atlantic Ocean and Barents Sea.

3.1.3.4 RISK CHARACTERIZATION

Regarding effects on the marine ecosystems, the project group finds that over all there is a **moderate** (bordering to high) risk associated with increased amounts of pink salmon. This is assessed with **low confidence**.

3.1.4 In terrestrial ecosystems

3.1.4.1 HAZARD IDENTIFICATION

Adult pink salmon is a keystone species in many coastal terrestrial ecosystems along the North Pacific Rim (Willson and Halupka 1995). Here, many species are adapted to, and dependent on, its presence (Scott et al. 2002). Pink salmon are important food for grizzly bear (*Ursus arctos*), whereas wolf (*Canis lupus*), North American river otter (*Lontra canadensis*), great blue heron (*Ardea herodias*), and bald eagle (*Haliaeetus leucocephalus*) will occasionally eat fish. In Norway, Eurasian otter (*Lutra lutra*) can be an important predator on Atlantic salmon and will eat both juvenile and adult fish (Carss et al. 2006).

Otters also feed on other fish species, and their feeding behaviour is related to the availability of prey (Carss et al. 2006), suggesting it is an opportunistic predator that will benefit from pink salmon. The diet of non-native mink (*Neovision vision*) includes fish, birds, and mammals (Bartoszewicz and Zalewski 2003), and they are likely to hunt for pink salmon. Harbour seals (*Phoca vitulina*) may also hunt for salmon in the lower reaches of rivers, while fox (*Vulpes vulpes*) may scavenge dead fish. Birds of prey, like osprey (*Pandion haliaetus*), may also take pink salmon.

The abundance of these predators and scavengers may increase following an increase in the abundance of pink salmon. Terrestrial animals can also carry fish into the riparian area (Ben-David et al. 1998). This process, along with flooding events and the actions of plant roots, may transport nutrients directly from the river or the hyporheic zone and increase the biomass of riparian trees (Helfield and Naiman 2001).

The white-throated dipper is closely associated with swiftly running rivers and streams, where it dives for invertebrates, and may potentially be negatively affected if the density of invertebrates is reduced. However, it seems the breeding dipper population is not influenced by the total salmonid density (Nilsson et al. 2018), suggesting little competition between dippers and salmonids for food. This is because salmonids and dippers have different feeding strategies, with salmonids mainly feeding on smaller insects and drift, while dippers feed on larger insects on the river floor (Nilsson et al. 2018, Ormorod et al. 1987). If pink salmon carcasses increase primary and secondary productivity, then there may also be advantages for species, such as the dipper, provided that this does not include a deterioration in overall water quality.

3.1.4.2 HAZARD CHARACTERIZATION

Predators and scavengers may increase in abundance following an increase in the abundance of pink salmon. Salmon carcasses may also fertilize the riparian area. Potential effects on terrestrial ecosystems will vary according to the number of pink salmon, where a higher number may support more predators and increase the fertilization of the riparian area. Morphological characteristics of a river can also influence the transport of nutrients to the riparian area, such as discharge, length of the river, presence of lakes and pools, content of particles, and white water. Effects from an increase in predators and scavengers in Norway are mostly unknown, but we expect terrestrial ecosystems to be less sensitive to pink salmon than freshwater ecosystems.

In sum, the project group assesses that the potential consequences for biodiversity in the terrestrial ecosystems in a river catchment are **minimal** with **high confidence** for low densities of spawning pink salmon, **moderate** with **medium confidence** for high densities spawning pink salmon, and **massive** with **low confidence** for very high densities of spawning pink salmon.

3.1.4.3 LIKELIHOOD

Pink salmon can potentially alter terrestrial food webs as living and dead fish can be food for various predators and scavengers, and fertilize the surrounding vegetation. The effect will be most pronounced in years when the pink salmon abundance is high. Overall, the project group assesses that it is **likely** with **medium confidence** that pink salmon will alter terrestrial food webs along rivers.

3.1.4.4 RISK CHARACTERIZATION

In sum, the project group assesses that the overall risk of negative consequences for biodiversity in the terrestrial ecosystems in a river catchment are **moderate** if the density of pink salmon spawners is low to medium (increased confidence with lower numbers). For ecosystems bordering rivers with a high to very high density of spawning pink salmon, the risk of negative impact is **high** (with **low to medium confidence**).

3.2 Interaction with native salmonids

Atlantic salmon and anadromous brown trout are present in all rivers on the Kola Peninsula where pink salmon spawn (Niemelä et al. 2016). Anadromous Arctic charr is present in some of them. This suggests that pink salmon and native salmonids have similar requirements regarding selection of rivers. Interactions between pink salmon and native salmonids can therefore be expected to the extent that they have overlapping niches within the river.

3.2.1 Competition for food and space

3.2.1.1 HAZARD IDENTIFICATION

Food competition between juvenile pink salmon and juvenile native salmonids must be expected, as the diet of pink salmon fry is similar to that of native salmonid fry and juveniles (Veselov and Zyuganov 2016). The extent of competition is related to the density of pink salmon fry and the time spent in the river between emergence and outmigration. Calculations of development time for pink salmon and native salmonids, suggest that in northern winter-cold rivers there may be considerable overlap between pink salmon and brown trout in the time they start external feeding, and overlap between pink salmon and Atlantic salmon one to two weeks later (Figure 3.2.1.1-1, and Berntsen et al. 2018).

Experience from Russia suggests that competition for food between pink salmon fry and Atlantic salmon fry may be severe (https://www.fylkesmannen.no/troms-finnmark/miljo-klima/internasjonalt-samarbeid/pukkellaks-i-finnmark/). Similarly, if a high number of pink salmon post-smolt spend time in the estuaries or coastal areas they may be competitors of native salmonids, as well as of other coastal zone fish. At this life stage (smolt), pink salmon are commonly much smaller than smolt of native salmonids.

Even if there is enough food for early life stages, there may still be competition between pink salmon fry and native salmonid fry for space. Little is known about this, but the overall impact likely depends on the number of pink salmon fry and the time spent in freshwater before river exit.
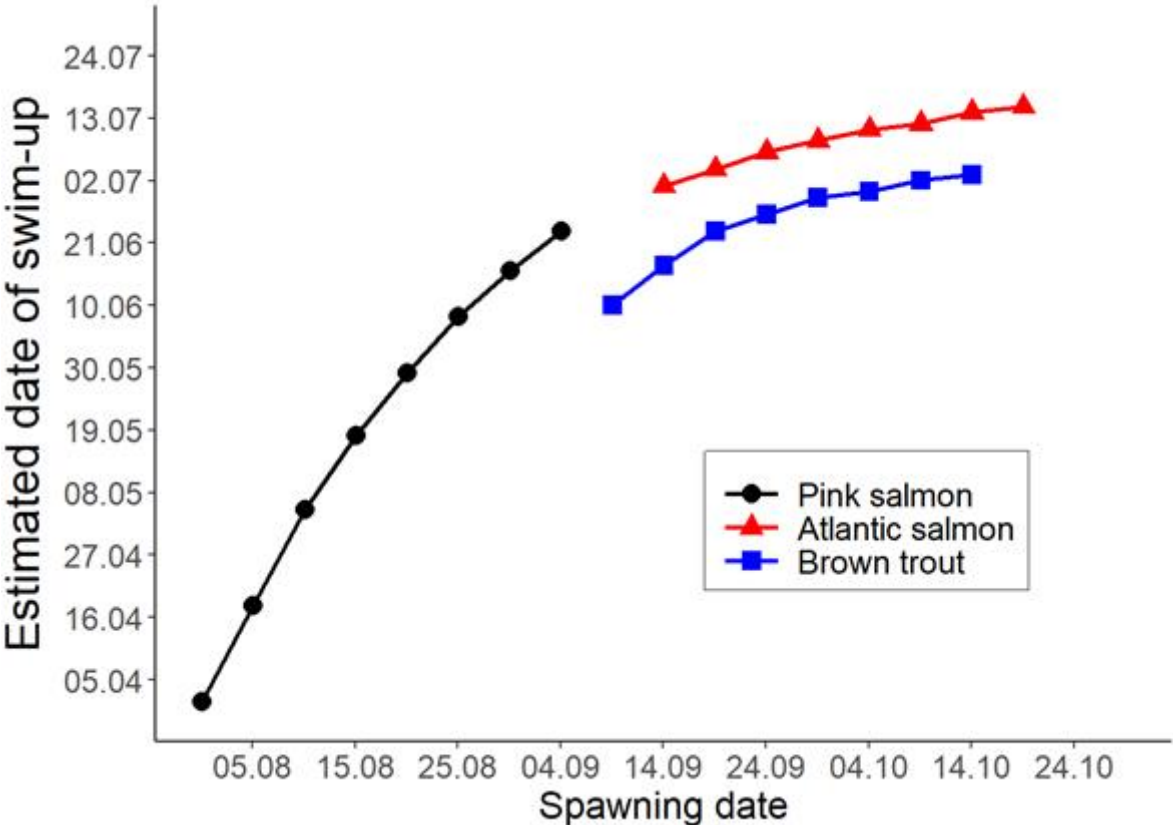
Figure 3.2.1.1-1 *Relationship between spawning time and the time when the yolk sac is used and fry must start feeding for pink salmon, Atlantic salmon, and brown trout, in a northern, winter-cold river in Norway. Spawning time varies between 1 August and 4 September for pink salmon, between 10 September and 10 October for anadromous brown trout, and between 15 September and 15 October for Atlantic salmon. From Berntsen et al. (2018).*

Adult pink salmon cease feeding when they enter the rivers, so at that stage, competition for food in the river is not expected.

3.2.1.2 HAZARD CHARACTERIZATION

The presence of a high number of pink salmon at the fry stage may cause major competition with early juveniles of native salmonid species. In situations where pink salmon leave the rivers and reach the sea shortly after emerging from the gravel at the spawning site, this competition may be limited. However, especially in large rivers where spawning sites of pink salmon may be located far upstream, it is likely that pink salmon fry feed for some time in the river after emergence, and that competition for food and space is strong, and may be severe where pink salmon densities are high.

The potential impact of competition between juveniles of pink salmon and native salmonids in watersheds where the pink salmon juveniles may remain feeding in the river for a few weeks is assessed by the project group to be **major**, with **low confidence**.

3.2.1.3 LIKELIHOOD

It is very likely that pink salmon fry feed where they spend time in the river after emergence. Competition from pink salmon fry may also be for resources such as shelter and space. It is also likely that there may be competition for food in estuaries between pink salmon post-smolt and native salmonids.

The project group assesses that it is **very likely**, with **medium confidence**, that there will be competition between juveniles of pink salmon and native salmonids in watersheds where the pink salmon juveniles may remain feeding in the river for a few weeks.

3.2.1.4 RISK CHARACTERIZATION

The project group concludes that the overall risk of negative impact on native salmonids, in terms of competition for food and space, following increased abundance of pink salmon in Norwegian water systems to be **high**, with **medium to low confidence**.

3.2.2 Competition for spawning grounds

3.2.2.1 HAZARD IDENTIFICATION

Observations from all parts of Norway in 2017 indicate that the first pink salmon was caught in the rivers around 1 July, regardless of the latitudinal position of the river. Exceptions were in the rivers Tana (70° 07′ N), Neidenelva (69° 42′ N), Sundfjordselva (66° 58′ N) and Mandalselva (58° 01′ N) where the first pink salmon was caught between 1 and 22 June. The *ad hoc* manner of information gathering at the beginning of the summer in 2017 may have resulted in particular underreporting of early cathces. The median number of pink salmon was recorded by 10 July in many rivers, but in several rivers, both in the north and the south of the country, the median number of fish was recorded as late as the end of August. This timing might be influenced by fishing activities in the rivers, but there seemed to be no geographic pattern in timing of the catches (Berntsen et al. 2018; Sandlund et al. 2019).

In River Tana, the timing of arrival of pink salmon has been recorded for several years through the collection of catch statistics (Niemelä et al. 2016). Over the years 2004-2014, catches indicate that the first fish arrived in the estuary in late May, moving to the central part of the river (> 40 km from the estuary) around 20 June. The 50% cumulative catch was reached around 10 July in both the lower and central river sections. Catches in the upper section of the river (> 60 km upstream) were delayed, with 50% of the cumulative catch reached in the middle of August (Niemelä et al. 2016).

Catches of pink salmon in Norwegian rivers in 2017 indicate that spawning generally occurs in August. Seven females caught between 3 and 27 August had running roe, indicating that they were close to spawning, and spent pink salmon spawners were caught between 8 and 30 August. This indicates that pink salmon spawn earlier than both Atlantic salmon and anadromous brown trout. This is also confirmed by the observation of pink salmon eggs under the eggs of anadromous brown trout (i.e., deeper in the gravel in the same nest) (T. Wiers, H. Skoglund, K.W. Vollset, unpublished data). In southern Norway, anadromous brown trout commonly spawn in October-November and Atlantic salmon in November-December.

In northern Norway, on the other hand, there may be some overlap in the spawning period between pink salmon and native salmonids. The latest spawning of pink salmon may occur in September (as late as 8 September is known from River Kongsfjordelva), and the river-spawning Arctic charr may spawn in mid-September (typically 10-20 September; Morten Falkegård, NINA, pers. comm.). Brown trout may also commence spawning in early September in northern rivers, whereas Atlantic salmon may start spawning in mid- to late September.

Despite earlier pink salmon spawning, there may still be interactions between pink salmon and native salmonids in the rivers during the summer, because the pink salmon may occur in the rivers in large numbers and in high densities in some areas, as also shown in several rivers in northern Norway in 2017 and 2019. Atlantic salmon, and many sea trout and Arctic charr, enter the rivers several weeks to a few months before spawning, and may be disturbed and stressed, and perhaps chased from their normal holding areas in the river, by the large number of pink salmon. Pink salmon are aggressive at the spawning sites, and pink salmon have been reported to attack Atlantic salmon that are at the spawning sites preparing for spawning (Veselov and Zyuganov 2016).

The result of agonistic behaviour by pink salmon may be that the Atlantic salmon move to river sections less suitable for holding positions prior to spawning and during spawning (Kaliuzin 2003). In White Sea rivers, Atlantic salmon avoid areas with many pink salmon. However, there are no formal studies of this in Norwegian rivers, but there is a common observation that native salmonids do not use parts of the rivers where pink salmon aggregate for spawning (Rune Muladal, Naturtjenester i Nord, pers. comm.).

If pink salmon survive for some time after spawning, they may be present in the rivers at the spawning time of the native salmonids, particularly Arctic charr and brown trout.

3.2.2.2 HAZARD CHARACTERIZATION

In southern Norway, direct interactions at the spawning sites may not occur between pink salmon and brown trout or Atlantic salmon. In northern Norway, on the other hand, we expect direct interactions to occur at spawning sites between pink salmon and early-spawning Arctic charr and brown trout.

A high density of, and agonistic behaviour by, adult pink salmon in the weeks before the spawning period of native salmonids may impose stress and likely influence the behaviour of native salmonids in the river before their spawning period. The effect of this extra stress is unknown, but is likely important if there are high densities of pink salmon.

The impact of competition at the spawning grounds is assessed by the project group to be **moderate**, with **low confidence,** for Atlantic salmon.

The impact of competition at the spawning grounds is assessed by the project group to be **major**, with **low confidence,** for brown trout and Arctic charr.

The impact of competition for space in the river before spawning of native salmonids is assessed by the project group to be **major** when high densities of pink salmon are present, with **low confidence**.

3.2.2.3 LIKELIHOOD

Direct interactions at the spawning sites between pink salmon and local salmonids are unlikely in southern Norway. In northern Norway, interactions are unlikely between pink salmon and Atlantic salmon, but likely between pink salmon and Arctic charr and brown trout.

Agonistic behaviour by pink salmon in the weeks before the spawning period of native salmonids is likely in all rivers with pink salmon, irrespective of the spawning time of native salmonids.

The project group assesses that it is **likely**, with **high confidence,** that pink salmon will compete with native salmonids for space in the river in the weeks before spawning and during the pink salmon spawning, and compete on the spawning grounds with early spawning Arctic charr and brown trout.

Further, the project group assesses that it is **unlikely**, with **high confidence,** that pink salmon will compete with Atlantic salmon on the spawning grounds during the spawning time of Atlantic salmon.

3.2.2.4 RISK CHARACTERIZATION

The project group concludes that the overall risk of negative impact on biodiversity, in terms of competition for spawning grounds, following increased abundance of pink salmon in Norwegian water systems to be **moderate** (with **medium confidence**) for Atlantic salmon and **high** (with **medium confidence**) for Arctic charr and brown trout.

3.2.3 Hybridization with native salmonids

3.2.3.1 HAZARD IDENTIFICATION

Interspecific hybridization in the Salmonidae family is a relatively common phenomenon, whereas hybridization between species of different genera (intergeneric hybrids) must be considered extremely rare (Chevassus 1979; Crespi and Fulton 2004). Hybrids between the introduced brook charr *Salvelinus fontinalis* and native brown trout *Salmo trutta* are known from both Sweden and Norway (Thorstad et al. 2019).

Hybrids between pink salmon and native European salmonid species have not been documented in the wild, but this has not been well studied. Laboratory experiments suggest that intergeneric hybridization between species of the Pacific genus *Oncorhynchus*, the Atlantic genus *Salmo*, and the Holarctic genus *Salvelinus* may lead to viable offspring, but most intergeneric combinations show almost total sterility (Chevassus 1979).

Pink salmon may produce viable and sexually mature hybrids with other *Oncorhynchus* species, especially chum salmon (*Oncorhynchus keta*). As long as the hybridization rate is low, Zhivotovsky et al. (2016) argue that there is no substantial hybrid load to either species because of selection against advanced-generation hybrids and backcrosses. With a high hybridization rate, however, interspecific hybridization is viewed as a genetic threat to the population. In that case, the greatest toll is likely on the species that supplies the majority of females involved in the interspecific crosses.

In Canada, scientists have crossbred farmed Atlantic salmon and various Pacific salmon species (Robert H. Devlin, DFO, West Vancouver, pers. comm.). All Pacific salmon produced hybrid progeny when Atlantic salmon was a parent, but usually at frequencies of less than 0.5%. In crosses between Atlantic salmon females and pink salmon males that were performed in the 1990s, survival of 5.5% up to hatching was observed, but no hybrids survived to maturity (Devlin, pers. comm.). Similar experiments found between 0.059 and 0.75% survival to the fry stage. New crosses between Atlantic salmon females and pink salmon males were performed in September of 2019 and a cross in the other direction (Atlantic salmon male X pink salmon female) will be started in mid-November 2019 (Devlin, pers. comm.).

Female brown trout have not been crossed with male pink salmon, but with males of other *Oncorhynchus* species. Some of these crosses resulted in high survival up to 18 months of age (Chevassus 1979). To our knowledge, artificial crosses between pink salmon and Arctic charr have not been attempted, but crosses between other *Oncorhynchus* and *Salvelinus* species in Japan suggest that some offspring may survive, but do not reproduce.

In southern Norway, pink salmon spawn 1-2 months earlier than brown trout and 2-3 months earlier than Atlantic salmon in rivers where this has been studied. Hybridization

between pink salmon and native salmonids therefore seems highly unlikely in southern Norway, if the spawning times remain unchanged.

In northern Norway, late-spawning pink salmon and early-spawning Arctic charr show a likely overlap in spawning time in early September (Morten Falkegård, NINA, pers. comm.). Brown trout commonly spawn later than Arctic charr, but have a more prolonged spawning period, and, in some tributaries to the Tana/Teno river system, have been found to start spawning in early September, at which time they may encounter spawning pink salmon. Atlantic salmon is the latest-spawning native species. A recent report from River Kongsfjordelva found late-spawning pink salmon until 8th of September, whereas the first spent Atlantic salmon female was found 15th September (Vistnes 2019), so overlap in spawning between pink and Atlantic salmon in northern Norway is not highly unlikely.

Spawning sites can overlap between pink salmon and brown trout, especially in shallow areas in the main river and in tributaries, and between pink salmon and Atlantic salmon in the main river. Arctic charr spawn in slower-flowing water and is less likely to overlap in spawning site with pink salmon.

3.2.3.2 HAZARD CHARACTERIZATION

Observations on spawning time and place indicate that hybridization between pink salmon and native salmonids in Norway is possible, although the overlap in spawning time and place is limited. The largest consequence will occur if females of any of the native salmonids engage in hybridization with male pink salmon.

However, although some hybridization experiments indicate that intergeneric hybridization is possible, there are no documented hybrids from the wild. In North America, there is overlap in distribution and spawning time between pink salmon and both Arctic charr and the more southerly Dolly Varden charr (*Salvelinus malma*) (Scott and Crossman 1973), so should hybridization occur there commonly, it would be expected to have been documented.

On this background, we assess that the potential consequences from hybridization on the productivity of salmonid populations in Norway are **minimal**, with **low confidence**.

3.2.3.3 LIKELIHOOD

In northern Norway, there is overlap in spawning time between late-spawning pink salmon and early-spawning Arctic charr and brown trout. Moreover, there may be overlap between the latest-spawning pink salmon and the earliest-spawning Atlantic salmon. Hybridization between pink salmon and any of the native salmonids in Europe is not known. We therefore consider hybridization between pink salmon and native salmonids in Norway to be **very unlikely**, with **low** confidence.

3.2.3.4 RISK CHARACTERIZATION

The potential consequences of hybridization between pink salmon and native salmonids in Norway (*Salmo salar*, *Salmo trutta,* and *Salvelinus alpinus*) are considered to be minimal and the potential for intergeneric hybridization to take place is considered very unlikely. This gives the overall risk assessment for hybridization as **low** with **low confidence**.

The level of confidence is low for the characterization of both risk assessment axes. Even if we should have stepped up our characterization to minimal, and the likelihood to unlikely, the conclusion for this part of the risk assessment would remain as **low**.

3.3 Pathogens

A fish species is considered susceptible to a particular pathogen if infection occurs by natural exposure or by experimental exposure mimicking natural transmission. Many factors affect susceptibility, e.g., developmental stage and size of fish. In general, young fish are especially vulnerable to infectious diseases. Clinical disease following infection is a result of a multitude of factors that are not always present in research experiments.

The detection of new and exotic diseases relies on diagnostic investigations. This requires efficient surveillance and standardization of criteria for disease diagnostics and characterization. New and previously unknown infectious diseases have frequently been detected in Norwegian aquaculture farming of Atlantic salmon and rainbow trout (*Oncorhynchus mykiss*). The World Organization for Animal Health (OIE) sets standards and lists many diseases of aquatic animals that are of major importance. National authorities can list other diseases of importance within their own country.

Many of the viral pathogens that are found in the seawater phase of Norwegian Atlantic salmon farming occur in freshwater farming in other geographical areas with other farming management systems. This can be explained by the lack of influence that water salinity has on the intracellular environment, within which viruses and other intracellular agents reside in the host. Thus, most fish viruses of anadromous fish can establish infections regardless of whether the host is in fresh water or sea water. For other pathogens, the seawater or freshwater phase may be of greater relevance; for example, ectoparasites are exposed to the external environment and have different tolerances or requirements for salinity. Furthermore, some parasites have complex lifecycles in which one or more hosts may be marine or freshwater, and this can limit spread of infection (e.g., for *Anisakis simplex* both the 1st intermediate host and the definitive host are marine).

Knowledge on the importance of epidemics among wild fish is very limited. One reason for this is that wild fish with reduced fitness are easily preyed on, but also that there are few studies specifically targeting diseases of wild fish (Bergh 2007). The available data indicate that diseases among wild fish are common, and that epidemics may be of ecological and economic importance (Miller et al. 2014; Miller et al. 2017a, 2017b).

The complete post-spawning mortality of pink salmon is preceded by pronounced immunosuppression (Cook et al. 2011), which presumably renders spawning pink salmon particularly prone to infection.

3.3.1 Viral pathogens

3.3.1.1 HAZARD IDENTIFICATION

Virus infection of a cell requires interaction between surface components of the virus particle with a component of the host cell. This interaction is specific and is an important determinant of the species specificity of a virus.

Table 3.3.1.1-1 lists known and assumed probable virus infections of pink salmon. However, pink salmon has not been a favoured species for farming, and therefore little is known about its susceptibility to various virus infections. Further characterization of some of the viruses in this table is presented below, based on the following inclusion criteria: 1) Listing by OIE in the Aquatic Animal Health Code, as these automatically are assessed as having serious consequences due to potential disease losses and implication for trade; 2) Viruses widespread in farmed Norwegian Atlantic salmon.

Table 3.3.1.1-1. Viruses known and assumed to infect pink salmon

Virus	Known or assessed as high probability of infecting pink salmon	Assessed as low probability of infecting pink salmon	Listed by OIE	Reference
Viral haemorrhagic septicaemia virus (VHSV)		+	Yes	(Follett et al., 1997)
Infectious haematopoietic necrosis virus (IHNV)		+	Yes	(Dixon et al., 2016)
Infectious salmon anaemia virus (ISAV)		+	Yes	(Rolland and Winton, 2003)
Salmonid alphavirus (SAV)	?	+	No	(Villoing et al., 2000)
Piscine orthoreovirus (PRV)	+	+	No	(Marty et al., 2015)
Piscine myocarditis virus (PMCV)		?	No	
Infectious pancreatic necrosis virus (IPNV)	+		No	
Oncorhynchus masou virus		+	No	
Chum salmon virus		+	No	
Salmon gill pox virus		?	No	
Viral erythrocytic necrosis virus	+		No	(Bell and Traxler, 1985)

Salmonid alphavirus (SAV): *Salmonid alphavirus* is also known as salmonid pancreas disease virus. It is listed, but is not notifiable to OIE. It belongs to the family *Togaviridae.* The virus causes the disease called pancreas disease, PD, which is endemic and very common in the Norwegian Atlantic salmon and rainbow trout farming during the sea phase. However, it does not occur north of approximately the southern border of Nordland County. Movements of farmed fish in this area are highly regulated, and any occurrence of PD north of the border will be resolutely combated. SAV is also common in European freshwater farming of rainbow trout, and the disease there is called sleeping disease (Villoing et al. 2000). There are no known reports of SAV infection in pink salmon; however, the ability of the virus to infect and cause disease in rainbow trout (also a *Oncorhynchus* species), indicate that infection of pink salmon should not be excluded on a theoretical basis.

Viral haemorrhagic septicaemia virus (VHSV): VHSV is listed and notifiable to OIE. VHSV is a rhabdovirus that infects a wide range of fish. It has been isolated from more than 80 wild and farmed fish species (OIE 2017). VHSV is divided into genogroups (Einer-jensen et al. 2004) and differences in virulence can be ascribed to a few amino acids, where low-virulence strains can mutate into highly virulent strains (Ito et al. 2016). Farmed Atlantic salmon and rainbow trout in Norway are currently free of VHSV, but the virus is present in marine fish populations in Norwegian coastal waters. In a relatively large survey including many different species of fish, VHSV was detected in Atlantic herring (*Clupea harengus*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), and silvery pout (*Gadiculus argenteus*) (Sandlund et al. 2014). It is thus very likely that pink salmon can be infected with VHSV, due to the ability of the virus to infect various fish species.

We are not aware of any current reports of VHSV infection in pink salmon. In an experimental waterborne challenge using a North American strain of VHSV, pink salmon was refractory to infection (Follett et al. 1997).

Infectious haematopoietic necrosis virus (IHNV): IHNV is listed and notifiable to OIE. IHNV also belongs to the family *Rhabdoviridae*. IHNV was initially identified in western North America, and isolates from farmed rainbow trout in Europe appear to have originated from western North America (Enzmann et al. 2010). The pathogen spread from North America through illegal imports to Europe and Asia. Both Atlantic salmon and rainbow trout are highly susceptible to the virus and disease. IHNV has never been found in Norway. In areas with both endemic IHNV in wild fish populations and farming of Atlantic salmon, i.e., British Columbia, all farmed salmon must be vaccinated. In Norway, this is a much-feared disease, both for farmed and wild Atlantic salmon. IHNV can infect at least eight different Pacific salmon species (*Oncorhynchus* spp.), however, it is very important to note that pink salmon is not listed among these by OIE or in the literature (Dixon et al. 2016; Follett et al. 1997). Furthermore, virological examinations during 1996 to 2005 of over 10,000 wild and cultured salmonid fish from the Kamchatka peninsula in eastern Russia, i.e., the assumed geographical origin of the pink salmon released in western Russia, revealed IHNV in several sockeye salmon (*Oncorhynchus nerka*), but not in pink salmon (Rudakova et al. 2007).

IHNV was recently found in Finland, where it was detected in a cage farm in the Bothnian Bay. The origin of the sea-farm infection was traced to a land-based fish farm selling juveniles, possibly contaminated through Russian fishing tourists (EVIRA 2018). Stamping out followed by disinfection and fallowing were used to control the infection.

Infectious salmon anaemia virus **(ISAV):** ISAV is listed and notifiable to OIE. ISAV belongs to the family *Orthomyxooviridae* and is a close relative to the influenza viruses. It is endemic in Norway, with 5-20 annual disease outbreaks in farmed Atlantic salmon. It is of significant economic importance, particularly for trade restrictions. ISAV has not been found to cause disease in Pacific salmon species (*Oncorhynchus* spp.). In an experimental infection with intraperitoneal injection of the virus (i.e., a non-natural route of exposure), the virus did not cause disease, but could be reisolated from some fish sampled at irregular intervals post-challenge (Rolland and Winton 2003). Pink salmon was not among the *Oncorhynchus* spp. that were tested, but the results indicate that subclinical ISAV infection of this species should not be excluded on a theoretical basis.

Piscine orthoreovirus **(PRV):** PRV is ubiquitous in the marine phase of Atlantic salmon farming, it is also rather common in wild Atlantic salmon. At least three different genotypes of PRV have been found in salmonids, i.e., in Atlantic salmon (PRV-1), coho salmon (PRV-2), and rainbow and brown trout (PRV-3). The subtype PRV-1, which causes heart and skeletal muscle inflammation (HSMI) in Atlantic salmon (Wessel et al. 2017), has recently (July 2019) been detected in pink salmon from the river Karpelva in the Finnmark county (Åse Garseth, Norwegian Veterinary Institute, pers. comm.). HSMI is not notifiable to OIE nor to the Norwegian Food Safety Authority. PRV-1 is found in various species of Pacific salmon in the Western America (Siah et al. 2015), but not reported from pink salmon there.

There are no reports of PRV in pink salmon, and PRV-1 was not detected when 316 fish (79 fry/juveniles and 235 adult sexually mature pink salmon) from British Columbia, Canada and Alaska, USA were tested (Marty et al. 2015).

Piscine myocarditis virus **(PMCV):** PMCV belongs to the family *Totiviridae* and is the cause of the disease cardiomyopathy syndrome (CMS) in farmed Atlantic salmon, mostly in the late stages of production. Like many other diseases in farmed fish, the severity depends upon host and management factors. CMS is not notifiable to OIE nor to the Norwegian Food Safety Authority. It is a common disease and about 100 outbreaks are registered annually. The disease occurs all along the coast.

Infectious pancreatic necrosis virus **(IPNV):** IPNV is a common virus in salmonids, and is, in general, not particularly host-species specific. It belongs to the family *Birnaviridae.* IPN is not notifiable to OIE nor to the Norwegian Food Safety Authority. Although there are no known reports of IPNV in pink salmon, it is very likely that this virus does infect pink salmon. IPNV readily grows and causes a strong cytopathic effect in most cell cultures. In a screening for IHNV in Kamchatka using the cell lines CHSE-214 and EPC, both susceptible to IPNV, no virus was detected (Rudakova et al., 2007).

Salmon gill pox virus (SGPV): SGPV is a common virus in farmed and wild Atlantic salmon in Norway. It is associated with gill diseases in farmed salmon, but the significance of the infection is not known (Gjessing et al. 2015). It is not notifiable to OIE nor to the Norwegian Food Safety Authority.

Viral erythrocytic necrosis virus (VENV): Viral erythrocytic necrosis (VEN) has been reported from many species of marine and anadromous fishes in both the Atlantic Ocean and Pacific Ocean. At least one strain of VENV has been confirmed to be a member of the family *Iridoviridae* (Emmenegger et al. 2014). However, the genetic relatedness of ENV from various fish species has not yet been investigated. A virus with similar morphology has been reported from pink salmon based upon light and electron microscopic studies (Evelyn and Traxler 1978).

Oncorhynchus masou virus and Chum salmon virus: In a survey from Japan in the years 1976-1991, including the fish species masu salmon (*Oncorhynchus masou*), chum salmon (*Oncorhynchus keta*), pink salmon (*Oncorhynchus gorbuscha*), sockeye salmon or kokanee salmon (*O. nerka*), and rainbow trout (*O. mykiss*), neither Oncorhynchus masou virus nor Chum salmon virus were detected in pink salmon (Yoshimizu et al., 1993).

3.3.1.2 HAZARD CHARACTERIZATION

Salmonid alphavirus (SAV): Movements of SAV-infected pink salmon from south to north could be a risk factor for the spread of PD, which is lethal to Atlantic salmon and rainbow trout. The project group assesses that the potential consequences for biodiversity in Norway are **moderate** with **low confidence.**

Viral haemorrhagic septicaemia virus: VHSV can cause serious disease in both farmed and wild salmonids, and other fish species. A subtype of VHSV has been found as a major pathogen for many fish species after introduction of the virus to the area of Great Lakes. Therefore, it is possible that pink salmon may contribute to spread of this pathogen in Norwegian water systems. The project group assesses that the potential consequences for biodiversity in Norway are **moderate** with **very low confidence.**

Infectious haematopoietic necrosis virus: Currently, there is no indication of IHNV occurring in Norwegian coastal waters and testing of pink salmon caught in Norwegian rivers has not revealed the virus. It is, however, likely that pink salmon can be infected with IHNV if exposed, and thus aid in spreading it further. The project group assesses that the potential consequences for biodiversity in Norway are **minor** with **low confidence.**

Infectious salmon anaemia virus: The non-virulent form of ISAV is very common in farmed Atlantic salmon and assumed to be present all along the Norwegian coast. The project group assesses that the potential consequences for biodiversity in Norway are **minimal** with **medium confidence.**

Piscine orthoreovirus: PRV is found in several species of fish. The project group assesses that the potential consequences for biodiversity in Norway are **minimal** with **medium confidence.**

Other viral pathogens: These include: *Infectious pancreatic necrosis virus, piscine myocarditis virus, salmon gill poxvirus, viral erythrocytic necrosis virus, and oncorhynchus masou virus.* For these pathogens, the project group assesses that the potential consequences for biodiversity in Norway are **minimal** with **medium confidence**.

3.3.1.3 LIKELIHOOD

The likelihood of exposure of viral pathogens to wild and farmed fish in Norway will be proportional to the number of pink salmon that enter the Norwegian water systems. Based on the number of fishes arriving in 2019, the project group assess that negative impact is **unlikely** for:

- Infectious hematopoietic necrosis virus, with **low confidence**
- Other viral pathogens (as listed in 3.3.1.1), with **medium confidence**

For Salmonid alphavirus (SAV) it is assessed that it is **unlikely** to result in negative consequences for wild fish. This assessment has **very low confidence**.

For piscine orthoreovirus, the project group assesses that it is **moderately likely** that this can have a negative impact on wild fish, as mediated by pink salmon. This is assessed with **medium confidence.**

3.3.1.4 RISK CHARACTERIZATION

The project group assesses that the risk of negative impact on biodiversity in Norway associated with introduction and/or spread of viruses, stemming from spread and potential establishment of pink salmon, is **moderate** (bordering high) with **low confidence** for:

- Viral hemorrhagic septicemia virus

The project group assesses that there is **low** (bordering medium) risk, with **medium to low confidence,** associated with spread of:

- Infectious hematopoietic necrosis virus
- Infectious salmon anaemia virus
- Salmonid alphavirus
- Infectious pancreatic necrosis virus
- Piscine myocarditis virus
- Salmon gill poxvirus
- Viral erythrocytic necrosis virus
- Oncorhynchus masou virus

3.3.2 Bacterial pathogens

3.3.2.1 HAZARD IDENTIFICATION

Renibacterium salmoninarum: Bacterial kidney disease (BKD) caused by infection with *R. salmoninarum* is a notifiable fish disease in Norway. BKD represents a significant disease of wild and farmed salmonids worldwide. Pink salmon is susceptible to *R. salmoninarum* infection (Meyers et al. 1993). Chronically infected subclinical carriers may be common amongst wild salmonid populations (Jónsdóttir et al. 1998), and transmission may occur either horizontally or vertically (Austin and Austin 2012). Interspecies transmission of *R. salmoninarum*, and from wild to cultured fish, has been documented (Mitchum and Sherman, 1981). The species occurs endemically in some rivers, particularly on the western coast of Norway, and sporadic outbreaks have occurred in farmed salmon in northern Norway in recent years (Hjeltnes et al. 2019). No vaccine against *R. salmoninarum* is commercially available.

Piscirickettsia salmonis: *P. salmonis*, an obligatory parasitic bacterial species, causes salmonid rickettsial septicemia (SRS) in salmonids, and is a problem for salmonid aquaculture in Chile (Almendras and Fuentealba 1997). It has also been detected in various fish species in Europe (Reid et al. 2004; Marcos-López et al. 2017), including, sporadically, in Atlantic salmon in Norway (Olsen et al. 1997). European strains appear less pathogenic than those found in Chile (Rozas-Serri et al. 2017). A disease like SRS was documented in seawater-reared pink salmon in British Columbia, Canada, during the 1970s, although it remains uncertain whether *P. salmonis* was the aetiological agent for these cases (Kent 1992). No vaccine against *P. salmonis* is commercially available.

Aeromonas salmonicida: Furunculosis caused by *A. salmonicida* subsp. *salmonicida* is a notifiable disease in Norway. Farmed salmon are protected by vaccination against the disease (Midtlyng 2014). *A. salmonicida* subsp. *salmonicida* is endemic amongst some wild salmonid populations in Mid-Norway, where it is regularly identified (Hjeltnes et al. 2019).

The distinct *A. salmonicida* subsp. *masoucida* causes disease symptoms like furunculosis in various fish species, including pink salmon and Atlantic salmon (Kimura 1969a,b; Du et al. 2019), but has, to date, only been documented in Pacific regions (Gulla et al. 2019). However, as pink salmon are a susceptible host that has repeatedly been introduced from its natural habitat in the Pacific region into northern Europe, it is conceivable that *A. salmonicida* subsp. *masoucida* may exist amongst pink salmon populations in Europe.

Flavobacterium psychrophilum: *F. psychrophilum* causes bacterial cold-water disease (BCWD), primarily in salmonids, worldwide, and systemic *F. psychrophilum* infection (in rainbow trout only) is listed as a notifiable disease in Norway. Strain differences in virulence and host preference exist, and although it is sporadically detected in farmed Atlantic salmon throughout Norway, a single strain virulent to rainbow trout poses a particular threat to

farming of this fish species in a single brackish fjord in western Norway (Nilsen et al. 2011, 2014; Hjeltnes et al. 2019). No vaccine against *F. psychrophilum* is commercially available.

***Mycobacterium* spp.:** Fish mycobacteriosis, caused by various *Mycobacterium* species, has been sporadically recorded in farmed Atlantic salmon in Norway in recent years. A marked increase in detections occurred in 2006-2007, and then again in 2018 (Hjeltnes et al. 2019), although the reason for these peaks remains unknown. Fish-pathogenic *Mycobacterium* spp. usually have a broad host range, and prolonged, asymptomatic carrier-status is common (Austin and Austin 2012).

Yersinia ruckeri: Although *Y. ruckeri* is an endemic species in Norwegian waters, one specific strain has been verified as almost entirely dominant amongst yersiniosis outbreaks internationally (e.g., Europe and North America) in farmed rainbow trout (Gulla et al. 2018). This strain has also occasionally been recovered from some other salmonid fish species, including e.g. Atlantic salmon and sockeye salmon, but remains undocumented in Norway. Were it to be introduced to Norwegian waters, it could represent a significant threat, particularly towards rainbow trout.

Due to their inclusion in aquaculture vaccination regimens and/or presumed ubiquitous presence in Norway, the significant salmon pathogens *Vibrio anguillarum*, *Aliivibrio salmonicida*, and *Moritella viscosa* are not considered.

3.3.2.2 HAZARD CHARACTERIZATION

***Renibacterium salmoninarum*:** As BKD caused by *R.* represents a common disease of wild and farmed salmonids worldwide, and pink salmon is susceptible to *R. salmoninarum* infection, the project group assesses that the potential consequences for biodiversity in Norway are **moderate** with **very low confidence.**

Piscirickettsia salmonis: Although *P. salmonis* can cause SRS in salmonids, it appears to be less pathogenic in Europe than in South America. The project group thus assesses that the potential consequences for biodiversity due to this bacterial species being introduced by pink salmon into the marine ecosystems are **minor** with very **low confidence.**

***Aeromonas salmonicida*:** Furunculosis caused by *A. salmonicida* subsp. salmonicida is a regularly found in wild salmon, but farmed salmon in Norway are vaccinated against the disease. In sum, the project group assesses that the potential consequences for biodiversity in Norway are **minor** with **very low confidence.**

***Flavobacterium psychrophilum*:** *F. psychrophilum* can cause disease in salmonids in Norway, but has not been reported to cause mass deaths. The project group thus assesses that the potential consequences for biodiversity in Norway are **minimal** with **very low confidence**.

Mycobacterium **spp.**: *Mycobacterium* species have sporadically caused disease in farmed Atlantic salmon in Norway in recent years, but does not appear to cause significant harm. The project group assesses that the potential consequences for biodiversity in Norway are **minor** with **very low confidence.**

Yersinia ruckeri: Based on the virulence and effect of this bacterial pathogen in other countries, the project group assesses that the potential consequences for biodiversity in Norway are **minimal** with **very low confidence.**

3.3.2.3 LIKELIHOOD

The likelihood of exposure of bacterial pathogens to wild fish in Norway will be proportional to the number of pink salmon that enter the Norwegian waters. Based on the number of fishes arriving in 2019, the project group assess that negative impact on wild fish is **unlikely** for:

- *Renibacterium salmoninarum*, with **very low confidence**
- *Piscirickettsia salmonis*, with **very low confidence**
- *Aeromonas salmonicida*, with **very low confidence**
- *Flavobacterium psychrophilum*, with **very low confidence**
- *Mycobacterium* spp., with **very low confidence**
- *Yersinia ruckeri*, with **very low confidence**

3.3.2.4 RISK CHARACTERIZATION

The project group assesses that the risk of negative impact on biodiversity in Norway associated with introduction and/or spread of bacterial pathogens stemming from spread and potential establishment of pink salmon, is **moderate** (bordering to low) with **low confidence** for:

- *Renibacterium salmoninarum*

The project group assesses that there is **low** (some bordering to moderate) risk with **medium confidence** associated with spread of:

- *Piscirickettsia salmonis*
- *Aeromonas salmonicida*
- *Flavobacterium psychrophilum*
- *Mycobacterium* spp.
- *Yersinia ruckeri*

3.3.3 Parasites

3.3.3.1 HAZARD IDENTIFICATION

Parasites are eukaryotic organisms that have a parasitic stage in their lifecycles – and are generally divided into two main groups – the metazoan parasites and the protozoan (single-celled) parasites. This group often tends to include the Microsporidia and the Myxozoa, which are both included here. However, phylogenetic analyses have indicated that the Microsporidia are more closely related to fungi than other "classical" protozoan parasites and the Myxozoa are more closely related to the Cnidaria (e.g., jellyfish).

Norway has a history of severe consequences associated with parasites entering the country with fish. The import of *Gyrodactylus salaris* into Norway from Sweden caused tremendous damage to wild populations of Atlantic salmon parr from the mid-1970s onwards. Salmon stocks in individual rivers were reduced by around 85%, and population reductions in smolt rose to over 95% within 5 years (Denholm et al. 2016). Although more easily controlled in hatcheries, if left untreated the salmon mortality can be 100%. The economic impact for Norway has been estimated to be in excess of US$ 55 million annually (Bakke et al. 2007).

Literature searches regarding parasites associated with pink salmon (see search terms and search strategies in Appendix Ic) identified 134 references concerned with parasite infections and pink salmon. Of these, over 64% were related to the salmon louse, *Lepeophtheirus salmonis.* This crustacean ectoparasite is established in Norwegian Atlantic salmon, and is a considerable economic and welfare issue in Norwegian salmon farming. Whether salmon lice brought to Norway with pink salmon will have specific characteristics that may be of greater concern is unknown. The parasites of interest can be divided into three main groups:

1. Parasites that may have an impact on the health and welfare of native salmonids (Atlantic salmon, brown trout, Arctic charr) and might be imported with an influx of pink salmon
2. Parasites that are zoonotic (may have a public health impact)
3. Aquatic organisms that have a parasitic stage in their lifecycle, but are of relevance and interest in the Norwegian ecosystem, and may be affected by the incursion of pink salmon.

Group 1: Parasites that may have an impact on native salmonids and might be imported with the influx of pink salmon

A large number of parasites (around 80 genera) have been considered as potentially relevant for this Assessment, and are listed in Appendix IV. For many of these parasites, we have very limited or no knowledge about their infectiousness or pathogenicity to either pink salmon or to native Norwegian salmonids. However, based on the literature search (see Appendix Ic) as well as knowledge of the field, the following parasites have been considered in greater detail regarding their occurrence and pathogenicity in pink salmon and in salmonids that are native to Norway, along with their current occurrence in Norway either in

pink salmon or in native Norwegian salmonids. Other parasites may also be of relevance. However, our current knowledge is insufficient to identify these.

Gyrodactylus salaris: As previously mentioned, import of this parasite had a devastating effect on Norwegian wild salmon stocks from the mid-1970s onwards. Following massive investment, rivers that were previously considered infested with this parasite have gradually been cleaned by targeted treatment. To our knowledge, neither *G. salaris* nor other Gyrodactylidae have been reported from pink salmon.

Lepeophtheirus salmonis **(salmon louse):** The most important parasite in the marine-based stage of salmon aquaculture, this crustacean is an ectoparasite of salmonid fish in marine waters, living off the mucus, skin, and blood. This increases morbidity and may also result in death when infections are heavy. Atlantic salmon, brown trout and Arctic charr in the marine environment are the natural hosts of salmon lice, which have experienced an enormous increase in the number of available hosts by the build-up of salmon farming. Salmon lice also spread from open net-pen salmon farms to wild fish and may reduce growth and survival of wild Atlantic salmon and sea trouttensive areas (Thorstad and Finstad 2018). Although pink salmon can also be hosts for salmon lice, it seems unlikely that they will affect the dynamics of salmon lice in either farmed or wild salmon in Norway, as the parasites are already so prevalent. Indeed, it may be more likely that salmon lice from Atlantic salmon farms impact on the pink salmon (as the fish are relatively small at the time of seawater entry, and more susceptible to infection). However, although a study from Norway indicated that infection pressure from fish farms affected infestation of wild sea trout (Vollset et al. 2018), a study from Canada indicated that the productivity of wild pink salmon was not negatively associated with farm lice numbers or fish-farm production (Marty et al. 2010). As many of the studies examining pink salmon for parasites are based on fish from rivers these do not represent the infection of the fish while in the marine environment, as the parasites do not survive in fresh water. In a study of parasites in pink salmon collected from rivers in Hordaland during 2017 (Fjær 2019), *L. salmonis* were found on three; these were considered to represent those few adult lice that had not succumbed to the transfer to fresh water.

In general, pink salmon are considered resistant to salmon lice based on a series of cohabitation studies (Jones et al 2007; Sutherland et al. 2011, 2014). Johnson and Albright (1992) first demonstrated resistance to salmon lice in Coho salmon, and it was later suggested that the mechanism is related to inflammation at the attachment site and a local and systemic elaboration of proinflammatory cytokines. The resistance is believed to occur shortly after the pink salmon enter the ocean, when the fish is approximately 1 g. It is thought that this correlates with the appearance of scales. The resistance is apparently absent in maturing adult individuals. It is important to note that pink salmon are not completely devoid of salmon lice at the end of such experiments, but the prevalence and intensity of the salmon lice is a fraction of that found on co-habiting Atlantic salmon. In addition, surveillance data of pink salmon in British Columbia, Canada suggest that post-smolt pink salmon can carry substantial amounts of parasites of all stages, indicating that although pink salmon mount an immune response that kills a large proportion, some of the

salmon lice on pink salmon on the west coast of Canada survive to adulthood. It is unknown whether the presence of resistant hosts has led to an evolution of salmon lice that can circumvent the immune response of the host.

In some regions in Norway, it is believed that Atlantic salmon and sea trout populations have been decimated because of salmon lice from fish farms. This is particularly the case on the west coast of Norway (Forseth et al. 2018; Skoglund et al. 2019). If pink salmon is resistant to salmon lice this will, potentially, reduce the competition between pink salmon and native salmonids, and could lead to faster establishment of pink salmon populations.

Caligus **spp. (sea lice):** Various *Caligus* species are ectoparasites feeding on the mucus and epidermal skin of their marine fish hosts, which can include salmonids. In Norway, large numbers of adult *Caligus elongatus* are frequently found on farmed salmon, and this species of *Caligus* is not particularly selective regarding host-fish species (Øines et al. 2006). Another species, *Caligus clemensi*, also infect pink salmon and are reported from both wild and farmed salmon (Atlantic salmon and pink salmon) in Canada (Byrne et al. 2018). The relevance of this sea louse species (described as commercially relevant though relatively under-studied) to native Norwegian salmonid species is unclear.

Argulus **spp. (fish lice):** Unlike salmon lice and sea lice, *Argulus* spp. are found in freshwater environments, and feed on the blood of the host. Inflammation of the skin, open wounds and fin corrosion may result, and secondary infections are common. In Norway, both *Argulus coregoni* and *A. foliaceus* are reported on freshwater salmonids. The extent to which pink salmon may be hosts to these species and affect their dissemination is unclear.

Eubothrium crassum: Salmonids are the definitive host of this large tapeworm (often around 80 cm in length, but over 1 m is possible), which has 1 or 2 intermediate hosts in the lifecycle (the 2nd being facultative). The lifecycle may be completed in marine or fresh water (Saksvik et al. 2001), although the freshwater and marine tapeworms may be different species. Infection is associated with a negative effect on fish growth and fitness. The parasites occur commonly in both wild and farmed salmonids in Norway (Sundnes, 2003). Infection with *E. crassum* has been reported from pink salmon, including in Norway where a prevalence of 34% was reported, with up to 87 worms in a single fish (Fjær 2019). However, in these fish it has never been found as large, mature tapeworms but usually as plerocercoids, indicating that pink salmon probably act as paratenic (transport) hosts.

Anisakis simplex: This nematode parasite, for which fish are the 2nd intermediate hosts, has a marine lifecycle, with marine crustaceans acting as first intermediate hosts and marine mammals as definitive hosts. It is reported from both farmed and wild salmonids in Norway and occur often in wild Atlantic salmon, with infection occurring during their marine phase, although specific data from Norway has not been identified. The effect on salmonid health is not clear, although it has also been associated with red vent syndrome in wild salmonids. In this condition, lesions occur in the vent area, with moderate to intense bleeding in more severe cases, and is associated with high numbers of *Anisakis* larvae in the vent region; ocean-scale environmental conditions have been speculated to be of relevance to this

condition also (Noguera et al. 2009). A Master's thesis study from Norway has indicated a 25% prevalence of *Anisakis* in the viscera of pink salmon collected from rivers in Hordaland during 2017 (Fjær 2019), and studies from other regions have indicated a high prevalence and intensity of infection of pink salmon with Anisakidae (Bilska-Zając et al. 2016).

Paramoeba perurans: This amoeba causes amoebic gill disease (AGD) in marine fish, and, after being first identified in Norwegian Atlantic salmon farms in 2006, has caused considerable losses (Hellebø et al. 2017). Clinical signs include lethargy, anorexia, and increased ventilation rates, and macroscopic pathology can be observed on the gills. As compromised gill function, with maximum rate of oxygen uptake is drastically reduced, infection with *P perurans* affects appetite, growth and survival; untreated, up to 80% mortality has been reported (Oldham et al. 2016). There is little information on the impact of this infection on wild fish (Hvas et al. 2017; VKM 2014). However, due to the timing of when farmed salmon are most affected (autumn/winter; September until end of December) and when smolt of sea trout and wild Atlantic salmon migrate from the Norwegian fjords to the open sea or return to fresh water to spawn (spring, summer) it seems unlikely that they will be of risk of infection (VKM 2014). A study from Canada of almost 3000 wild fish, including from near salmon farms, did not identify this infection, and similar results have also been obtained from Scotland (Oldham et al. 2016). The Canadian study also included 12 pink salmon, all of which were negative for this parasite, and there are no reports of which we are aware that describe infection of pink salmon with this parasite.

Ichthyobodo necator and *I. salmonis*: These flagellate ectoparasites colonise the skin and gills of a range of fish, including salmonids. Whereas *I. necator* seems to be restricted to freshwater environments, *I. salmonis* is found in both marine and fresh water. In Norway, infections have been reported in Arctic charr, brown trout, rainbow trout, and Atlantic salmon, with infected fish in fresh water, brackish water, and sea water (Isaksen et al. 2011; Isaksen 2013). Severe infections result in the destruction of epithelial or epidermal cells, and are associated with osmoregulatory or respiratory problems. In addition, epidermal damage to the skin makes the host more susceptible to secondary infections. Ichthyobodosis occurs in both wild and farmed fish and is considered as an important parasitic disease in Norwegian salmon farms; in wild brown trout a prevalence of 27% has been reported (Isaksen et al. 2013). *Ichthyobodo* infection was found in juvenile pink salmon in Japan, although at low prevalences – only 1.7% compared with over 20% in 3 other species of Pacific salmon (Urawa 1992). Nevertheless, this indicates that pink salmon could spread the parasite.

Spironucleus spp.: There are two species in the flagellate genus *Spironucleus* that infect salmonids, *S. salmonicida* and *S. barkhanus. S. salmonicida* is an endoparasite infecting marine salmonids, including Atlantic salmon, and is distinct from the freshwater species, *S. barkhanus*, that infects salmonids, such as grayling (*Thymallus thymallus*) (Jørgensen and Sterud 2006). Whereas *S. salmonicida* causes severe systemic disease, characterized by sub-cutaneous and muscular lesions along with extensive necrotic changes in internal organs, with high morbidity and mortality, *S. barkhanus* has little or no pathogenicity in its host

species (Sterud et al. 2003). Both species are present in Norway, with outbreaks of *S. salmonicida* showing prevalence of close to 100% in some farms. Although outbreaks in farmed chinook salmon have been reported (Kent et al. 1992), we have no information on whether pink salmon are hosts for the *Spironucleus* species, nor whether infection of pink salmon would affect the dynamics of *S. salmonicida* or *S. barkhanus* in native Norwegian salmonids.

Ichthyophthirius multifiliis: Various ciliates can infect salmonids, including several in the subclass Peritrichia, and include the genus *Trichodina*. Another ciliate, also an ectoparasite, *Ichthyophthirius multifiliis,* causes white spot disease on freshwater fish. In this disease, each white spot on the body, fins, and gills of the fish is an encysted parasite, feeding on the skin and gills, and, in heavy infections, resulting in fish death due to reduced oxygen uptake, osmoregulatory problems, and secondary infections. In the mid-1970s, an outbreak of ichthyophthiriasis at an Atlantic salmon hatchery in Finland wiped out over 80,000 Atlantic salmon smolt (Valtonen and Keränen 1981), but, in general, the parasites are controlled in freshwater fish farming through chemical treatments. Among wild salmonids, an epizootic with very high mortalities has been reported among adult sockeye salmon (spawning and pre-spawning) in Canada (Traxler et al. 1998); pre-spawning losses reached over 80% at some locations. Investigations on this outbreak also reported the occurrence of infection in pink salmon (Traxler et al. 1998). In wild fish in Norway, a 2% prevalence of *I. multifiliis* has been reported among salmon parr in the Alta River (Larsen and Lund 1997).

Desmozoon lepeophtherii (syn. *Paranucleospora theridon*): This microsporidian infects both farmed Altantic salmon and salmon lice, and has been associated with gill disease in Norwegian salmon. The nomenclature has been somewhat controversial and it also unclear whether it is associated with pathology or disease in salmon (see Freeman and Sommerville 2011; Matthews et al. 2013). Although identification of the parasite in different lesions indicates that it may be associated with chronic proliferative gill inflammation (Weli et al. 2017), it has also been suggested as having a potential use as a biological control for salmon lice (Freeman and Sommerville 2011).

Nucleospora salmonis: This microsporidian infects a broad range of salmonids, and the main clinical presentation is lethargy and anaemia; pale gills are the main specific external sign (Hedrick et al. 2012). In France, infection has been reported from Atlantic salmon, brown trout, and Arctic charr, both from hatcheries and wild (El Alaoui et al. 2006), in association with increased morbidity and mortality. To our knowledge, the parasite has not been reported from salmonids (or any other fish) in Norway to date.

Tetracapsuloides bryosalmonae: This myxozoan cycles between an invertebrate host (freshwater bryozoans) and a vertebrate host, salmonid fish, where it causes proliferative kidney disease (PKD). PKD is characterized by swollen kidneys and spleen, with anaemia. In fish farms and hatcheries, outbreaks have been associated with 100% prevalence and 95% mortality (Carraro et al. 2016). A variety of salmonid fish can be hosts, including Atlantic salmon and brown trout (although the latter are dead-end hosts). In Norway, as well as

reports of PKD outbreaks in salmonid hatcheries (Mo and Jørgensen 2017), a further outbreak between 2002-2004 caused extensive mortality amongst wild Atlantic salmon fry (Sterud et al. 2007). Furthermore, a retrospective survey on previously collected fish found that *T. bryosalmonae* occurred in Atlantic salmon parr in over 70% of 91 sampled Norwegian rivers, in brown trout parr in almost 90% of 19 sampled rivers in southeastern Norway, and was also found in Arctic charr (Mo and Jørgensen 2017). Increases in the prevalence and severity of infections with this myxozoan in northern Europe have been associated with climate change, which has been suggested to reflect increased production of the spore stages from the invertebrate hosts (Tops et al. 2006). Given that pink salmon can also be infected with *T. bryosalmonae* (Braden et al. 2010), it may be speculated that they may act as additional hosts and contribute to the dissemination of this parasite.

Parvicapsula **spp.:** The myxozoans *Parvicapsula pseudobranchiola*, *P. minibicornis,* and *P. kabati* all have been shown to infect salmonids, with differing degrees of host specificity and geographical distribution. *P. pseudobranchiola* has been detected in farmed and wild salmonids (Atlantic salmon, Arctic charr, and sea trout) in marine environments in Norway, with clinical signs including sluggishness, cataracts, exophthalmia, and eye bleeding, with the pseudobranchs of infected fish often extensively affected (Jørgensen et al. 2011). *P. kabatai* has been reported from pink salmon in Canada and seems to be associated with proliferative chronic nephritis in some species of Pacific salmon (Jones et al. 2006). *P. minibicornis* infection, also associated with kidney disease, has been reported from sockeye salmon, coho salmon, and pink salmon in USA and Canada (Atkinson et al. 2011). The lifecycles are not well described.

Myxobolus cerebralis: This myxozoan parasite infects both wild and farmed salmonids (including Atlantic salmon and Arctic charr), causing whirling disease that affects juvenile fish with deformation of the skeleton and cartilage, as well as neurological damage. Affected fish cannot swim normally, instead using a corkscrew type of motion. They cannot feed properly and are vulnerable to predation. The lifecycle is between the vertebrate host (salmonid fish) and the invertebrate oligochaete *Tubifex tubifex*. Although considered to have a very wide distribution, from Central Europe to Northern Asia, associated with unrestricted transfer of live rainbow trout, and also introduced to USA in 1950s (Sarker et al. 2015), it has not been reported from Norway recently; there is a single paper from 1971 (Håstein 1971).

Group 2: Parasites that are zoonotic (may have a public health impact)

Zoonotic, fishborne parasites include several nematodes and cestodes in addition to numerous different trematodes. These can all be transmitted to humans by ingestion of undercooked fish (Anisakiidae, Diphyllobothriidae, Opisthorchiidae, and Heterophyidae) or, for *Spirometra* species, by ingestion of other lifecycle stages (or, alternatively, through open wounds or across mucous membranes). Both Anisakidae and some Diphyllobothridae are endemic parasites in Norway and Norwegian waters. Due to the first intermediate hosts of these parasites (freshwater copepods for Diphyllobothridae and marine crustaceans for Anisakids), the fish that may act as transmission routes (second intermediate hosts) to

humans are freshwater and marine, respectively. As all the parasites that can be transmitted to humans by ingestion of stages in fish, adequate cooking of the fish or sufficient freezing to kill the parasite will prevent transmission. Thus, the risk from spread or establishment of zoonotic parasites (that may infect consumers via the foodborne route) due to the incursion of pink salmon are not considered further here. However, it should be noted that allergenic responses in response to exposure to Anisakids may still occur, even if the parasite is dead and thus transmission is impossible; this parasite is already established in Norwegian fish.

Group 3: Aquatic organisms that have a parasitic stage in their life cycle, but are of relevance and interest in the Norwegian ecosystem, and may be affected by the incursion of pink salmon.

Freshwater pearl mussel (*Margaritifera margaritifera*, Bivalvia: Unionoida) is an endangered species, and, in Europe, Norway holds the largest numbers of individuals and over 25% of the European populations (Larsen 2010). Freshwater pearl mussels can live up to 150-300 years, but an obligatory initial stage of the lifecycle is a parasitic larva, known as glochidia, which encapsulates on the gills of a suitable host fish, either brown trout or Atlantic salmon. Although adverse effects on Atlantic salmon associated with infestation with the glochidia of freshwater pearl mussels appear to be low (Makharov and Bolotov 2010), very heavy infestations of brown trout with the glochidia (900 glochidia per g fish weight) are associated with elevated mortality and reduced swimming performance (Taeubert and Geist 2013).

The duration of this parasitic stage seems to be critical in determining the survival of the post-parasitic phase of the mussels, with a longer parasitic stage being associated with larger size and better growth rate (Marwaha et al. 2017). In Norway, the populations of freshwater pearl mussels are divided into two genetically distinct strains, one of which preferably uses brown trout as hosts for glochidia and one which preferably uses Atlantic salmon as hosts (Karlsson et al. 2014). Glochidia of freshwater pearl mussels have been observed on pink salmon spawners (E.P. Ieshko, pers. comm.), but as they die after spawning these glochidia will not survive. Moreover, even if juveniles of pink salmon might occasionally become infested by glochidia, their stay in freshwater is far too short for the glochidia to develop into the free-living stage (Zyuganov and Veselov 2015). Any potential impact of establishment of pink salmon on pearl mussels would be indirect, through a possible reduction in the density of Atlantic salmon or brown trout, or if the pearl mussel spread its glochidia to pink salmon instead of obligate hosts.

3.3.3.2 HAZARD CHARACTERIZATION

Many parasites (around 80 genera) have been considered as potentially relevant for this assessment, and are listed in Appendix III. Given the extent and variety of parasites of salmonid fish, these should be considered only as examples. Other parasites may also be relevant, but our current knowledge is insufficient to identify these.

For those parasites already present in Norway, the incursion of pink salmon into Norwegian waters is expected to have only **minimal** impact, with **medium confidence**, on biodiversity in Norway, mediated through the following parasites:

- *Gyrodactylus salaris*,
- *Lepeophtheirus salmonis* (salmon louse),
- *Caligus* spp. (sea lice),
- *Argulus* spp. (fish lice),
- *Eubothrium crassum*,
- *Anisakis simplex*,
- *Paramoeba perurans*,
- *Spironucleus* spp.,
- *Desmozoon lepeophtherii* (syn. *Paranucleospora theridon*).

For some parasites that can infect pink salmon, the introduction with these fish may result in native salmonids being exposed to a new pathogen, or new strain of pathogen, that may have more serious effects. Alternatively, or additionally, the pink salmon themselves may spread the parasites already present in Norwegian waters further by acting as new hosts.

The project group assesses that the potential consequences for biodiversity in Norway are **major**, with **medium confidence**, following introduction of:

- *Ichthyobodo necator* and *I. salmonis*
- *Ichthyophthirius multifiliis*
- *Tetracapsuloides bryosalmonae*
- *Parvicapsula* spp.
- *Myxobolus cerebralis*

This assessment is based upon the knowledge on the severity of the diseases that may result from such infection, particularly in combination with predicted climate change (50-year perspective). Of these, *Myxobolus cerebralis* could perhaps be considered of greatest concern regarding impacts on native salmonids, as this parasite has been reported to cause the most severe outbreaks both in aquaculture and wild fish in USA, where it remains a serious issue that has both ecological and financial impacts on juvenile salmonids and also appears to be hard to diminish and control.

3.3.3.3 LIKELIHOOD

Most of the parasites assessed to have potential consequences for aquaculture in Norway have already been reported from Norway. Establishment or increased influx of pink salmon could therefore both increase the distribution and prevalence of these parasites with new introductions (possibly new strains), but also spread further the parasites that are already here. Based on the information that we have on parasites in pink salmon, both in Norway and elsewhere, the likelihood of this occurring for any of these parasites (see list of species assessed in 3.3.3.1) is **moderately likely** with **low confidence**.

3.3.3.4 RISK CHARACTERIZATION

The project group assesses that the risk of negative impact on aquaculture in Norway associated with introduction and spread of parasites, stemming from spread and potential establishment of pink salmon, is **moderate** (bordering to high) the parasites that has not yet been detected in Norway:

- *Ichthyobodo necator* and *I. salmonis*
- *Ichthyophthirius multifiliis*
- *Tetracapsuloides bryosalmonae*
- *Parvicapsula* spp.
- *Myxobolus cerebralis*.

The project group also assess that there is **low** (bordering to moderate) risk associated with further spread of the parasites that are already present in Norway:

- *Gyrodactylus salaris*
- *Lepeophtheirus salmonis* (salmon louse)
- *Caligus* spp. (sea lice)
- *Argulus* spp. (fish lice)
- *Eubothrium crassum*
- *Anisakis simplex*
- *Paramoeba perurans*
- *Spironucleus* spp.
- *Desmozoon lepeophtherii* (syn. *Paranucleospora theridon*).

The overall **confidence** of these assessments is **medium to low** due to little available data on the host status of pink salmon for most of these parasites (see 3.3.3.2 and 3.3.3.3).

4 Hazards to the aquaculture industry

4.1 Pathogens

Aquaculture is a major industry in the marine areas that were invaded by pink salmon in 2017 and 2019. The hazards most relevant for aquaculture come from the introduction and spread of various pathogens (see 3.3).

Disease agents that could have been transferred from the native area of pink salmon in the northern Pacific, and disease agents that can be transferred with pink salmon from the White Sea and Barents Sea drainages, are potential candidates for being hazards to the industry. In addition, pink salmon may contribute to the spread of pathogens that are already in Norwegian waters.

All farmed Atlantic salmon in Norway in the marine phase are vaccinated. The significant salmon pathogens *Vibrio anguillarum*, *Aliivibrio salmonicida,* and *Moritella viscosa* are therefore not considered.

4.1.1 Viral pathogens

4.1.1.1 HAZARD IDENTIFICATION

Potential viral hazards are

- Viral haemorrhagic septicaemia virus
- Infectious hematopoietic necrosis virus
- Infectious salmon anaemia virus
- Salmonid alphavirus
- Infectious pancreatic necrosis virus
- Piscine myocarditis virus
- Salmon gill poxvirus
- Viral erythrocytic necrosis virus
- Oncorhynchus masou virus

4.1.1.2 HAZARD CHARACTERIZATION

The project group assesses that the potential consequences of viral pathogens associated with pink salmon for aquaculture are:

- Viral haemorrhagic septicaemia virus**: minimal** with **very low confidence.**
- Infectious haematopoietic necrosis virus: **major** with **low confidence.**
- Infectious salmon anaemia virus: **minimal** with **medium confidence.**

- Salmonid alphavirus (SAV): Movements of SAV-infected pink salmon from south to north could be a risk factor for the spread of PD, which can be lethal to Atlantic salmon and rainbow trout. The project group assesses that the potential consequences for aquaculture in Norway are **moderate** with **low confidence.**
- Piscine orthoreovirus: **minimal** with **medium confidence.**
- **Other viral pathogens:** These include: infectious pancreatic necrosis virus, piscine myocarditis virus, salmon gill poxvirus, viral erythrocytic necrosis virus, and Oncorhynchus masou virus. In sum, the project group assesses that the potential consequences for biodiversity in Norway are **minimal** with **medium confidence**.

4.1.1.3 LIKELIHOOD

All viral pathogens identified as potential hazards for biodiversity in Norway, can potentially transported and spread by pink salmon to farmed fish in Norway (see 4.1.3). The likelihood of spread is dependent on the number of pink salmon in Norwegian coastal waters, the prevalence of the infection in farmed and native wild fish and in pink salmon, the ease of spread (survival of pathogen in environment, duraton and amount of shedding, availability of secondary or intermediate hosts etc). The success of spread is also dependent on the susceptibility of target population; i.e. should farmed fish be vaccinated against particular pathogens, they will not be susceptible to that pathogen, unlike wild fish.

4.1.1.4 RISK CHARACTERIZATION

The project group assesses that the risk of negative impact on aquaculture in Norway associated with introduction and/or spread of viruses, stemming from spread and potential establishment of pink salmon, is **moderate** with **low confidence** for:

- Infectious hematopoietic necrosis virus

The project group assesses that there is **low** risk, with **medium to low confidence,** associated with spread of:

- Viral haemorrhagic septicaemia virus
- Infectious salmon anaemia virus
- Salmonid alphavirus
- Infectious pancreatic necrosis virus
- Piscine myocarditis virus
- Salmon gill poxvirus
- Viral erythrocytic necrosis virus
- Oncorhynchus masou virus

4.1.2 Bacterial pathogens

4.1.2.1 HAZARD IDENTIFICATION

Potential hazards in relation to introduction or spread of bacterial pathogens to aquaculture by pink salmon are the same as described for biodiversity. See 3.3.2.1 for details.

4.1.2.2 HAZARD CHARACTERIZATION

For aquaculture, the project group assesses that the potential consequences differ in relation to impact on biodiversity in these aspects:

- The potential impact of *Piscirickettsia salmonis* is upgraded to **moderate** with **very low confidence.**
- The effect of *Aeromonas salmonicida* is downgraded to **minimal** with **low confidence.**

4.1.2.3 LIKELIHOOD

The likelihood of negative impact on aquaculture in relation to introduction or spread of bacterial pathogens by pink salmon is assessed to have the same likelihood as for impact on biodiversity for the considered hazards (see 3.3.2.3 for details), with the following exceptions; Negative effects are assessed as **moderately likely** (still with **very low confidence**) for *P. salmonis*, and **very unlikely** (with **medium confidence**) for *A. salmonicida.*

4.1.2.4 RISK CHARACTERIZATION

The project group assesses that the risk of negative impact on aquaculture in Norway associated with introduction and/or spread of bacterial pathogens, stemming from spread and potential establishment of pink salmon, is **moderate** with **low confidence** for:

- *Renibacterium salmoninarum*
- *Piscirickettsia salmonis*

The project group assesses that there is **low** risk with **medium confidence** associated with spread of:

- *Aeromonas salmonicida*
- *Flavobacterium psychrophilum*
- *Mycobacterium* spp.
- *Yersinia ruckeri*

4.1.3 Parasites

4.1.3.1 HAZARD IDENTIFICATION

Potential hazards in relation to introduction or spread of parasitic pathogens to the aquaculture by pink salmon are the same as described for biodiversity. See 3.3.3.1 for further information.

4.1.3.2 HAZARD CHARACTERIZATION

The assessment of parasites as a potential hazard to aquaculture is the same as for biodiversity. See 3.3.3.2 for further information.

4.1.3.3 LIKELIHOOD

The likelihood of negative impact on aquaculture in relation to introduction or spread of parasitic pathogens by pink salmon is assessed to be the same as for impact on biodiversity. See 3.3.3.3 for further information.

4.1.3.4 RISK CHARACTERIZATION

The project group assesses that the risk of negative impact on aquaculture in Norway associated with introduction and spread of parasites, stemming from spread and potential establishment of pink salmon, is **moderate** (bordering to high) the parasites that has not yet been detected in Norway:

- *Ichthyobodo necator* and *I. salmonis*
- *Ichthyophthirius multifiliis*
- *Tetracapsuloides bryosalmonae*
- *Parvicapsula* spp.
- *Myxobolus cerebralis*.

The project group also assess that there is **low** (bordering to moderate) risk associated with further spread of the parasites that are already present in Norway:

- *Gyrodactylus salaris*
- *Lepeophtheirus salmonis* (salmon louse)
- *Caligus* spp. (sea lice)
- *Argulus* spp. (fish lice)
- *Eubothrium crassum*
- *Anisakis simplex*
- *Paramoeba perurans*
- *Spironucleus* spp.
- *Desmozoon lepeophtherii* (syn. *Paranucleospora theridon*).

The overall **confidence** of these assessments is **medium to low** due to little available data on the host status of pink salmon for most of these parasites (see 4.1.3.2 and 4.1.3.3).

5 Impact on ecosystem services

5.1 Pink salmon and ecosystem services

The pink salmon is regarded as good food, provided that they are captured in the sea and early in the season, but their quality as food is quickly reduced after they have entered the rivers and later in the season, as they undergo morphological changes towards spawning. In the Pacific Ocean, large shoals of pink salmon are caught by trawling and purse seine. Most of the catch is canned, as other Pacific salmon are considered more valuable. In the White Sea, the shoals of pink salmon are not considered large enough for trawling in a commercial fishery. In this region, most pink salmon are caught by fencing the large rivers and taking all upmigrating salmonids every third day.

5.2 Pink salmon affecting other ecosystem services

Angling for Atlantic salmon, sea trout, and Arctic charr is an important recreational activity for nearly 100,000 people in Norway and generates a large income to landowners along rivers spread along the entire coastline of Norway (Myrvold et al. 2019). In 2018, 73,000 Atlantic salmon anglers spent about 730,000 days angling. Salmon anglers' daily expences for fishing permits, food, travel etc. in 2018 was estimated at 188 euros per angler, and the total consumpton related to salmon angling in Norway was 129 million euros (Andersen and Dervo 2019). There is also a coastal fishery, using bag nets and bend nets (about 850 active fishers in 2017, Myrvold et al. 2019), which is most extensive in northern Norway, in the areas with the largest occurrence of pink salmon at present.

If the abundance and productivity of native salmonids decreases, this will have direct negative consequences on the harvestable surplus available for coastal fisheries, and the recreational fishery in the rivers.

The high densities of pink salmon in some Finnmark rivers in 2019 was viewed negatively both by angling tourists, who consider pink salmon a less valuable catch than native salmonids, and by the local anglers and managers who try to control the number of upmigrating pink salmon (Kollstrøm 2019).

We know of no formal studies (either biological or social science) of the influence of introduced pink salmon on ecosystem services. Based on the deliberations above, we believe that pink salmon are more likely to impact negatively than positively on the value of fishing in Norway.

6 Identification of pink salmon habitats in Norway

6.1 Under current climate conditions

In 2017 and 2019, pink salmon spawners were recorded in rivers all along the Norwegian coast. Whether this may lead to establishment of self-sustaining pink salmon in many rivers in Norway remains unclear, but juvenile pink salmon were observed in many Finnmark rivers monitored in spring 2018, in one river in Trøndelag, and in several rivers in Vestland counties.

Regular occurrence of pink salmon over several generations has so far only been seen in rivers in eastern Finnmark, and for the odd-year pink salmon breeding line. It is not clear whether this restricted occurrence is related to climatic conditions.

Using data on pink salmon catches in 2017 and some potential explanatory variables that have been used to study the distribution of escaped farmed Atlantic salmon (chapter 2, and see Hindar et al. (2018)), we built a simple model for the geographical variation in catches of pink salmon in Norway on the supposition that pink salmon are "homeless", in the same sense that escaped farmed salmon are homeless. We found that pink salmon catches in 2017 were positively correlated with the long-term (2006-2018) catches of wild Atlantic salmon, and interpret this as being caused by: (1) pink salmon choosing rivers and habitats that commonly occur in rivers with native salmonids, and (2) reporting of pink salmon being better in rivers where there are many anglers.

Two other factors were important to explain the distribution of pink salmon catches in 2017: the catches were higher in rivers close to the border to Russia than in rivers farther away, and the catches were higher in rivers that are situated close to the coastline than in rivers located far away from the coastline. We interpret that the primary cause for the pink salmon invasion of Norwegian rivers in 2017 was the spreading of pink salmon from sources in the White Sea and eastern Finnmark. No quantitative results are shown here, because this modelling is based on uncertain data and is still preliminary.

Only preliminary data are available for the 2019 observations of pink salmon (Berntsen et al. 2019 and Natural Resources Institute Finland, unpublished data), but large numbers of pink salmon were reported in Finnmark, and in eastern Finnmark high numbers of pink salmon were found in the small rivers Karpelva and Klokkerelva, in addition to several larger rivers. In 2019, substantial numbers of pink salmon occurred in rivers in western Finnmark and in Troms, where few fish were seen in 2017. The largest discrepancies relative to the 2017 observations were found in the rivers Målselv, Reisaelva, Altaelva, and Repparfjordelva, due to higher numbers of pink salmon being reported from these northwestern rivers in 2019 than in 2017.

6.2 In a 50-year perspective

Current climate conditions are unlikely to be representative of those of the coming decades. The temporal trends in sea temperature and ice extent are already strong (Figures 6.2-1 and 6.2-2 below, as well as Figure 1.2.10-3 and Figure 7-1). This signals a dramatic development for the whole ecosystem in which pink salmon may be establishing, with major consequences for all fish stocks, as well as for marine mammals, birds, plankton, and oceanic chemistry far beyond the scope of this report.

There are strong and coordinated responses of salmonid production to trends in climate and atmospheric-oceanic coupling (Beamish et al. 1999; Naiman et al. 2002). For example, a positive North Pacific Gyre Oscillation (NPGO) indicates increased primary productivity, which, again, causes increased marine growth and age at maturity for salmon in the Pacific (Debertin et al. 2016). The great increases in abundance of pink salmon during the last few decades in the North Pacific Ocean and Bering Sea have been linked to the strength and position of the Aleutian Low altered winds, elevated ocean temperatures, and increased primary and secondary production (Mantua et al. 1997). Effects are direct, since temperatures drive the speed of physiological processes, and indirect, as temperature influences the timing and development of zooplankton prey stock (Springer and Vliet 2014).

Such effects of climate on the abundance of pink salmon in the North Pacific Ocean and Bering Sea suggest that the abundance of pink salmon in the North Atlantic Ocean, Barents Sea, and White Sea will also be positively influenced by a warming climate. However, it is not clear whether a warmer climate will have a negative or positive effect on the potential for pink salmon to establish in Norwegian rivers south of Finnmark/Troms. Climate conditions, have a considerable impact on time from spawning to hatching of eggs and emergence of fry as they influence water temperatures in rivers during autumn and winter. Water temperatures in the ocean may influence the migration behaviour and timing of adult fish returning to the rivers to spawn. The failure of the first introductions of pink salmon to northwest Russia in the 1960s and 1970s was explained by Russian scientists (e.g., Gordeeva and Salmenkova 2011) as being due to the failure of these fish to return to rivers at the appropriate time in autumn. This implies that the broodstock from Sakhalin was not adapted to the climate in Northwest Russia. On the other hand, broodstock from further north in the Pacific was apparently better adapted to conditions in the north. Thus, climatic conditions were likely important for the subsequent establishment of self-reproducing pink-salmon populations in the White Sea area. Also, studies have demonstrated that both native and introduced pink salmon populations may adapt to a changing climate regime in relatively few generations (Taylor 2008; Gordeeva and Salmenkova 2011; Kovach et al. 2012).
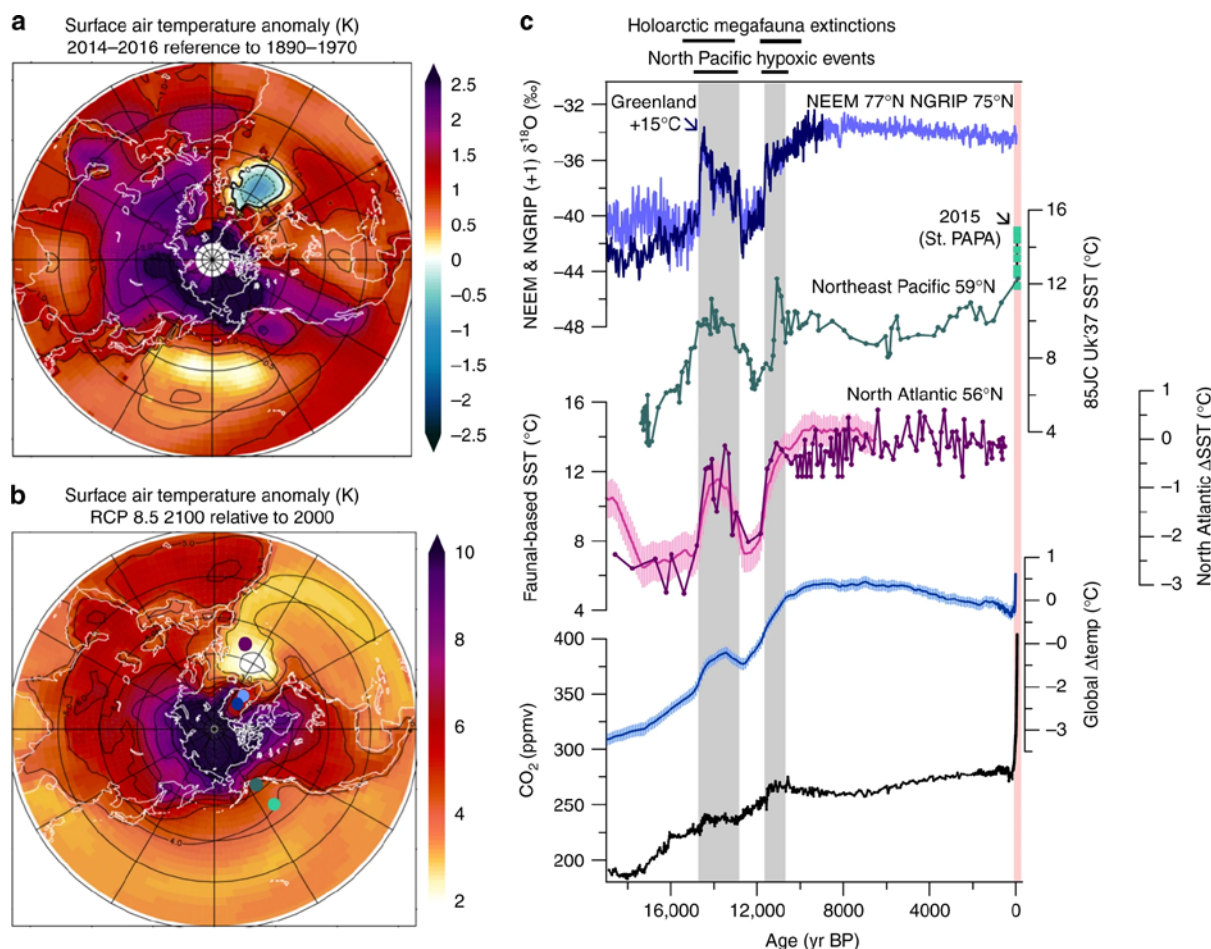
Figure 6.2-1: Climate projections for the Arctic and North Atlantic. Recent and projected surface air temperatures (SAT) in context of past abrupt warming events in the northern hemisphere: (a) The projected SAT anomalies for 2014–2016 relative to 1890–1970 and (b) paleoclimate records spanning the past 19,000 years, show abrupt Arctic warming in concert with abrupt warming in the mid-latitude North Pacific and North Atlantic basins (c). Record-breaking Arctic warming in recent years associated with anomalously high SSTs in the Northeast Pacific, despite a cold spot in the North Atlantic (a). Grey shaded bars over the paleoclimatic series represent two episodes of rapid warming in Greenland that seem to coincide with abrupt SST increase in the Northeast Pacific and North Atlantic, increases in CO_2 concentration, and intervals of widespread hypoxia in the North Pacific and Holarctic megafauna extinctions. Pink shaded bar (far right of c) highlights changes since 1950. Figure from Praetorius et al. (2018).
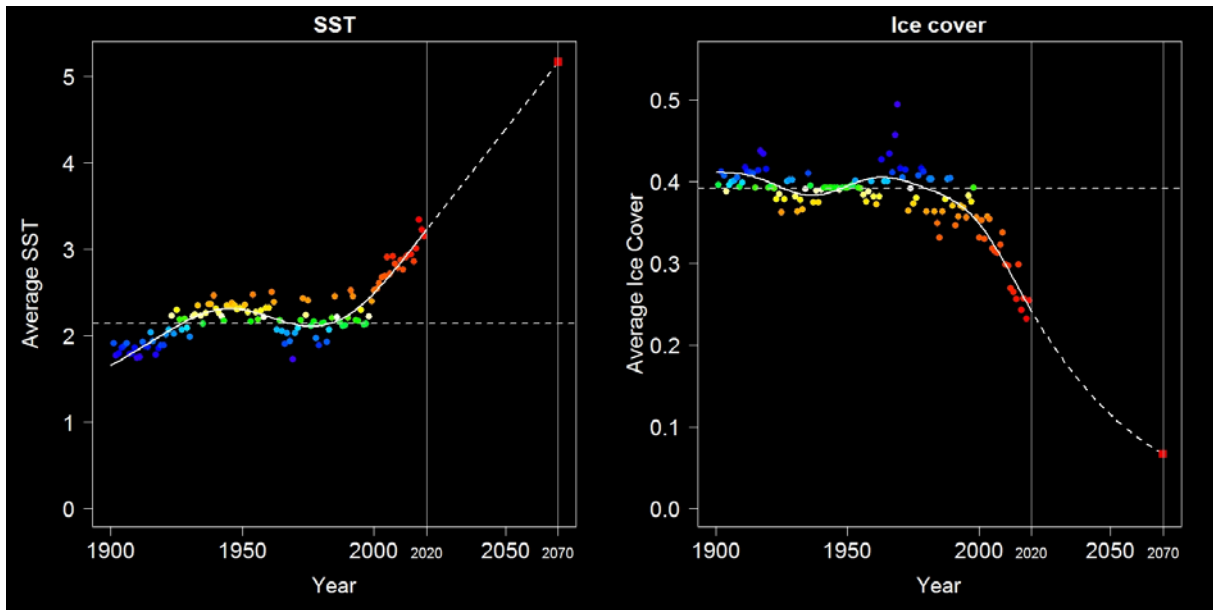
Figure 6.2-2: Temporal trends in annual average sea surface temperature (SST, given as °C) and ice cover (gven a proportion of area-cover) in the data area (see Figure 1.2.10-1), with trends extrapolated over the next 50 years until 2070. We see that this non-linear extrapolation of trends visible in the data predicts an SST in 2070 that is 3.0 °C over the 1900-2000 mean, which is consistent with, if slightly less than, the increased air temperature predicted by the Coupled Model Intercomparison Project (CMIP) shown in Figure 6.2-1. This illustrates the magnitude of expected change compared with observed interannual variance and the consistency of observed trends with long-term projections based on climate forcing.

7 Effects of climate on the spread of pink salmon to Norwegian waters

Sea surface temperatures (SST) may play an important role in determining the success of pink salmon in their year at sea in the Arctic. Pink salmon from Sakhalin Island did not establish self-sustaining populations in northwestern Russia, whereas the 1985 year-class from the Magadan oblast adapted to the environmental conditions of Barents- and White Sea drainages (Gordeeva and Salmenkova 2011). This implies that the success of pink salmon is, to some degree, temperature limited and thus the annual abundance of adult pink salmon in the Arctic and North Atlantic may increase with increasing sea temperatures (see Figure 7-1 for SST map). Climate change was associated with growth of many wild Pacific salmon stocks in the North Pacific Ocean and Bering Sea in the 1980s and 1990s, apparently through bottom-up forcing, linking meteorology to ocean physics, water temperature, and plankton production (Springer and van Vliet 2014).
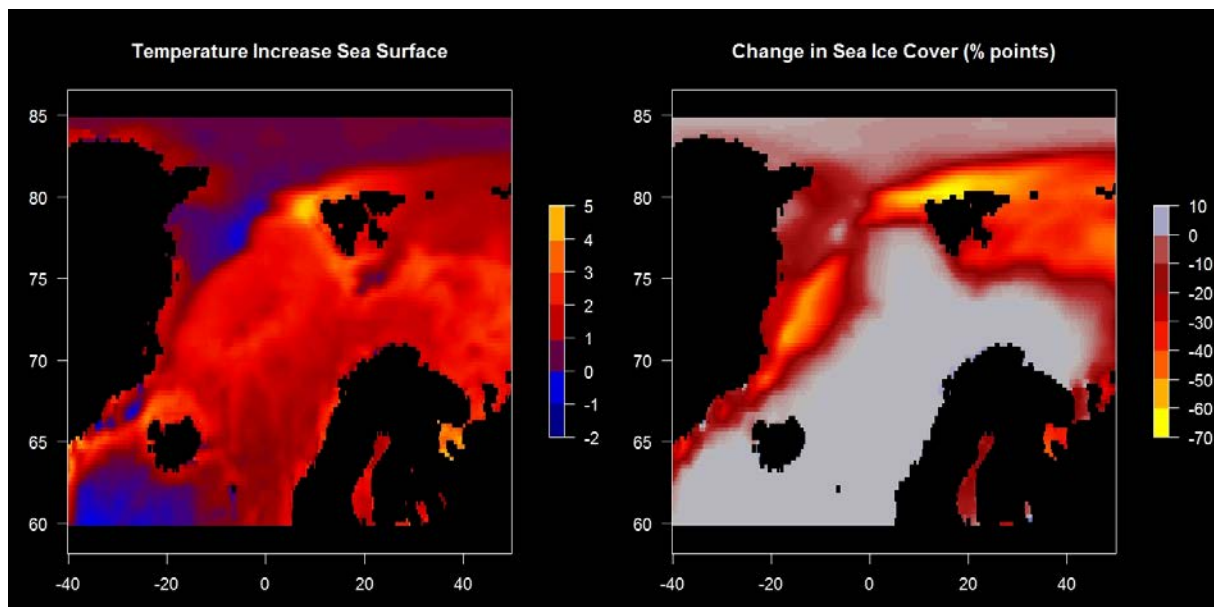
Figure 7-1: Changes in sea surface temperature (SST, given as °C) and ice cover (given a % area change) in the data area shown as a difference between average SST and ice cover from the period June 1901 - June 1981 to the period June 2014 - June 2019. (Some ice cover data is lacking for the 1940s). Note the increase in SST (left), and the corresponding decrease in ice cover (right), where most of the ice cover loss has occurred along the ice edge.

7.1 Pink salmon data

We used a time series of pink salmon "peak years" in Norway, based on available records 1957-2019 to denote years as "low years" with little or no pink salmon reported caught, "medium years" when catches were reported in several rivers, and "peak years" when large

numbers of pink salmon were caught in most rivers including rivers where the species had not previously been reported (see Figure 7.1-1).
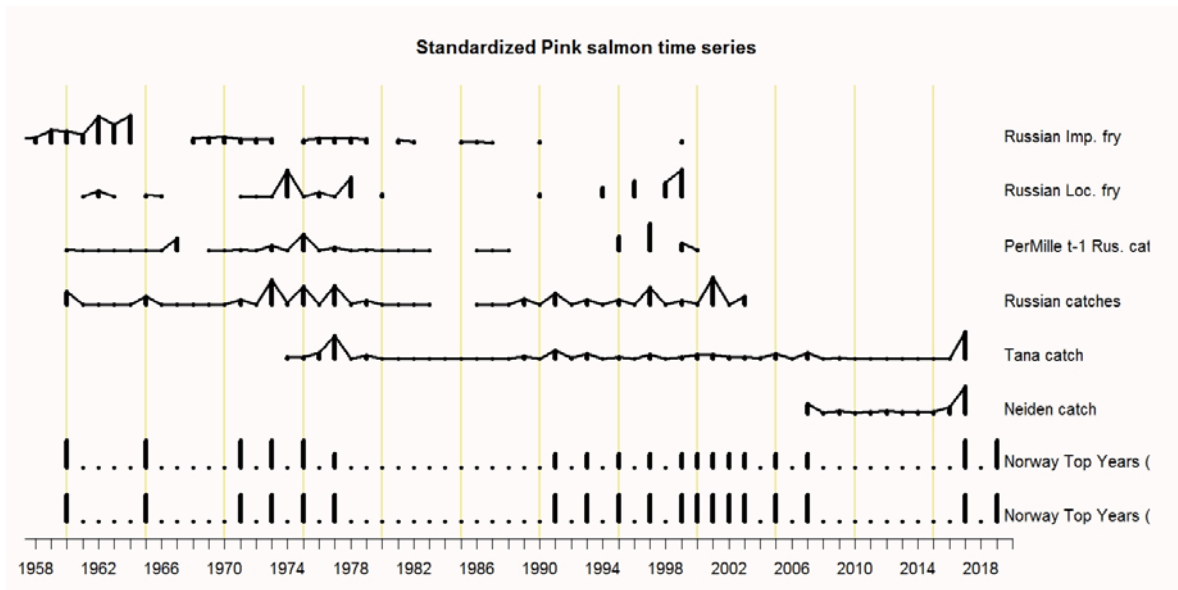
Figure 7.1-1: Available data shown as normalized time series. The quantitative data are connected by lines, all standardized to a 0-1 scale. The imported and locally produced fry in Northwest Russia are added together to one "Fry" variable in the model below. The quantitative Norwegian data are shown both graded to "medium" and "large peak" years, as well as binomially (peak/non-peak years in bottom time series). Small dots designate known zeros, bars either 0.5 (medium peak) or 1 (peak years). See Appendix III for details.

There is a peculiar two-year life cycle of pink salmon in the autocorrelations, albeit with enough noise to suggest considerable influence by data uncertainty, climate influence, and/or other factors. The Tana and Russian catches seem moderately but significantly correlated, both with each other and with the Norway peak year index (see Figure 7.1-2).
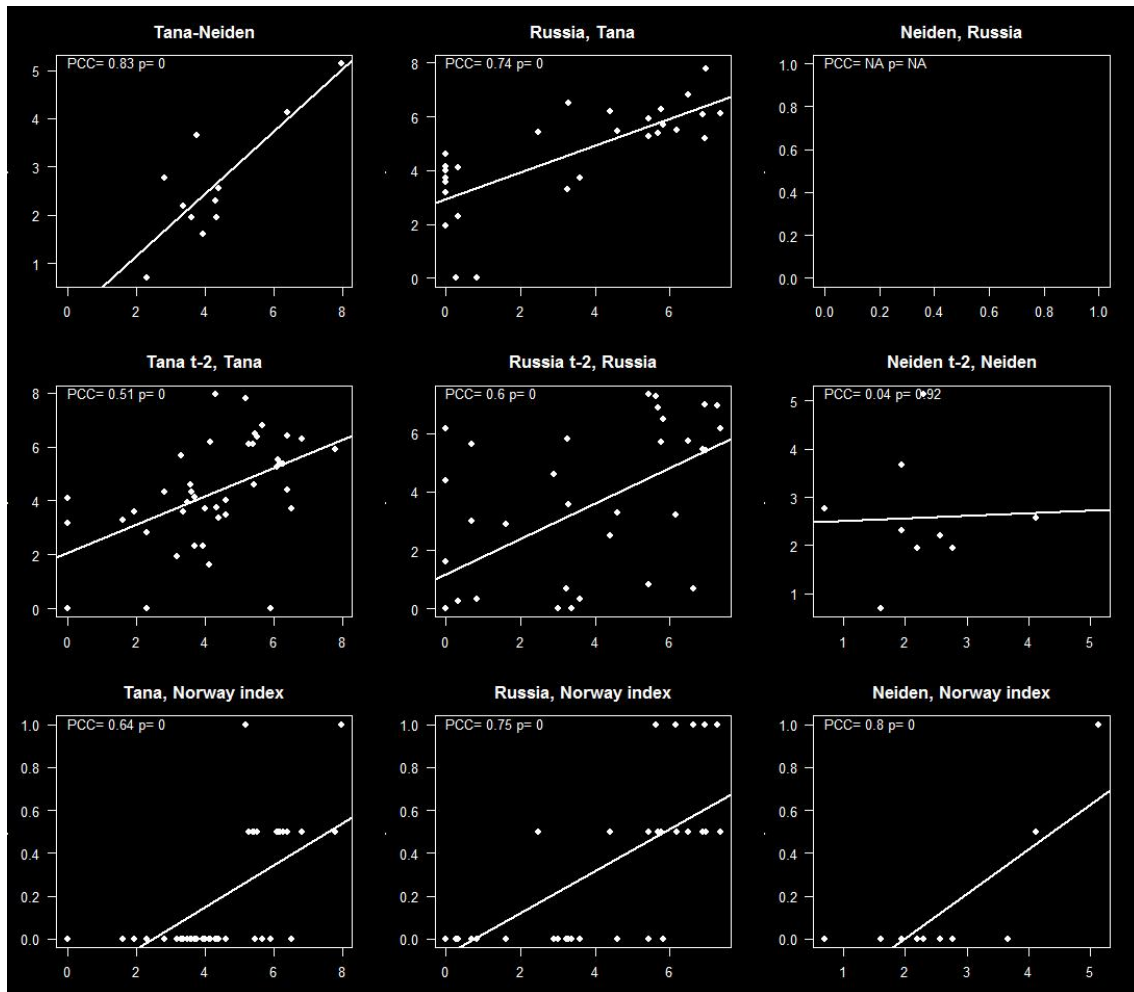
Figure 7.1-2: Relationships within and between the pink salmon data. The titles for each figure are the the names of the data being compared, with first the X-axis, then the Y-axis. The Neiden series is too short for much inference beyond a possible correlation with Tana. Catches in the Tana, on the other hand, are closely correlated with catches in Russia. The direct lag 2 correlations for catches in Russia and Tana (i.e., essentially lag1 autocorrelation for the alternating two-year populations) are moderate but significant. Both Tana and Russia seem to be correlated with the catch index in Norway in the same year.

7.2 Approach

The effect of sea temperature on marine survival of pink salmon is estimated through a proportional (quasi-)binomial generalized additive model where the expected mean μ is 0, 0.5 or 1 and denote none, half or full peak year (as defined under "Data") and expressed with a link function connecting the expected value

$$\mu_t = \frac{1}{1+e^{-X_t}}$$

(1)

to the predictor function

$$X_t = a_0 + a_1 B + f(G) + \varepsilon$$

(2)

where a_0 and a_1 are constants, B is a monotonic predictor, and f(G) is a thin plate (non-parametric) smoothing spline function allowing non-linear responses by minimizing

$$||y - g||^2 + \lambda J_{md}(g)$$

(3)

where y is the vector of y data, g =(g(x1), g(x2),.. g(xn))', and $J_{mnd}(g)$ is a penalty function for the deviations from linearity for g, and λ weights the trade-off between data fitting and smoothness of g. (For further details see Wood (2017)). Here λ is set to <5 and unimodality considered the only biologically plausible result.

To deal with any increased variance the underlying probability distribution was allowed an extra variable to make it a "quasi-binomial" distribution capable of handling the data directly:

$$P(X = k) = \binom{n}{k} p(p + k\phi)^{k-1}(1 - p - k\phi)^{n-k}$$

(4)

For the catch data from Tana and Russia we used the same smoothing spline approach, but as they consist of count data that had to be controlled for potential overdispersion, this was done similar to a Poisson regression with a log link function, but where a Poisson distributed data series Y would indicate that the mean μ = var(Y) a quasi-Poisson model assumes an overdispersion parameter θ so that var(Y) = θμ.

The software used was R 3.5.2 with packages mgcv (for GAM), ggmap (for mapping) and with raster and ncdf4 (for accessing and using ice cover temperature data).

7.3 Models

The main weakness of the present study is that the resulting lack of statistical power limits the options for searching for anything than single major effects – there may very well be multiple areas and time periods where sea temperature is important, but with the available data we are unlikely to detect anything but the strongest of effects.

As a baseline, we try a model of the form

$$X_t = a_0 + a_1 F_{t-m} + \varepsilon \qquad (5)$$

When X is the measure of Norwegian pink salmon catches, Russian fry at t-1, t-2 (or any other time step) had essentially no predictive value for Norwegian peak years (p>0.1, adjusted R.sq < 0.1). The same is apparent if we set X to be the Russian catches. The fry variable is thus not used in further models as it has little or no predictive power and its paucity would further reduce statistical power.

However, the model

$$X_t = a_0 + a_1 \ln(R_t) + \varepsilon \qquad (6)$$

where R is the Russian catches, confirms them to be correlated with the Norwegian peak years (p<0.05, adjusted R.sq=0.5). More importantly, models including lag2 autocorrelation perform significantly better for both Norway index data, Russian catches and Tana catches.

Given the shortness of the time series, their low resolution (one time point per year), low quality (a few rivers, inconsistent sampling over time) and in particular the non-stationary underlying process (due to variability in the Russian fish releases, the pink salmon being in an invasion phase, and the climate changing rapidly), the analysis is challenging and must be extrapolated upon with caution.

7.4 Ice-edge models

$$X_t = a_0 + a_1 X_{t-2} + f(D) + \varepsilon \qquad (7)$$

where D is a function of the distance from an unknown focal point to the nearest ice edge in a particular month of the year. This was addressed with 1000 randomly drawn focal points for all months of the year, but no systematic improvement of the model was detected beyond what would be expected by chance. Thus, it seems that distance from river estuaries and coastline to ice edge i is not a major influencing factor that is detectable with the current data set. This could be due to the salmon not following the ice edge or being particularly dependent upon it, but the lack of power to detect an effect due to data scarcity means that an effect of distance from ice edge cannot be ruled out.

7.5 SST aggregation

For a first assessment of temporal trends and statistical analysis, we focussed on the data from east of Svalbard that is defined by any spatial variance in sea ice distribution (i.e., influenced by ice edge dynamics) and not too close to the coastlines (Figure 7.5-1). The focus area described above does not appear qualitatively different from the rest of the data regarding seasonality and temporal trends.
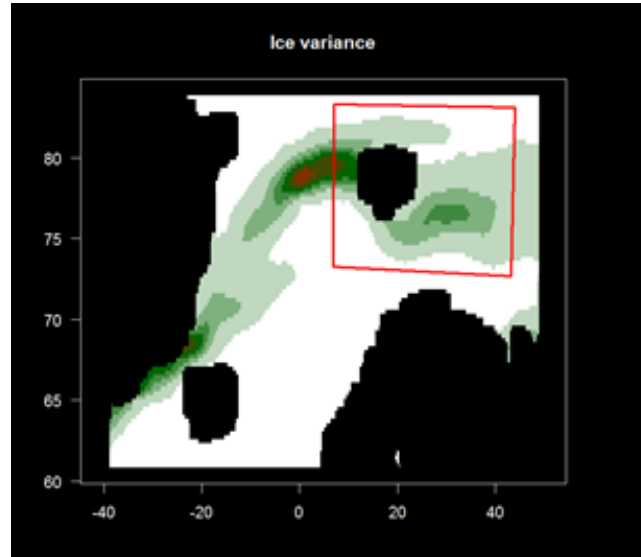
Figure 7.5-1: Variance in sea ice over the North Atlantic. The area singled out for initial analysis is defined by a variance > 0.001 (non-white) and being within the red polygon.

The temporal trends are strong, especially towards the end of the data period. Since the year 2000, the average SST seems to have increased by about one full degree C. When measuring years from June to June to have full winters enclosed in each year, 2019 enters with the average of June 2018-June 2019 an unprecedented full degree above the preceding year, two degrees over the normal range for the preceding century. Ice cover is shrinking correspondingly, as would be expected, both in maximum extent and minimum cover.

7.6 Temperature models

To address the effects of SST on pink salmon catches we used a set of models based on the framework described above:

$$X_t = a_0 + a_1 X_{t-1} + a_2 X_{t-2} + f(S_{t-m}) + \varepsilon \tag{8}$$

$$N_t = a_0 + a_1 \ln(N_{t-1}) + a_2 \ln(N_{t-2}) + f(S_{t-m}) + \varepsilon \tag{9}$$

Here (8) denotes the Norwegian graded index, X, in a quasi-binomial setting, while the N in (9) denotes the number of pink salmon caught in Tana or Russia, respectively. S is a series of monthly SST. The autoregressive term at t-1 was always insignificant, as would be

expected if the odd and even year populations are as isolated as they are assumed to be, and not yet big enough to interfere with each other negatively to a measurable extent (or big enough to exclude other generations from having detectable interannual variability).

As the SST data contain 36,000 cells, and 12 months for every annual salmon data point, searching through every plausible time lag for every likely ocean area easily produces so many candidate temperature variables that controlling for spurious relationships in these short time series using conventional methods like Bonferroni correction becomes futile.

First, an *a priori* series for S was tried, using the average of the focus area described above. If m denotes the number of months prior to June that mediates the main oceanic temperature effect, we can assume that $2 < m < 18$, as oceanic temperatures should be of little consequence late in spring when migration has begun, and cannot affect smolt before they have entered the ocean. Out of the resulting 16 candidate variables, $m = -13$ showed the most promise, i.e. hinting at an effect of May the previous year. However, the gain in predictive ability was modest unless the focal area and time lag were hand-picked, which would invalidate the statistical aspects. Thus, although this was considered promising and consistent with the existence of real effects, it is insufficient as a stand-alone analysis.

Instead, a pragmatic approach was chosen since we do not know either the most critical time periods or the sea areas in the Atlantic where the most temperature-critical stages takes place for pink salmon, we allowed a data-driven, if computer-intensive, search for the most influential temperature variability in space and time over the entire dataset of temperatures. Thus, we mapped the explanatory power of SST in predicting peak years for pink salmon catches along the Norwegian coast, as well as the numbers of pink salmon reported from Tana and the Russian river fisheries, as expressed in the models 8 and 9 above. The resulting 3-dimensional map, delineating which areas and time periods have the greatest explanatory powers, could then be assessed for biological plausibility and statistical validation.

Preliminary analysis where the SST series were smoothed with a moving average so

$S_m = \sum_{t=m-z}^{t=m} a_z SST_{i,j,t=t-m}$ (where *a* is a vector of corresponding weighting parameters), but this was found to not add perceptible predictive value. However, mapping the predictive power of each cell gave a set of interesting results as shown in the following maps presented in 7.7.

7.7 Results

The effect of SST on the Norway catch index was mainly constrained to May and June the previous year. April-June in the year of catching show practically no sign of predictive value, while the few areas of significance the other months are not very logically placed, small and scattered and thus likely to be spurious. Centered in May the previous year, however, a sea surface temperature in a substantial area between the Finnmark coast and Svalbard exhibits

a significant positive relationship with the number of pink salmon entering Norwegian rivers the following year (see Figure 7.7-1).

Figure 7.7-1: Map of the estimated p-value for the S term (function of temperature) in the model of Norwegian pink salmon peak years. Blue means no correlation, red a possible correlation (p < 0.025), yellow a very clear correlation (p < 0.01). There is a (positive) significant relationship with SST in May of the previous year in a substantial area between Finnmark and Svalbard.

Similar results were achieved for the catches in Tana River. However, there is a risk of potentially spurious correlations since this series is shorter. However, "real" numeric count data may display a closer relationship with ecological processes than a qualitative assessment. For one or both reasons, the areas where temperature significantly predicted pink salmon numbers in Tana were larger and with higher explanatory power than for Norway (see Figure 7.7-2).
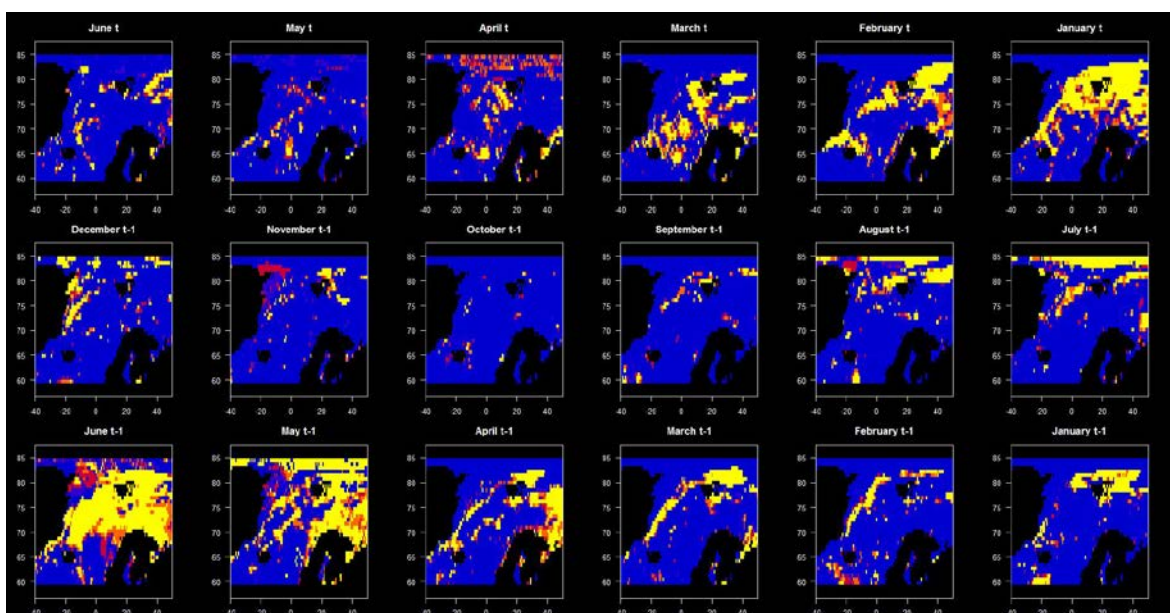
Figure 7.7-2: Map of the estimated p-value for the S term (function of temperature) in the model of Tana River pink salmon catches. Blue means no correlation, red a possible correlation (p < 0.025), yellow a very clear correlation (p < 0.01). There is a (positive) significant relationship with SST in May of the previous year in a large area between Finnmark and Svalbard, as well as in a more northerly area after the winter.

The major areas of significance for Tana are suggested to be between Finnmark and Svalbard in May and June the preceding year, which is consistent with the results for Norway as a whole. In addition, there may be a connection with the same waters, or further north, in the immediately preceding winter, centered on January.

Finally, for the Russian catches the results are again consistent, with the main area of effect being north of Finnmark, but further east than for Tana and Norway, essentially on the edge of the map, but also centered on May (April-June) the preceding year, and with a weaker effect in the northern areas for the immediately preceding January (see Figure 7.7-3).
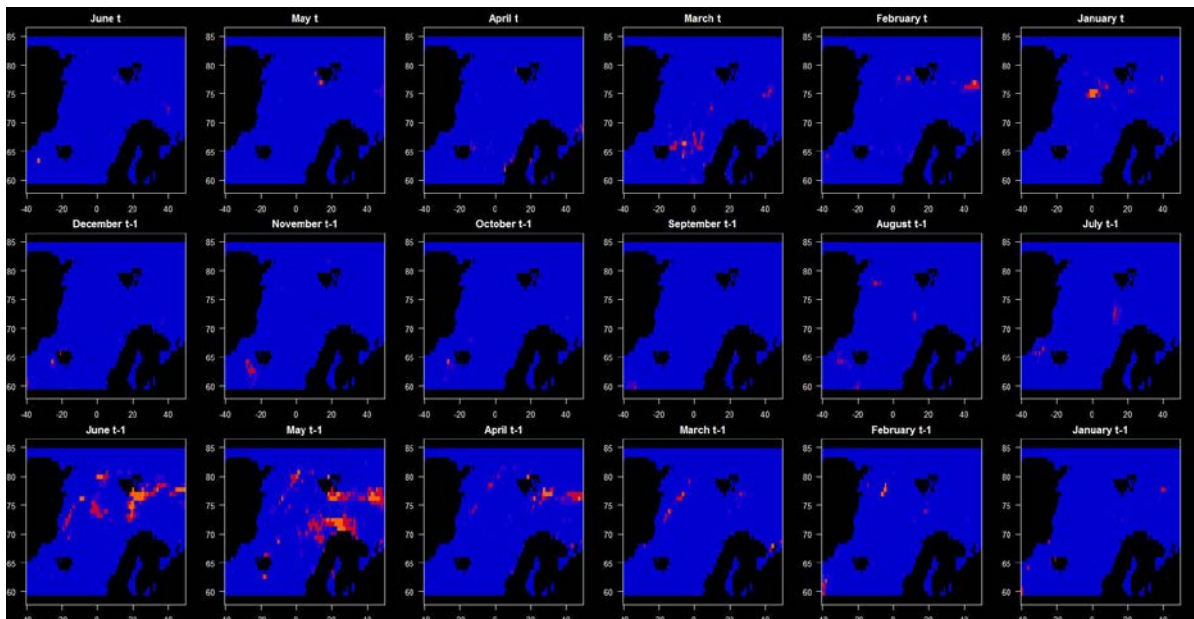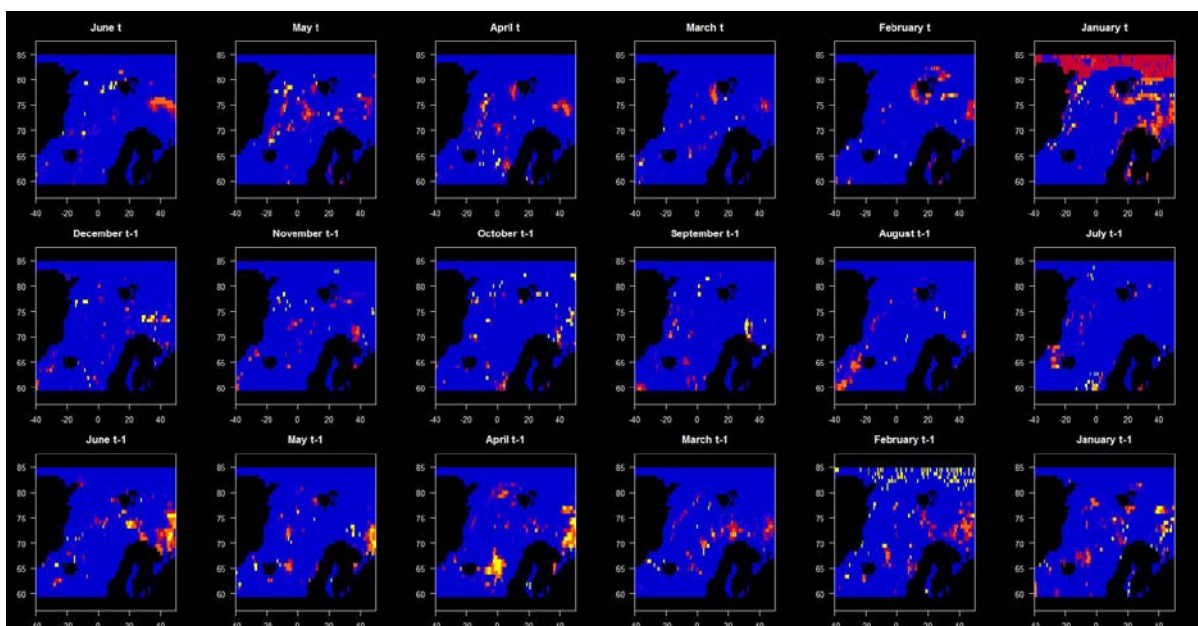

Figure 7.7-3: Map of the estimated p-value for the S term (function of temperature) in the model of Russian river pink salmon catches. Blue means no correlation, red a possible correlation (p<0.025), yellow a very clear correlation (p<0.01). There is a (positive) significant relationship with SST in April, May, and June at t-1 (the previous year) in a substantial area between Finnmark and Svalbard, as well as in a more northerly area for the immediately preceding winter. This is consistent with findings for Tana River and the whole of Norway.

Testing the distributions of p-values and explained deviances for these time steps with a series of non-parametric Kolmogorov-Smirnov tests confirmed that the months differed significantly in predictive capability and significance of the sea surface temperature (S-term). Thus we can conclude that the predictive power of SST chosen for different months do not just differ at random but with some time steps being of greater importance. As the main areas of statistical significance within these months also seem to make biological sense, we conclude that it is very likely that temperature has an effect on the northern pink salmon catches and the invasion dynamics of pink salmon.

7.8 Simulation and validation

In order to address predictive capability, we selected the area north of Finnmark (for Tana catches and Norway index) and northeast of Murmansk (for Russian catches) and trained the respective models on data for the last decade (training models on data 1957-2009). We then predicted the last decade using one-step-ahead models for the Tana catches and Norway index, and simulated the last decade and other missing data points for the Russian fisheries for comparison with qualitative sources.

We see that for Norwegian peak years of pink salmon catches, the model robustly predicts the last decade even when trained on only the partial data set (see Figure 7.8-1). Notably, it still predicts a peak year in 2017, a low year in 2018, and a new peak in 2019. It misses, or at least underestimates, the peaks in 1965, 1971, 1997, and 2000. However, except for a temperature-driven higher baseline from the late 2000s onwards, it has no major false positives and seem to capture the peaks in 1973, 1975, 1977, 1991, 1993, 1995, 1999, 2001, 2002, 2003, 2005, 2007, 2017, and 2019.
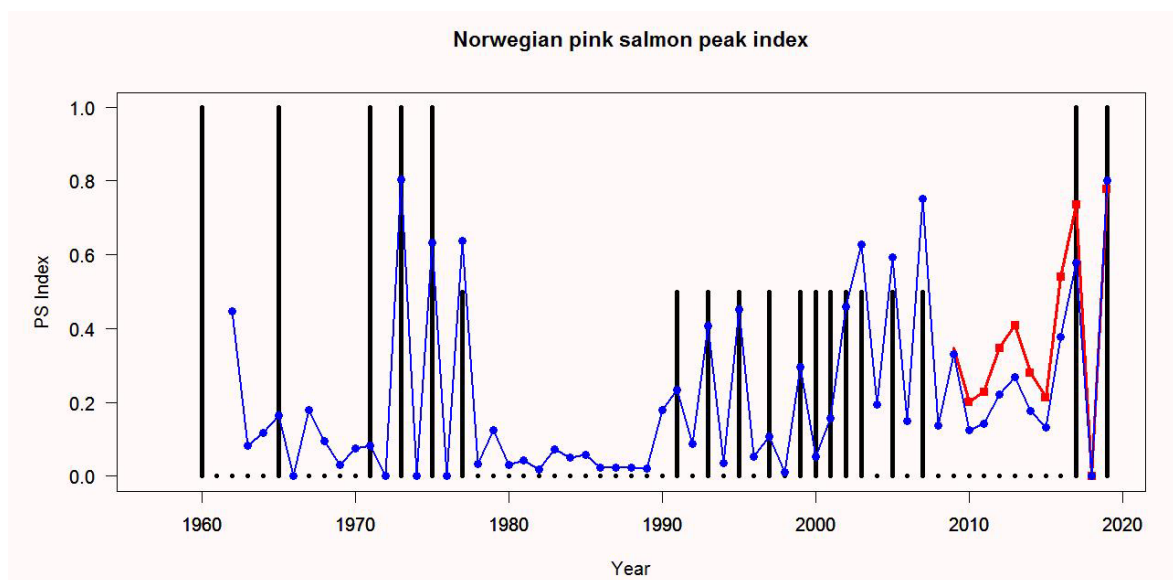
Figure 7.8-1: The time series of qualitatively assessed Norwegian peak years for pink salmon catches (black lines), a quasi-binomial autoregressive model (eq. 8) with a temperature component based on May temperatures between Finnmark and Svalbard in May the preceding year (blue line). The same model when only trained on data until 2009 and then predicting 2010-2019 is shown as the red line.

The Tana catches may be the most visibly climate driven. A purely autoregressive model, including only the Tana catches for the two preceding years and the simulated Russian catches for the two preceding years, explains only about 27% of the deviance in the catch data. However, adding the effect of SST of May the previous year from the area between Finnmark and Svalbard increases the amount of explained deviance to 72%. Including the simulated Russian catches in a validation test, where the model is fitted only until 2009 and then one-step predicts the rest of the decade, makes the model predict the 2019 peak one year early. This problem is not as large if the Russian simulation is not included as a predictor variable, but then the predicted variance is reduced (Figure 7.8-2).
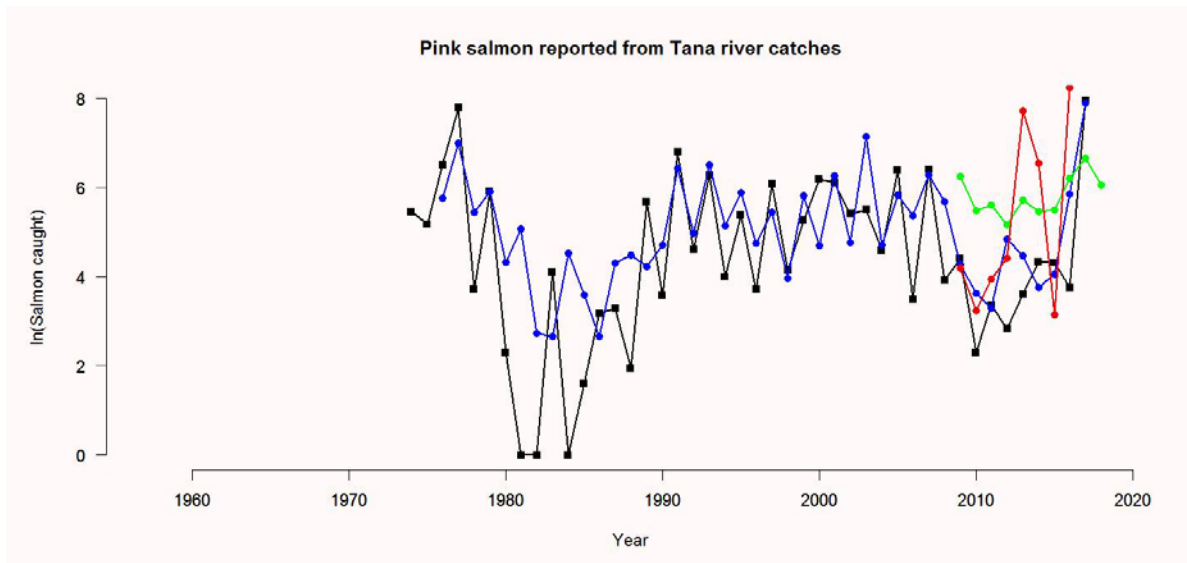
Figure 7.8-2: Reported catches of Tana River pink salmon (black lines) and a model (eq. 9) based on May SST between the Finnmark coast and Svalbard in the preceding year (blue line). The model included the simulated Russian catches of the two preceding years. The same model trained on data until 2009 and used as one-step prediction is shown in red. The same situation when only Tana and Russian catches are used to train the model is shown in green.
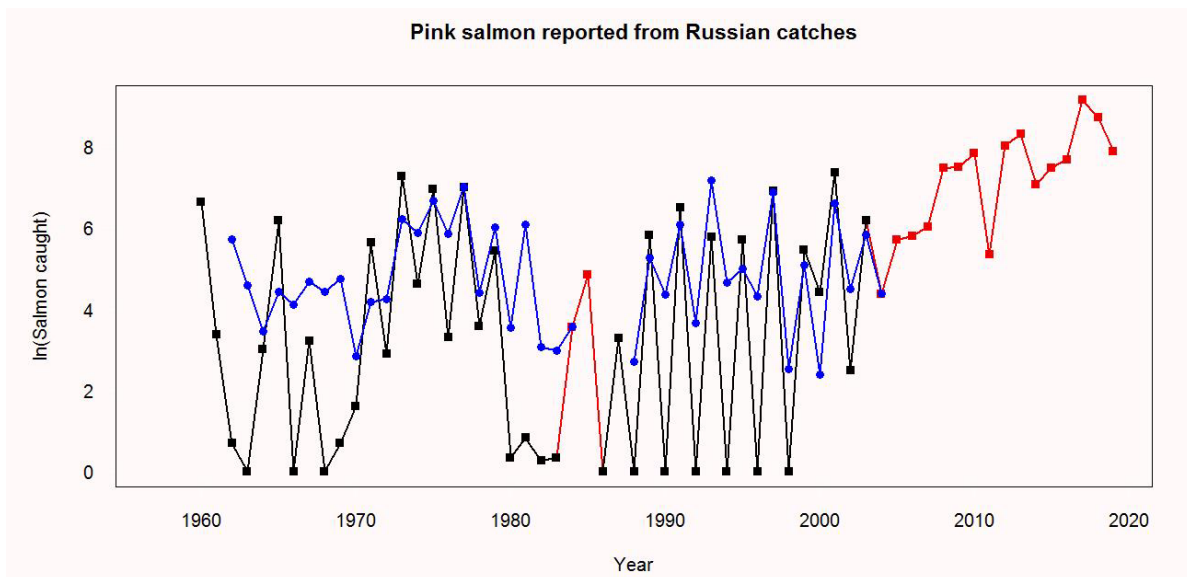
Figure 7.8-3: Russian pink salmon catches (black lines), a quasi-Poisson autoregressive model (eq. 9) with May temperatures north of Murmansk in May the preceding year (blue line). The same model, when used to simulate stepwise (i.e., inserting next-year predictions to obtain missing values and repeating the process), missing values is shown as red line. We see that it predicts considerable and, on average, increasing pink salmon stocks in the relevant part of Russia since the mid 2000s.

Looking at the Russian data we see that the model that includes SST in the area north of Murmansk in May the previous year explains about 57% of the deviance in the Russian catches, as opposed to the purely autoregressive model that explains 35%. If we simulate the model for the missing years, Russian pink salmon catches should be consistently high and increasing since the mid 2000s. However, as there is no saturation point or significant negative density dependence in the available data, such an increase may have levelled off, even if the model is correct (Figure 7.8-3).

If we use independent available data on pink salmon catches for Russia from the North Pacific Anadromous Fish Commission (https://npafc.org/statistics/), these correlate well (r=0.59, p<0.01) with the catches, both predicted and simulated (red line Figure 7.8-3).

7.9 Conclusions

- These data show a positive association between SST and pink salmon returns to northern Fennoscandian river systems.
- Extrapolation from these data are fraught with uncertainty, due to the relative paucity of salmon data, uncertainties, and the non-stationary underlying processes of establishment and continued climate change.
- The climate data points to dramatic changes being in process in the northern Atlantic.
- Combining statistical inference on several scales with biological argument, it seems likely that SST north of the Finnmark coast in spring are most positively associated with the return of pink salmon to Fennoscandian rivers the following year. The same seems likely for Northwest Russian pink salmon catches, except the main area of effect is further east than for Fennoscandia.
- The number of pink salmon entering Norwegian and Russian rivers was a strong signal of odd-year populations and correlations between rivers.
- It is likely that the species will continue to establish viable populations in the Arctic and North Atlantic over the coming years and decades.
- Rising temperatures, in particular in southern Scandinavia, may be above the optimum for pink salmon, and, if so, the southern limit to establishment should move northwards over the next decades. However, this depends on the ability of pink salmon to adapt to different environmental conditions.

In sum, the project group finds that the available data suggest large and increasing numbers of pink salmon occurring in Northwest Russian and Norwegian waters. The project group thus assess that it is **very likely**, with **very high confidence**, that pink salmon will continue to spread to Norwegian rivers on a regular basis, increasing in distribution and abundance, initially mainly in odd years.

8 Likelihood of pink salmon establishing self-sustaining populations in Norway

8.1 Homing precision and establishment

Pink salmon has less homing precision than other salmonid fish (Hendry and Stearns 2004). The unprecedent invasion of naturally spawned pink salmon in the North Atlantic in 2017 is, firstly, the result of spreading from pink salmon established in Russian rivers, and the huge distances over which pink salmon were observed is likely a result of this year class being highly successful. Secondly, the recent increase in pink salmon numbers in Norwegian rivers may be caused by pink salmon homing to rivers where they have recently spawned. Outmigrating juvenile pink salmon have been observed in rivers in eastern Finnmark for more than a decade, and we take this as evidence that the species already has established itself in Norway.

The westward geographical expansion of pink salmon from 2017 (eastern Finnmark) to 2019 (entire Finnmark and parts of Troms) may be further evidence of establishment in Norwegian rivers, with straying primarily to rivers in the same or neighbouring regions.

Genetic or other studies of origin may be necessary to verify establishment of pink salmon in Norwegian rivers. However, for similar rivers running into the White Sea and Barents Sea, Gordeeva and Salmenkova (2011) have presented evidence that pink salmon populations adapt to local conditions and may increase the likelihood for establishment and building large populations over time.

8.2 Density-dependence

A mechanism for the lack of establishment in rivers can be caused by an Allee effect. This theory states that the per-capita growth rate is negative until the population density reaches a certain threshold. In other words, there must be a certain number of pink salmon in a river before the number surviving until the next generation is more than one individual per spawner (i.e., per capita growth rate > 0; Figure 8.2-1).

There is mixed evidence for such effects in natural populations (Myers et al. 1995). Indirect evidence from models has demonstrated that it does occur in some salmonid populations (Chen et al. 2002). In an analysis of 128 fish stocks, Myers et al. (1995) demonstrated that out of three fish stocks where the Allee effect was significant, two were pink salmon. This result might be skewed, as pink salmon populations often are more numerous than other

salmon, but it still demonstrates that an Allee effect might be an important mechanism that impacts the likelihood of population establishment and collapse in pink salmon.
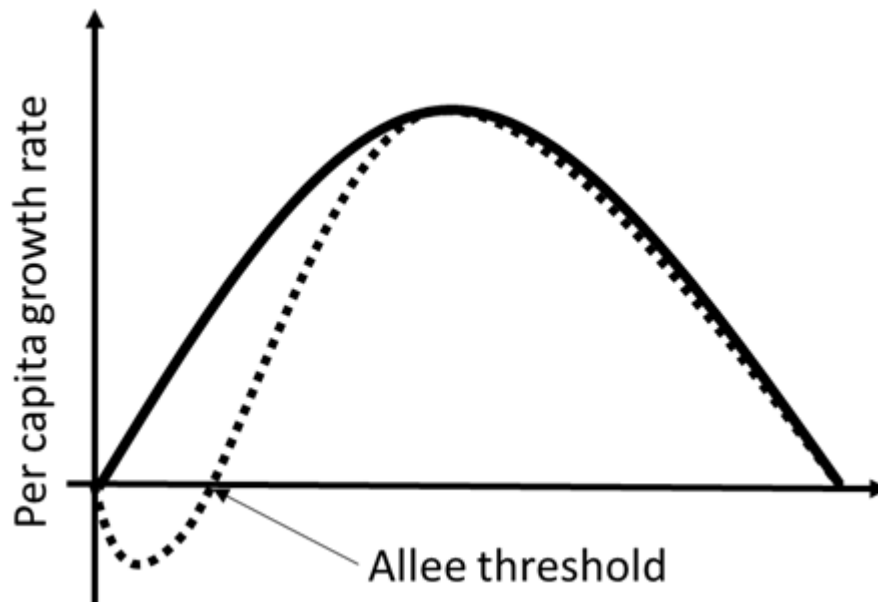
Figure 8.2-1. Population per-capita growth rate in a population without depensation (solid line) and with depensation (dotted line, i.e. Allee effect).

8.3 Life history and production in the sea

The likelihood of establishment of self-sustaining populations may also relate to the life-history strategy of the species. Pink salmon is known to be one of the species with the fastest growth in body size during its early marine life compared with other salmonids, and grows much faster than Atlantic salmon (Gjedrem and Gunnes 1978). This may suggest that pink salmon is adapted to a prey condition that is higher than that commonly experienced for salmonids in Norway. Early marine growth of Atlantic salmon has, according to scale reading in southern Norway in the last decade, plummeted (Harald Sægrov, Rådgivende Biologer, pers. comm.), which may suggest that conditions for life histories that depend on an extremely high energy levels may be maladaptive. Simultaneously, growth has increased for Atlantic salmon in the region where pink salmon has been seen in highest numbers (Finnmark). This general trend is also seen for other species. For example, Sundby and Nakken (2008) showed that the liver index of cod has increased in northern Norway, while simultaneously decreased in southern Norway. The authors suggested that climate change has caused shallow and more productive regions of the Barents Sea to open. This may explain the successful return of pink salmon in 2017 and 2019, which is positively correlated with increased temperature in the Barents Sea.

8.4 Conclusion

Despite limitations associated with density-dependent effects and life history pattern, the large numbers of pink salmon in eastern Finnmark in 2017 and the expansion to western Finnmark and Troms in 2019 indicate an ongoing expansion within Norway. In several small rivers, between 1000 and 1500 pink salmon were fished out by local people in these years.

In sum, the project group assesses that it is **very likely**, with **very high confidence**, that pink salmon will establish, regularly spawn, and produce offspring in more Norwegian rivers than those in which the species has already established (i.e., in eastern Finnmark).

9 Mitigation measures

Norway's concerns regarding barring or removing unwanted pink salmon from rivers with native anadromous salmonids, are similar to those related to escaped farmed salmon. It has been documented that farmed salmon interbreed with wild salmon and negatively affect wild Atlantic salmon populations (Glover et al. 2012; Karlsson et al. 2016; Bolstad et al. 2017; Glover et al. 2017). Consequently, there is abundant experience and infrastructure in place to remove unwanted salmonids from rivers and fjords in Norway.

In this section, we discuss two general methods of mitigation: (1) measures to decrease populations by limiting spawning, and (2) measures to decrease populations after spawning.

9.1 Mitigation measures that limit spawning

9.1.1 Active removal of adult pink salmon returning to rivers to spawn.

Næsje et al. (2013) summarized potential methods to remove escaped farmed salmon from fjords and rivers in Norway. They categorized rivers and localities according to the potential for removing escaped farmed salmon and described the most suitable removal methods. This categorization is also relevant for pink salmon, because the same physical properties of rivers that influence mitigation measures will also be present when removing pink salmon. Rivers can be categorized based on the following characteristics:

- River size
- Water velocity
- Visibility
- Depth
- Bottom substrate
- Presence of lakes
- Presence of deep pools
- Shape of river mouth
- Presence of traps or fishways (or other constructions that funnel fish)
- River regulation (i.e., presence of hydropower station)

Common methods to remove salmon from rivers or coastal waters include:

- Permanent installations (fishways and traps)
- Trap nets (bag net, "kilenot")
- Gill nets
- Seines
- Resistance board weirs
- Electrofishing (using backpack)
- Electrofishing boat

- Rod fishing (angling)
- Harpoon
- Light fishing (removal of fish by use of strong lights and dip nets during dark hours)
- Hand nets
- Catching fish with bare hands

The various methods, the associated costs, and their applicability are described in detail in Næsje et al. (2013). In the following, we describe relevant approaches to catch pink salmon, some of which may differ substantially from catching farmed fish. For the coming years, trials of potential methods for removal need to be coordinated in order to document successes and failures and thereby to develop more efficient measures.

9.1.1.1 Biological and ecological aspects of pink salmon and farmed salmon relevant for mitigation measures

There are several ecological and biological aspects of pink salmon that differ from Atlantic salmon, and thus influence the feasibility and efficiency of different mitigation measures. The most important differences are discussed here.

Weight

The average pink salmon weighs less than escaped farmed fish caught in surveillance fishing. The weight of the pink salmon caught in 2017 and 2019 ranged from ~0.5-4 kg, with most fish being around 1.5 kg. In comparison, wild Atlantic salmon usually range from 1.5 and up to more than 15 kg when returning to the rivers, depending on time at sea. However, escaped farmed salmon do not normally exceed 6 kg. In some instances, escaped farmed salmon entering rivers can also be relatively small (~1 kg) if the escape events occur during the early production cycle and relatively close to a river. Such young and small individuals are most often observed in the estuary and lower part of the river as immature individuals in late autumn. The recapture of farmed salmon therefore focuses on fish in the weight range 1-6 kg. However, small fish are often linked to escape events, and abundant numbers of small individuals in the lower part of the rivers are usually targeted differently from larger mature individuals. From a conservation point of view, it is most important to recapture the larger mature individuals among escaped farmed salmon. These are usually around 4-6 kg and are targeted by larger trap installations in the fjord (with large mesh sizes) and active removal using methods such as harpoons or seine nets in the river.

Some methods that are suitable for capturing escaped farmed fish may be less efficient for capturing pink salmon. This may be the case for methods used in the sea (e.g., bag net "kilenot" and "sittenot"), where the mesh size is commonly ~58 mm. This large mesh size may allow pink salmon to escape by swimming through the net and result in a low catch rate. These capture techniques might therefore need to be modified with smaller mesh sizes. In Russia, nets with 55 mm mesh size are used to catch pink salmon. Other trap nets, for example the trap nets used for sea trout surveillance during annual sea lice surveys (Barlaup

et al. 2013; Nilsen et al. 2016), could be used to catch pink salmon in the sea (Figure 9.1.1.1-1).

Behaviour

Behavioural differences between pink salmon and escaped farmed Atlantic salmon may affect their catchability and the choice of capture methods. Fishers and drift snorkelers observing pink salmon in 2017 reported that pink salmon on the spawning grounds were relatively aggressive (Muladal 2018). This would perhaps make them suitable for capture using rod and reel. Observation also indicates that lures are more effective than flies for pink salmon during the spawning period in August, but that it is easier to catch them with flies in the estuary and river mouth in July. However, the catchability of pink salmon (compared with native salmonids) in Norwegian rivers is generally unknown. Some anecdotal reports suggest that that the catchability may vary, perhaps even daily and within rivers. Behavioural differences between farmed and wild salmon have been observed during snorkelling surveys, where farmed fish apparently hide less (Helge Skoglund, NORCE LFI, pers. comm.). It is common knowledge among anglers that Atlantic salmon and sea trout are easier to catch when they ascend rivers than when they have stayed in the river for some time. Hence, in situations when pink salmon are not migrating at the same time as most Atlantic salmon and sea trout, it should be investigated whether pink salmon can be removed by angling with minimal effects on native salmonids. Pink salmon often gather in shoals on the spawning grounds, and this can be exploited to increase the catch per unit effort. Targeted fishing with lures can be very effective, and the use of short stiff rods with strong nylon and lightweight colourful lures works well. A fisherman can catch 10-30 pink salmon per hour, and there are examples from Finnmark that around 75 pink salmon are caught in one day by one person with targeted fishing (Rune Muladal, pers. comm.).

Figure 9.1.1.1-1. Example of trap net installation used in Norway to catch salmonids in lakes, estuaries, and fjords. Photo: Bjørn T. Barlaup

Time of river entry

Time of river entry is relevant for mitigation efforts because it will affect: (1) the overlap with the angling period, (2) the potential overlap with native fish migration and spawning periods, and (3) the discharge patterns in the rivers during mitigation. This will influence our ability to remove pink salmon without harming native fish. Most pink salmon enter Norwegian rivers in July and the beginning of August, although the first ones may enter in June. The first catches of pink salmon in the estuary of River Tana in the period 2004-2014 occurred in May, while the first catches mid-river occurred around 20 June. This indicates that pink salmon in some rivers might stay in the estuary for some time before entering the river, perhaps making them available for targeted action in the estuary. In general, it seems that the most effective time of capture is either during spring/early summer in the estuaries or during mid-summer in the rivers, before spawning in August. Native salmonids ascend most Norwegian rivers between late May and late August, and the angling period is typically 1st of June through 31st of August. This suggests that it is difficult to catch large numbers of pink salmon by angling without affecting native salmonids, but attempts should be made to find the best timing for selective removal of pink salmon.

9.1.1.2 Experience from removal of pink salmon from the 2017 and 2019 seasons

The most comprehensive information on removal of pink salmon in Norwegian rivers in 2017 is from the Barents Sea region, where Muladal (2018) registered more than 3500 pink salmon in 29 rivers, constituting 46% of all salmonids registered in these rivers. Various removal methods were tested, including harpoon, Hawaii sling spear, electro fishing, seine nets and gill nets (including fixed net) (Figures 9.1.1.2-1 and 9.1.1.2-2). The conclusion was that most of these methods could be efficient, depending on the local habitat and conditions. For example, harpoons were effective in small rivers, with an estimated catch per person per day of 20-40 pink salmon (75 - 100 in some instances), when local knowledge was available on spawning locations.
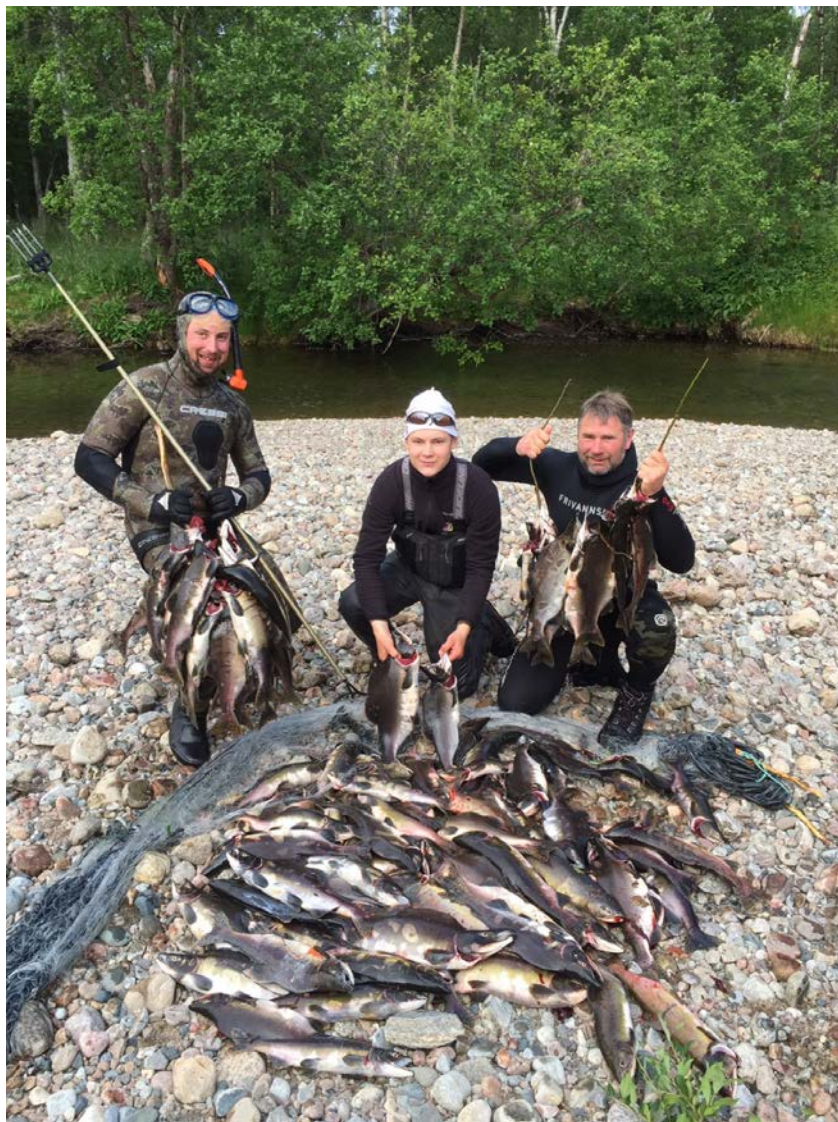
Figure 9.1.1.2-1: Removal of pink salmon using harpoon and nets is an efficient method under the right conditions. Photo: Rune Muladal/Naturtjenester i Nord

Muladal (2018) also argued that trapping pink salmon with nets was efficient, although labour intensive, and with the danger of unintentionally catching other salmonids. In 2019, Naturjenester i Nord managed to catch up to 100 pink salmon with harpoon and Hawaii-sling on one day per person, after first surveying and planning the activity the day before (Rune Muladal, pers. comm.).

Fishing with dip nets and lights were regarded as a suitable catch method at low water discharge in a small river by Berlevåg Jeger og Fiskerforening (Vistnes 2019). They noted that in the northern summer it is not dark enough at night, but the method may be suitable in smaller rivers in southern Norway.

Experience with removal of salmonids in western Norway was made by NORCE LFI in summer and autumn of 2017 and their conclusions were similar to those of Muladal (2018). The main difference was that the number of pink salmon in western Norway was much lower. Again, targeting pink salmon in relatively small rivers using harpoons was efficient, but here again this depended on the timing and knowledge about spawning locations. However, it was observed that spawning also took place in estuaries where no surveillance is usually conducted.

Figure 9.1.1.2-2: Seine net used to catch pink salmon in Kongsfjordelva in 2019. Photo: Håvard Vistnes/Berlevåg Jeger og fiskerforening.

9.1.1.3 Experience from fishing methods for pink salmon in the Pacific and in the Atlantic

In the Pacific, pink salmon sustain large fisheries in marine waters. Purse seine and trolling are the most common catch methods according to the Alaska Department of Fish and Game.

The average annual harvest in Alaska between 1959 and 1992 was 45.1 million pink salmon. According to Kingsbury (1994), the most common methods for fishing in Alaskan territories were purse seines, drift or set gillnets, while lesser numbers were caught with trolling gear or beach seines. Fixed or floating trap nets were extensively used historically, but their use was prohibited in 1959. The methods used in the Pacific are most likely costly and inefficient when the abundance of pink salmon is low. Thus, we consider the general methods of commercial fishing in the Pacific unsuitable for removal of pink salmon when occurring in low numbers. Experience from catching pink salmon in the North Pacific may still be important for streamlining catching methods. For example, according to local fishers in Puget Sound, purse seiners are more efficient, followed by round-hauls, beach seines, reef nets, gillnets, and set nets (Diego Holmgren, The Tualip Tribes, USA, pers. comm.). Another fisher pointed out that pink salmon are colour sensitive and tend to swim along the net and seek out openings (Peter Knutson, Loki Fish Company, USA, pers. comm.). Although anecdotal, knowhow about catching pink salmon (such as described above) may be valuable when designing mitigation efforts to remove pink salmon in Norway.

Catching pink salmon in the estuaries or lower part of rivers is probably the best approach, given that the abundance of pink salmon in Norwegian waters does not reach (commercial) levels similar to the North Pacific. It appears that the principles for the construction of fish traps in rivers and estuaries, where the migration of fish likely will be directional (upstream) are the same all over the world. The same principles are followed in bag nets (kilenot) for use in coastal waters. One or two leader nets that guide the fish (without the fish being caught in the net meshes) towards a net cage (funnel, trap, box) where the fish cannot escape, but is kept alive. The construction of the cage or funnel may allow sorting of the catch, such that native salmonids may be released unhurt. This is the principle used in rivers and estuaries in northwest Russia (A. Veselov, pers. comm.) as well as in the 2017 trial in Vesterelva, Finnmark (cf. https://www.nrk.no/finnmark/fanger-all-laks-i-elva-for-a-bli-kvitt-den-pukkelryggede-fisken-som-har-invadert-elvene-1.14133755).

Benefits: Infrastructure and programmes are in place that can be utilized for active removal of pink salmon. There are also several institutions in Norway that have considerable experience with removal of adult salmonids from rivers and fjords using a variety of techniques. The final decision on method needs to be locally adapted and should be based on expert opinion.

Drawbacks: Depending on the number of pink salmon returning to Norwegian rivers, the methods may be inadequate when it comes to removing all pink salmon from all rivers. Removal may still succeed in removing enough individuals to reduce the population below the Allee´ threshold. Removal of fish in the sea is likely to be inefficient, as it is impossible to target a large proportion of the individuals. Removal of fish in the rivers will be limited by the discharge patterns during the season. High waters will reduce the efficiency of traps, nets, and angling. In addition, given that the pink salmon spawn early, the window of opportunity for removing the fish is limited to a few weeks during the summer. This is during the angling period for native salmonids, and activity in the river to remove pink salmon may affect

angling. Finally, bycatch of native salmonids may affect local populations, depending on the methods used.

9.1.2 Avoiding discharge suitable for spawning in regulated rivers

Knowledge on the spawning behaviour of salmonids can be used to limit the spawning success of pink salmon, using the different spawning times of pink salmon and native salmonids to focus on the target species. By changing discharge patterns in regulated rivers, it is, theoretically, possible to limit spawning of salmon. Flow management has been successfully implemented to limit reproduction of unwanted species, such as below Canyon Dam in Colorado River where water discharge during the spawning period of non-native rainbow trout was reduced to deter fish from spawning at some spawning areas (Korman et al. 2011). In Norway, a parallel example is the design of seasonal discharge patterns to enhance survival of native salmonids, where the goal of this mitigation effort would be to deter, rather than to enhance, spawning.

Benefits: The method may be effective if properly designed.

Drawbacks: The drawbacks are that the method may be costly and have negative impacts on native salmonids and local ecological conditions.

9.1.3 Closing rivers by fish traps and barriers

Closing river inlets for upstream migrants using weirs or other installations is a mitigation measure that can be used alone or in combination with other capture methods (Figure 9.1.3-1).

Figure 9.1.3-1. Use of trap installed in Vesterelva 2018, ans sketch of the trap used. Drawing: Sigrid Skoglund, NINA. Photo: Nesseby Herreds Jeger- og Fiskeforening

There is also a trap installed in the relatively large River Etneelva in Hardanger. This is a resistance board weir across the river that can catch all salmon that are migrating upstream. It is important to note that the cost of this trap is high, and it may not be feasible to install

similar traps in many rivers. There are indications that native salmonids may be reluctant to enter and pass the trap during low discharge conditions.

Another example from Norway is in the River Driva, where a fish barrier has been constructed 20 km from the river outlet. The main purpose of the barrier is to eradicate the parasite *Gyrodactylus salaris*, by hindering upstream migration of its host Atlantic salmon, but letting brown trout pass. The construction and operation of this fish barrier are costly.

Fish traps targeting pink salmon were installed in rivers in Finnmark in 2017, 2018 and 2019 (Vesterelva, Karpeelva, Klokkerelva).

Benefits: Closing rivers by fish traps and barriers may be effective methods to hinder pink salmon from entering rivers to spawn.

Drawbacks: (1) Potentially large effects on native salmonids and may also hinder the passage of other migrating fish species. (2) Requires detailed knowledge and adjustment according to local conditions. (3) Relatively high costs, depending on the methods used. (4) Labour intensive, particularly if fish are to be sorted.

9.2 Mitigation measures after spawning

In some cases (as, for example, in 2017), spawning had already occurred when the invading pink salmon were reported. In these instances, mitigation measures may focus on attempts to remove eggs and young life stages of pink salmon, but such methods are labour intensive.

9.2.1 Active removal of spawning redds

Some attempts have been made to actively dig up and remove eggs from the gravel in the spawning redds. In western Norway, this was carried out in the River Dale, River Ekso, and the estuary of the River Vosso. Experience from these few field operations indicates that success is dependent on expertise. Spawning redds can only be localized based on the morphology and visible exposure of gravel and is therefore most effective shortly after spawning, when the redds are still easily identified. For example, following a flood event in 2017 it was no longer possible to identify redds.

In the case mentioned above, an experienced field biologist identified the redds early, and four persons wearing dry suits were able to dig up an unknown proportion of the egg pockets in the rivers and estuary using pointed spades. The eggs were transferred to the laboratory at the University of Bergen where they were hatched and start-fed on commercial fish feed, confirming that all the eggs collected were pink salmon and not sea trout.

Muladal (2018) reported that removal of pink salmon redds was performed when possible in several rivers in Finnmark. However, the efficiency of the method was not discussed. The method was also used in Kongsfjordelva in 2019, after the spawning areas were mapped by snorkelling surveys (Figure 9.2.1-1).

Benefits: (1) The work does not require expensive equipment. (2) The salmon eggs collected may be used in other biological studies on pink salmon. (3) In combination with other methods, it may have a substantial effect in limiting the reproductive success of pink salmon, particularly in small streams.

Drawbacks: (1) Time consuming and labour intensive. (2) The proportion of eggs removed is unknown. (3) Limited to a short time window between spawning of pink and native salmonids. (4) Requires experienced staff. (4) Not possible in larger/deeper rivers. (5) Requires periods of low flow.

Figure 9.2.1-1: Removal of spawning redds in Kongsfjordelva in Finnmark in 2019. Photo: Håvard Vistnes.

9.2.2 Measures using redd dewatering in regulated rivers

It is theoretically possible to lower the water discharge in periods after spawning and thereby desiccate pink salmon redds. Depending on the dewatering time and the ground water conditions, this will kill the eggs. This is only possible in regulated rivers and in rivers where the spawning times of native salmonids and pink salmon are separated by a substantial period, which seems unlikely in most rivers in Norway. In Eidfjord, the role of discharge in the dewatering and subsequent desiccation of eggs has been documented. Skoglund et al. (2017) demonstrated that the most important parameter in the likelihood of desiccation is a high relative discharge during spawning compared with the discharge during low-discharge events.

Benefits: The method can kill a large proportion of the spawned eggs in those rivers where the method can be used.

Drawbacks: (1) Depending on the time and river, the method may be costly, because of shifts in potential power production. (2) It is difficult to ensure that native salmonids (particularly young stages) are not affected. (3) The low-discharge events will also affect other fauna and flora.

9.2.3 Other methods

Other methods, such as using chemicals to kill all fish in a watershed (like one of the mitigation measures used for eradicating *G. salaris*) are also possible. We have not considered these options in detail. Other measures, such as changing the morphology of rivers to make them less accessible for smaller adult pink salmon, have also been discussed. We view changing the river morphology as an unsuitable approach because of its potential ecological impact on the ecosystem.

9.2.4 Need for regional and international coordination of mitigation measures

The invasion of non-native pink salmon to Norway and several other countries has resulted from establishment of pink salmon from rivers in Russia (Sandlund et al. 2019). The establishment of pink salmon in Russian rivers has resulted in the regular occurrence of pink salmon in a few Norwegian rivers close to the Russian border in Finnmark in previous years. However, before 2017, there were very few recordings of pink salmon elsewhere (Sandlund et al. 2019).

The sudden increase in the occurrence of pink salmon in rivers along the entire Norwegian coast, and in other countries in the Northeast Atlantic in 2017 and 2019, very probably stems from spawning in Russian rivers, and possibly in some Norwegian rivers close to the Russian border in Finnmark (Sandlund et al. 2019). Hence, pink salmon spread widely among rivers and across national borders when they returned for spawning in 2017 and 2019. This migration pattern and the potential for spreading show that pink salmon cannot be eradicated from single rivers on a long-term basis by isolated mitigation efforts, but that larger areas must be considered for coordinated efforts such that mitigation measures have the opportunity to be efficient over time. Hence, mitigation efforts to reduce the risk of establishment and negative impacts of pink salmon in the Northeast Atlantic and Barents area, including Norway, may not be efficient without a regional and international collaboration and coordination to reduce the populations.

9.3 Surveillance

The success of mitigation measures hinges on proper surveillance and biological understanding of the potential pink salmon entering Norwegian fjords and rivers. This is covered under section 12 on Data Gaps.

9.3.1 Environmental DNA

Environmental DNA (eDNA) represents a new possibility for monitoring invasive species, where a water sample can be used to detect minute remains of DNA from rare species. A new genetic assay for pink salmon has recently been published together with proof-of-concept using eDNA to detect pink salmon in a Norwegian river (Gargan et al. 2019). This assay is currently being used as a first step in a cross-Atlantic citizen-science project where eDNA is used for surveying river fish communities (www.1000rivers.net). eDNA can also indicate relative density of fish using DNA-concentrations in the water as a proxy. However, eDNA-concentrations of pink salmon will vary much during the salmon run, and depends on river flow, depth, length and water contribution from tributaries. Hence, comparisons between rivers is not straight forward, although large differences in fish density likely will result in clear difference in eDNA-concentrations. Pink salmon monitoring using eDNA will be very useful in smaller rivers and streams where catches are not regularly reported as part of Atlantic salmon fishing.

10 Uncertainties

10.1 Types and magnitude of uncertainties

10.1.1 Ecological uncertainty

Due to their limited history of overlap, not much is known about the interactions between Pacific and Atlantic salmonids. Moreover, we have limited knowledge about how Pacific salmon interact with prey, pathogens, and predators in the North Atlantic Ocean, Norwegian Sea, and Barents Sea, and in Norwegian freshwater systems.

10.1.2 Data uncertainty

10.1.2.1 Climate data

The reconstructed data have inherent imprecisions and are based on reconstructions and interpolations from many sources, some of which are sparse towards the beginning of the time series. However, compared to the other sources of uncertainty this seems likely to be small.

10.1.2.2 Biological data

For most Norwegian rivers, surveillance for pink salmon has been unsystematic, especially prior to 2017. Field data on interactions with native salmonids or other local species are absent. We have no systematic data on the distribution of pink salmon in its oceanic phase, just incidental observations and assumptions. Although we have some observations on parasite findings on pink salmon in Norwegian rivers, there are no systematic data on food items in either rivers or ocean. This makes it difficult to predict interactions quantitatively.

10.1.2.3 Effects on productivity caused by carcass additions

Native salmonids in Norway breed repeatedly, while pink salmon breed only once, and then die shortly after reproduction. We lack data on the effects caused by decomposing carcasses of pink salmon on the nutrient status of rivers and terrestrial ecosystems in Norway.

10.1.3 Climate change

A major source of uncertainty and unpredictability is the rapid climate change in the Arctic. This alters water temperatures, ice cover, and oceanic currents to regimes not previously observed by humans. These, in turn, change phenology and ocean chemistry, necessarily impacting the vital rates of every living species in the system. This is likely to have

fundamental cascading effects involving inter- and intra-species interactions, making it difficult to predict the net outcome for any specific species.

The uncertainties in climate forecasts also include which political steps are taken to mitigate this ongoing change, and thus the most likely global climate scenario that we will experience over the coming decades. As these vary from moderate to large temperature increases, any prediction for a species in a severely impacted area, like the North Atlantic Ocean, must take this into consideration.

10.2 Summary of uncertainties

The overriding uncertainty is the magnitude and effects of ongoing climate change. Thereafter there are uncertainties regarding the ecological interactions of pink salmon in the Atlantic ecosystem and in Norwegian rivers. A lack of data on both pink salmon abundance and the organisms with which this species interacts limits the quality of any predictions.

11 Conclusions (with answers to the terms of reference)

11.1 Potential hazards associated with increasing abundance of pink salmon (regardless of establishment) in Norwegian water systems (ToR #1).

Almost all hazards associated with invasive alien pink salmon are, at any time, correlated with the number of pink salmon in the ocean, coastal waters, and rivers.

A high number of pink salmon spawners will have negative effects on native salmonid spawners through their aggressive behaviour and crowding, and there may also be overlap in spawning time with native salmonids. Decomposing dead pink salmon will release organic matter and nutrients, and impact river water quality. This will enhance production of algae and macrophytes. In oligotrophic rivers, a small to medium number of decomposing fish will likely cause an increased density and biodiversity of invertebrates. With high numbers of dead fish, this will constitute a pollution problem. A high number of pink salmon in the ocean may also impact the food web in the marine ecosystem and, similarly, a high number of pink salmon in rivers may also impact the food web in terrestrial ecosystems surrounding the rivers.

A high number of spawners will produce a high number of offspring. The impact of pink salmon fry or smolts on the river ecosystem depends on their density and the duration of their stay in the river before moving to the sea. The impact is associated with competition for space and food with native salmonid fry, and will affect the biodiversity and the food web in the rivers.

The hazards related to pink salmon as a vector of pathogens infecting native salmonids and farmed fish is also likely to correlate with the number of pink salmon in the area. However, in some cases, only a few pink salmon harbouring a particularly virulent pathogen may have considerable effect. Several viral, bacterial, and parasitic pathogens may pose a threat to both biodiversity (affecting several species), productivity of native salmonid populations in the wild, and salmonid aquaculture.

A high number of pink salmon entering rivers will result in anglers' catches being dominated by moderately sized pink salmon (around 1.5 kg) with deteriorating quality already early in summer. This will negatively affect the economic value of salmon fishing.

11.2 Areas and habitats that are best suited for, and thus most vulnerable to, spread and establishment of pink salmon (ToR #2a and 2b)

Under the present climate conditions, pink salmon can spawn and produce offspring in all rivers suitable for anadromous fish populations in Norway. Observations in Finnmark demonstrate that this includes even very small rivers. Establishment in various regions likely depends on the number of pink salmon entering each river and the survival of offspring from hatching until return as spawners.

Over the last decades, high sea surface temperatures (SST) might have favoured pink salmon survival and resulted in high numbers of spawners. A continued increase in SST and reduced ice cover may further increase sea survival of pink salmon. The effect of a warmer climate on conditions in the rivers is less certain. With pink salmon being a cold-water species, conditions in rivers in southern Norway may become less favourable over the next 50 years.

11.3 Consequences of the spread and potential establishment of pink salmon in Norwegian water systems (ToR #3a, 3b and 3c).

Decomposing pink salmon spawners in oligotrophic rivers may increase the production of algae and invertebrates, at least up to a threshold density of pink salmon. Increased productivity will benefit native fish in the river. However, with many native salmonid populations at a low and vulnerable status, interactions with pink salmon spawners for several months during the summer, along with potential competition for food and space between fry of native fish and pink salmon, may seriously interfere with native salmonid populations. These interactions will reduce native salmonid productivity and genetic diversity.

The consequences of pink salmon as a vector for pathogens will often depend on the number of pink salmon. The potential for dissemination of pathogens is likely to be greater with higher numbers of pink salmon, but may nevertheless remain low if other circumstances are unfavourable for the spread of the pathogens. In addition, even if the numbers of pink salmon are low, should they be carrying a pathogen of particular virulence to Norwegian salmonids, this could still exert a considerable impact.

11.4 The likelihood of spread and potential establishment of pink salmon in Norwegian water systems (ToR #4a and 4b).

Pink salmon will continue to spread to Norwegian waters as long as production in self-sustaining populations in Northwest Russia and in Finnmark continue. The spread is seemingly aided by rising temperatures in the Barents Sea. Establishment of more self-

sustaining populations in Norway (in addition to East Finnmark) will depend on the number of offspring produced in the various regions. This number must be enough to satiate predators, particularly in estuaries and coastal waters, allowing a number of adults to have a certain level of homing to the region in order to return and reproduce.

The likelihood of spreading diseases to native fish and aquaculture is likely to increase with increasing number of potential vectors.

The likelihood of other impacts on biodiversity is also correlated with the number of sub-adult and adult pink salmon in the sea and entering the rivers, and the number of pink salmon fry and smolts emerging from the spawning redds.

11.5 The likelihood of introduction and spread of pathogens, and other negative impacts on biodiversity in Norway, following increased abundance of pink salmon (ToR #4c and 4d).

The likelihood of spreading diseases to native fish and aquaculture is likely to increase with increasing number of potential vectors, i.e., the number of pink salmon in the vicinity of net pens and in rivers with native salmonids.

A high number of pink salmon in rivers may negatively impact vulnerable populations of native salmonids through interference prior to spawning and during spawning.

A high number of juvenile pink salmon in the rivers may influence invertebrates in the rivers and interfere with juveniles of native salmonids. This would have an impact on the food web in the river.

11.6 The overall risk of negative impact following spread and potential establishment of pink salmon in Norway

The overall risk of negative impacts on biodiversity in Norway following the spread and potential establishment of pink salmon in Norway will vary according to the aspects of biodiversity being considered.

11.6.1 On biodiversity (ToR #5a)

The project group considers that a negative effect on water quality is likely to occur in fresh water due to influx of pink salmon (Figure 11.6.1-1), and that the potential magnitude varies with the trophic level prior to invasion of pink salmon, the current (fast- or slow-flowing water), and the number of adult pink salmon entering (and dying in) the river (high or low densities). The risk for negative impact is high (magnitude is Massive or Major) in all mesotrophic rivers and in slow-flowing oligotrophic locations with high densities of pink

salmon, and the risk is Moderate (magnitude is Minimal to Moderate) in slow-flowing mesotrophic locations with low densities of pink salmon, in fast-flowing oligotrophic locations with high densities, as well as in other oligotrophic locations.
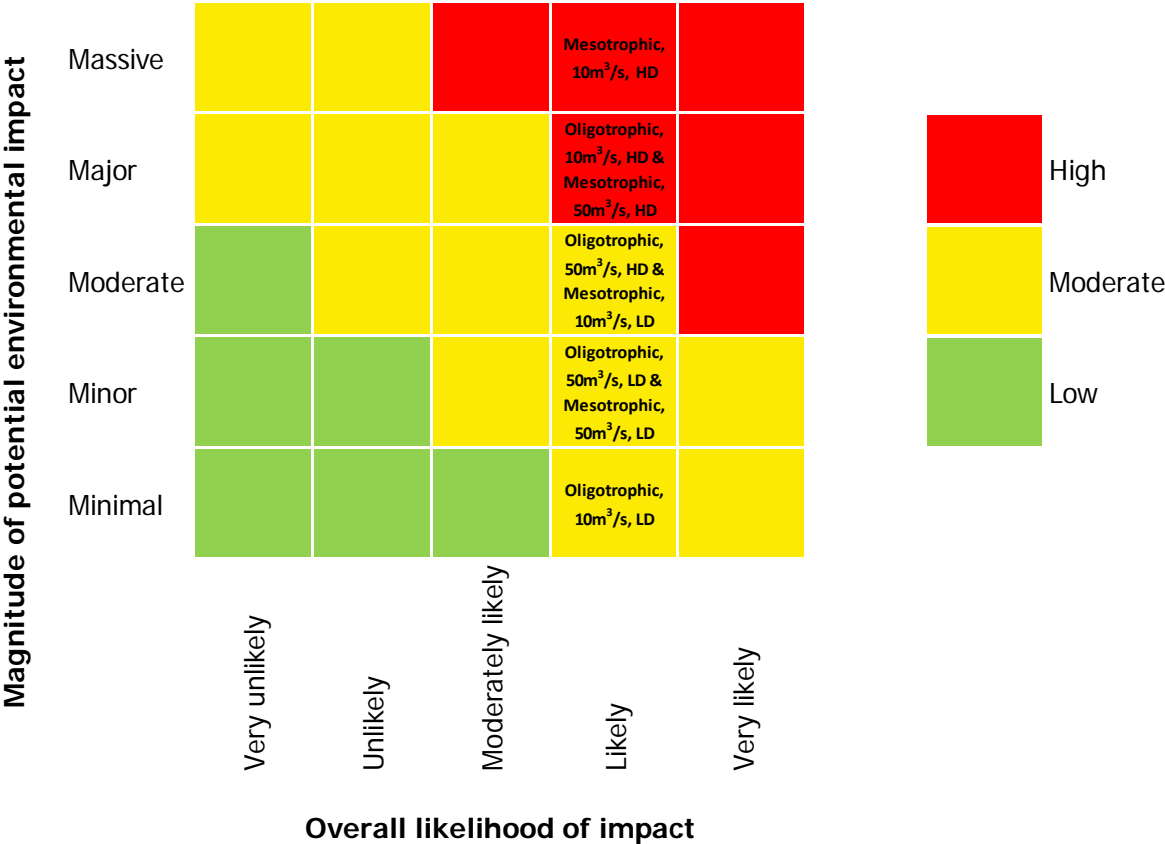
Figure 11.6.1-1: Risk of negative impact on biodiversity in Norway related to changes in river ecosystems following an increased abundance of pink salmon in Norway. HD = High density, and LD = Low density.

We find that an effect on aquatic ecosystems is likely (Figure 11.6.1-2), the magnitude of which varies with the presence/absence of freshwater pearl mussels, and the type of aquatic ecosystem. The risk of negative impact is High (and magnitude is Major) in localities where freshwater pearl mussel is present, and the risk is Moderate in other streams (where magnitude varies with number of pink salmon present) and in marine ecosystems.
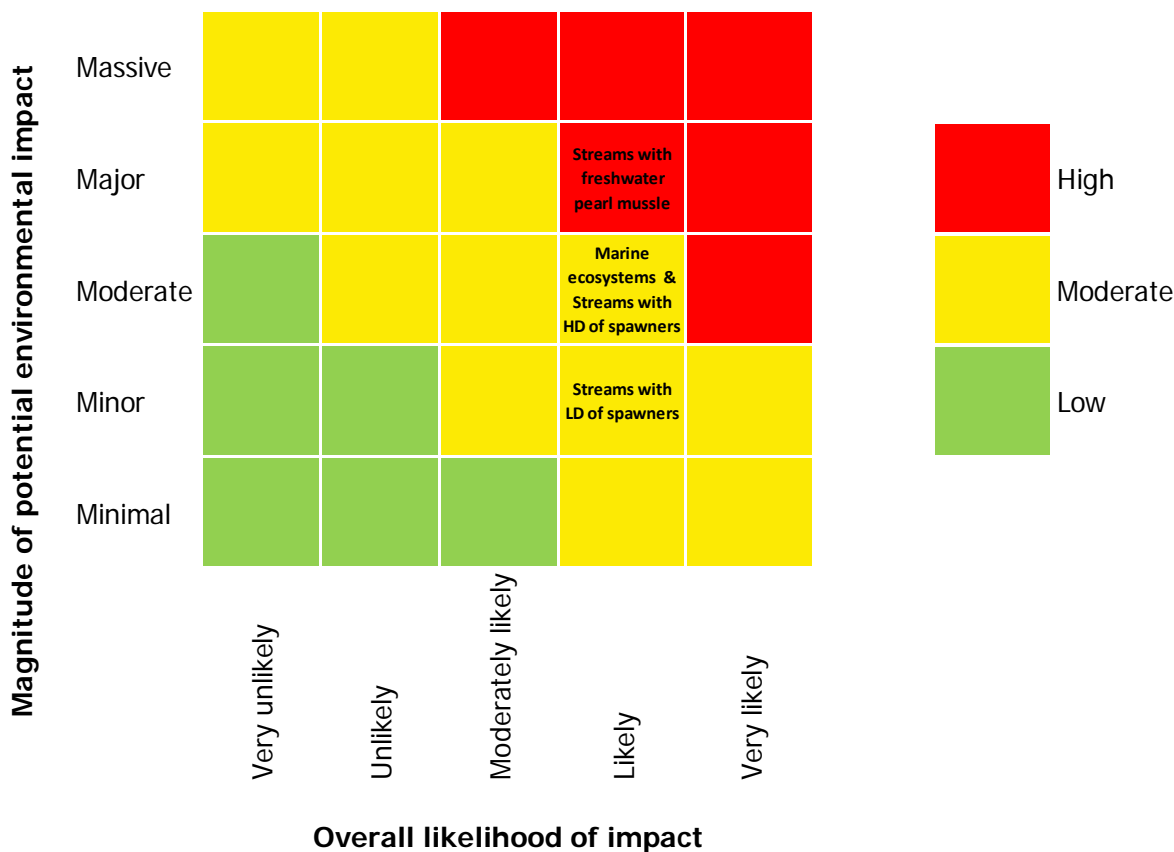
Figure 11.6.1-2: Risk of negative impact on biodiversity in Norway related to changes in marine ecosystems following an increased abundance of pink salmon in Norway. HD = High density, and LD = Low density.

We find that an effect on terrestrial ecosystem is likely (Figure 11.6.1-3), the magnitude of which varies with the number of pink salmon spawning (and dying) in the local rivers. The risk of negative impact is High (and magnitude Massive) in rivers where very high densities of pink salmon spawn, and the risk is Moderate where smaller densities of pink salmon spawn (the magnitude varying with the abundance of pink salmon).
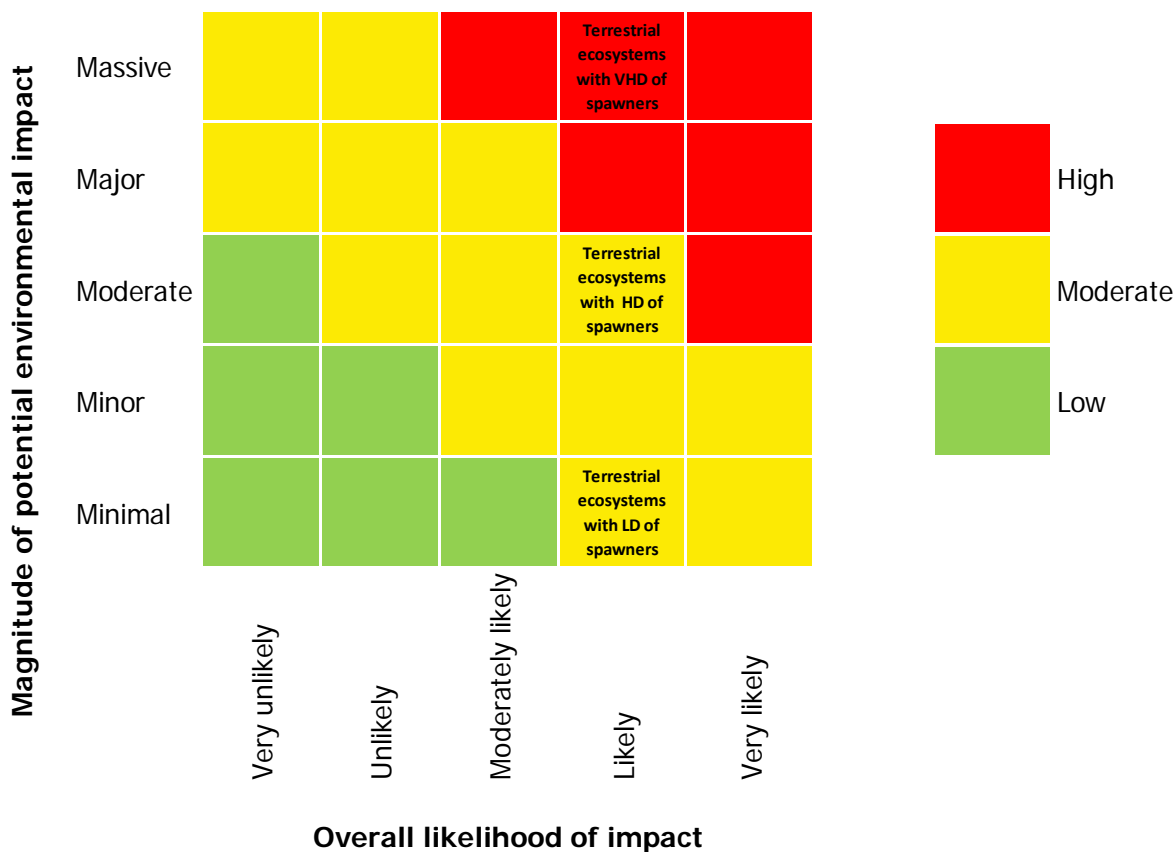
Figure 11.6.1-3: Risk of negative impact on biodiversity in Norway related to changes in terrestrial ecosystems following an increased abundance of pink salmon in Norway. VHD = Very high density, HD = High density, and LD = Low density.

We consider that the risks of negative impacts from pathogens associated with pink salmon to be moderate for some parasites not yet present in Norway (with moderately likely impact of major magnitude) and to be minor for parasites that are present in Norway and for the PRV-1 virus. We also find that risks for negative impacts of other pathogens are moderate (with an unlikely probability of impact of moderate magnitude) for *R. salmoninarum* and the viruses SAV and VHSV. The risks of negative impacts from other pathogens (bacteria and viruses) are considered minor (with an unlikely probability of impacts of minor to minimal magnitude) (Figure 11.6.1-4).
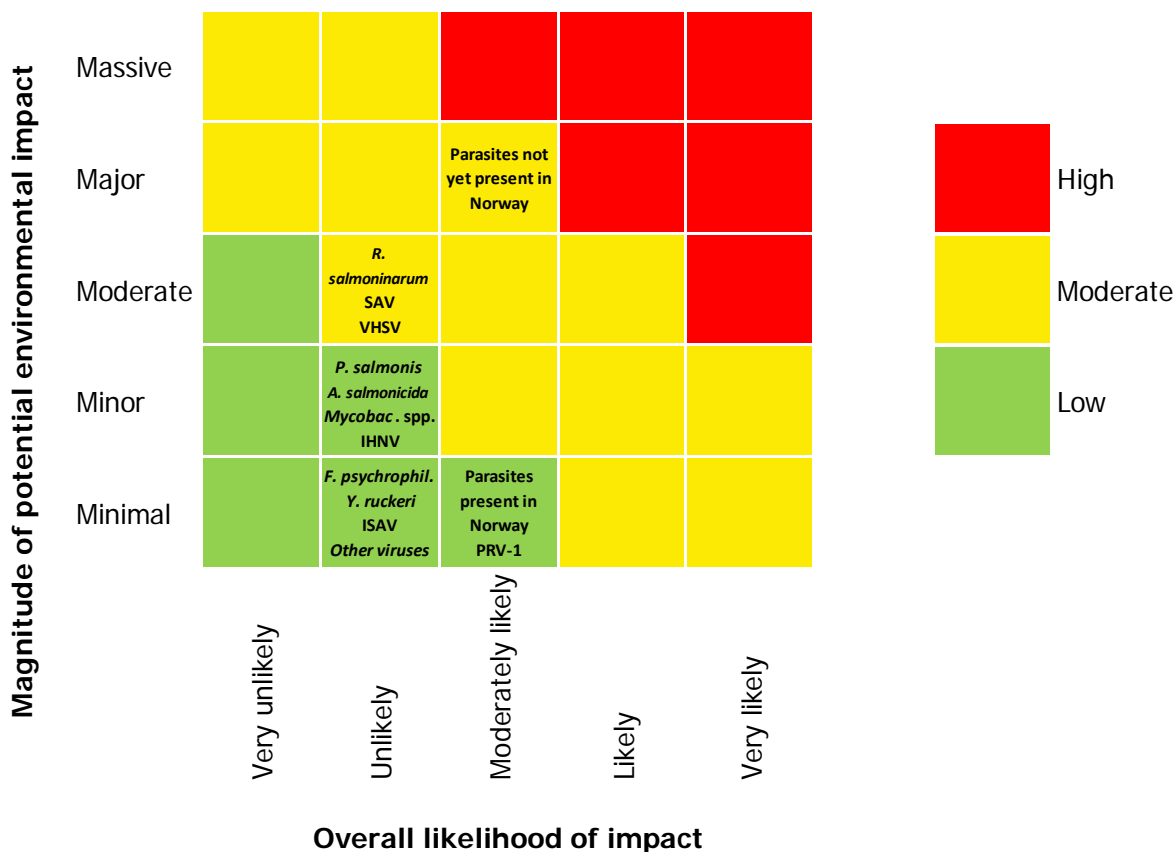
Figure 11.6.1-4: Risk of negative impact on biodiversity in Norway related to the introduction or spread of pathogens following an increased abundance of pink salmon in Norway.

11.6.2 On aquaculture (ToR #5b)

The overall risk to aquaculture from the spread and potential establishment of pink salmon is tightly linked to the risks associated with the transfer of pathogens (Figure 11.6.2-1). Moderate risk is assigned to four groups that differ in likelihood (unlikely to moderately likely) and whose impact differs in magnitude (moderate to major). Some parasites not yet present in Norway have been considered to have moderate likelihood of major impact; IHN virus has been considered to have an unlikely probability of presenting a major impact; *P. salmonis* and SAV are considered to have a moderate likelihood of a moderate impact; whereas *R. salmoninarum* has been considered to present an unlikely probability of exerting a moderate impact.
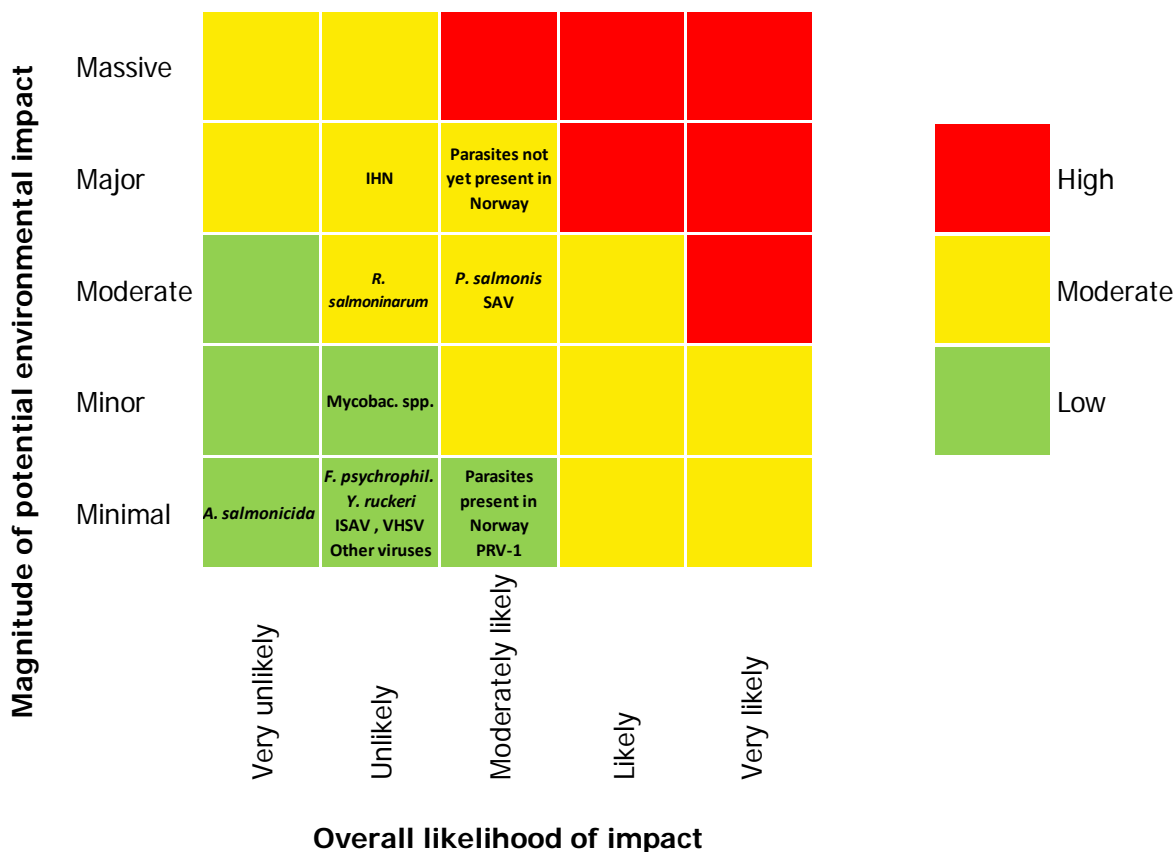
Figure 11.6.2-1: Risk of negative impact on aquaculture in Norway related to the introduction or spread of pathogens following an increased abundance of pink salmon in Norway.

11.6.3 On the productivity of native salmonid populations (ToR #5c)

The overall risk on the productivity of native salmonids from the spread and potential establishment of pink salmon varies with the life stage and species of the native salmonid being considered (Figure 11.6.3-1), and we may also add a south-to-north geographical gradient in expected risk. Pink salmon enter rivers in the summer and early autumn, and we consider the pre-spawning interactions on the spawning grounds of native salmonids to constitute a high risk to their productivity (it being very likely that they will have a major impact). This is because of the agonistic behaviour shown by pink salmon towards native salmonids that may be stopped on their spawning migration, and face aggressive encounters with pink salmon when searching for spawning places. During spawning, we consider that Arctic charr and brown trout are at high risk as their spawning period is likely to overlap with that of pink salmon in some of the northernmost rivers, whereas the risk to Atlantic salmon is moderate as the probability of overlap is unlikely.

Hybridization is associated with low risk (being both very unlikely and having minimal impact), but if gametes (especially eggs) are wasted on attempted spawning encounters, weak populations of native salmonids may become less viable.

During the fry stage, we also consider that there is a high risk associated with pink salmon coexisting with native salmonids, as we find it very likely that they will compete for food and space, and this will have a major impact on native salmonid productivity.
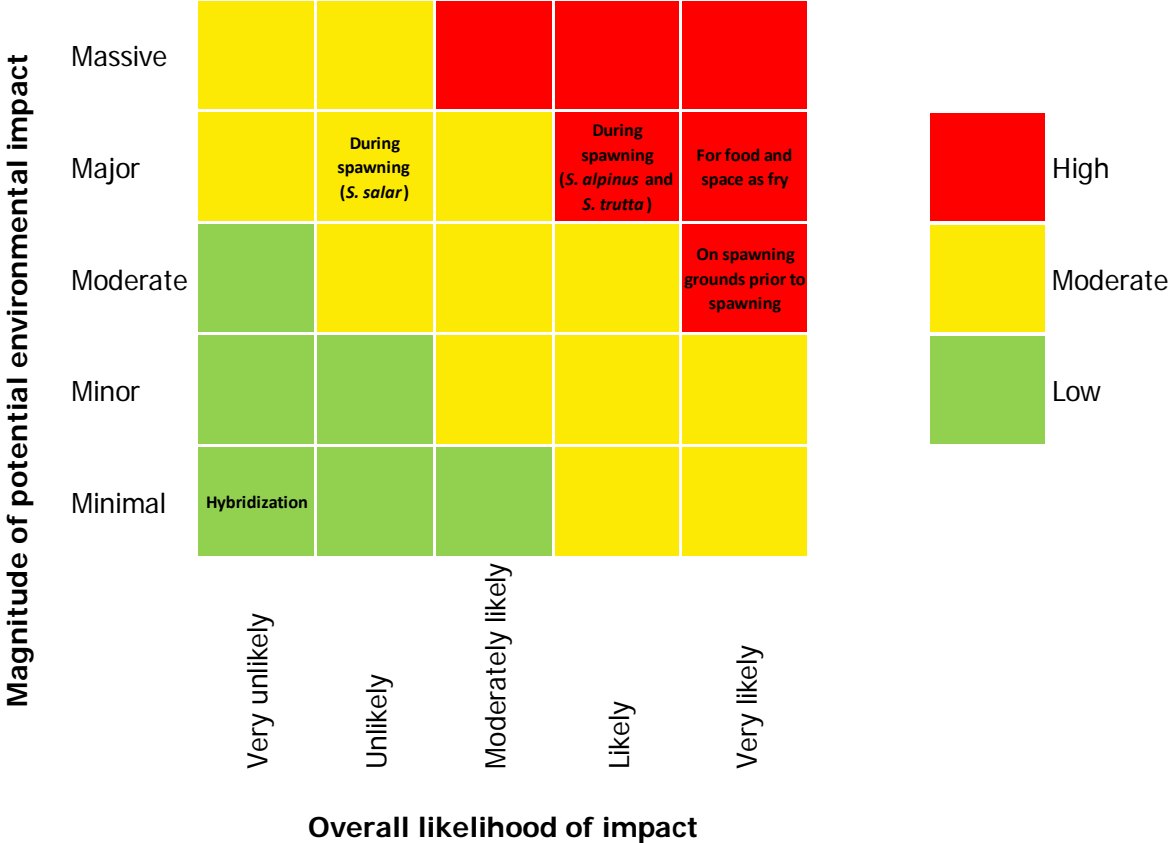
Figure 11.6.3-1: Risk of negative impact on the productivity of native salmonid populations in Norway related to hybridization and competition for food and space following an increased abundance of pink salmon in Norway.

We find that the risks of negative impacts from pathogens associated with pink salmon to be moderate for various parasites not yet present in Norway (with a moderate likelihood of an impact of major magnitude) and to be minor for those parasites already present in Norway and for the PRV-1 virus. We also find that risks of negative impacts associated with other pathogens are moderate (being unlikely to exert an impact of moderate magnitude) for *R. salmoninarum* and for the viruses SAV and VHSV. The risk of negative impacts from other pathogens (bacteria and viruses) is considered to be minor (being unlikely to exert an impact of minor to minimal magnitude) (Figure 11.6.3-2).

The matrix shows Magnitude of potential environmental impact (vertical axis) against Overall likelihood of impact (horizontal axis).

Vertical axis (bottom to top): Minimal, Minor, Moderate, Major, Massive

Horizontal axis (left to right): Very unlikely, Unlikely, Moderately likely, Likely, Very likely

Cell contents:
- Moderate / Unlikely: *R. salmoninarum*, *SAV*, *VHSV*
- Minor / Unlikely: *P. salmonis*, *A. salmonicida*, *Mycobac*. spp., *IHNV*
- Minimal / Unlikely: *F. psychrophil.*, *Y. ruckeri*, *ISAV*, *Other viruses*
- Major / Moderately likely: Parasites not yet present in Norway
- Minimal / Moderately likely: Parasites present in Norway PRV-1

Legend: High (red), Moderate (yellow), Low (green)

Figure 11.6.3-2: Risk of negative impact on productivity of native salmonid populations in Norway related to the introduction or spread of pathogens following an increased abundance of pink salmon in Norway.

11.7 Assessment of various mitigation measures (ToR #6)

Feasible measures to reduce the impact of pink salmon in rivers include targeted fishing adapted to local conditions. Experience from 2017 and 2019 shows that this approach may almost completely remove the threat of pink salmon to native salmonids and biodiversity in individual rivers, at least in smaller rivers.

However, in order to reduce the number of pink salmon in the sea and the recurring returns of odd-year pink salmon spawners to Norwegian coastal waters and rivers in general, concerted action on a regional and international level is required.

12 Data gaps

12.1 Number of adult pink salmon

Numbers of adult pink salmon in Norwegian rivers are critical for being able to assess and follow the risk that they may impose. Surveillance programmes are needed to determine the appropriate number of fish that could be tolerated. Priority should be put on informing anglers and having a functional system for reporting observations of pink salmon. It is important to inform various projects that collect and survey salmonids (and other species) along the coast and in rivers about the potential threat from pink salmon, and to include this species in ongoing routine surveys. Environmental DNA is one method that could be implemented in surveillance programs.

12.2 Spawning ecology

Information on preferred spawning areas in Norwegian rivers is lacking, e.g., how far up in the river pink salmon spawn and how much overlap there is, both temporally and spatially, with native salmonids. This is pertinent information in order to assess the level of competition with native fish. Information on interactions between native salmonids and pink salmon in the weeks before and during the spawning season are also lacking. Critical questions relate to the corresponding consequences in different situations for space and habitat according to densities of fish.

Salmonids depend on connectivity in the river for their spawning migration. Information from some rivers in Norway suggest that native salmonids are better able to pass barriers than pink salmon, as they can swim faster and jump higher. This suggests that we can leverage this information towards selective disruption of the migration of fish based on their ability to pass barriers. However, location-specific information on this ability for pink salmon is currently lacking.

12.3 Ecology of fry

Information on the ecology of juvenile pink salmon in Norwegian rivers is lacking, e.g., survival rates, growth, and behaviour during the river phase. We also lack information on competition and density-dependent factors in the river. A study on the feeding of pink salmon fry and native salmonid fry in the river may reveal this. This is particularly interesting as some observations indicate that pink salmon can emerge very early in the winter and thus expand their juvenile residence in rivers. Pink salmon should therefore be surveyed during the freshwater stages.

Little is known about the time of sea entry of pink salmon in Russia and Norway. Studies on when pink salmon leave river, and of the duration of feeding in the river prior to

outmigration, will be useful when assessing the impact of the pink salmon invasion in Norway,

12.4 Effects on invertebrates

We lack knowledge on the potential consequences that pink salmon fry have on the biodiversity and production of invertebrates in the rivers. Studies should be performed on the type and amount of food intake during the freshwater stage. This information may indicate potential effects on the invertebrate community in rivers and how the diets of pink salmon fry overlap with diets of native salmonids. Such analyses require stomach and gut analyses of pink salmon fry in combination with surveys on invertebrate fauna.

12.5 Pathogens

Information about the occurrence, spread, and survival of parasites and in pink salmon is very limited. The possibility of pathogen transmission between pink salmon and other fish hosts represents a potentially large impact on local native salmonids and on the aquaculture industry in Norway. A surveillance programme of pathogens occurring on invasive pink salmon is needed to assess this as a risk factor.

An efficient setup for surveillance of pathogens includes the use of sampling sites that are representative of a wider geographic range, for instance areas where there is substantial aquaculture of Atlantic salmon and/or rainbow trout. At these sites, samples of sexually mature pink salmon should be collected for identification of viral pathogens (such as VHSV, IHNV, ISAV, SAV, PRV, PMCV, IPNV), bacterial pathogens, and different endo- and ectoparasites.

12.6 Effects on water quality and terrestrial ecosystems

Studies on the effects caused by pink salmon carcasses on the nutrient status of rivers in Norway are lacking. In order to gain knowledge on such effects, the ecological and chemical status of waters should be monitored. Information on properties of the waterbody that may potentially influence its sensitivity to eutrophication should be included, such as point-source input of nutrients, the density of terrestrial vegetation, and the proportion of bogs, and information on the food chain of the ecosystem. The aim of extensive monitoring is to obtain knowledge on the carrying capacity of rivers with respect to eutrophication caused by pink salmon. Predictions on eutrophication can then be made in rivers where we expect that pink salmon may spread.

We also lack knowledge on the potential consequences of marine-derived nutrients for terrestrial ecosystems in Norway. We need to monitor the population of scavengers and the riperian vegetation to assess effects on terrestrial ecosystems.

12.7 Behaviour in the sea

We know very little about the behaviour, survival, and prey preferences of pink salmon smolt in the estuaries and in the open sea in Norwegian waters. A comparison between the production of prey for different life stage of salmonids in the Atlantic Ocean may provide information on growth rates, survival, and competition in the marine life stage. This is important for predicting the carrying capacity of salmon in the sea.

12.8 Origin of fish in Norway

A comparison of pink salmon DNA (and possibly eDNA) between rivers in Norway and Russia may provide relevant information of the origins of the pink salmon in Norwegian rivers, potentially providing insights about whether the fish originate from Russian rivers or are self-recruiting from the rivers in Norway (and thus have already established in Norwegian rivers). Scale samples can be used for DNA analysis and water samples are useful as a source for eDNA.

12.9 Environmental contaminants

Pink salmon gather environmental contaminants from the ocean and concentrate these in the river. The concentrations of environmental contaminants in pink salmon that have fed in the Atlantic Ocean and Bering Sea are not known.

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Appendix I

Appendix Ia Search: Pink salmon and virus

Ovid MEDLINE(R) Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid MEDLINE(R) <1946 to Present>

Date: 24.01.2019

Number of hits: 1

#	Searches	Results
1	(Oncorhynchus gorbuscha or pink salmon or gorbuscha or humpback salmon or Salmo gorbuscha).kf,tw.	250
2	Hemorrhagic Septicemia, Viral/ or Infectious hematopoitic necrosis/ or Infectious pancreatic necrosis/ or Infectious pancreatic necrosis virus/ or Isavirus/ or Alphavirus Infections/ or Orthoreovirus/ or Poxviridae Infections/ or Reoviridae Infections/	6627
3	(Viral haemorrhagic septicaemia or viral hemorrhagic septicemia or viral haemorrhagic septicemia or VHSV or Infectious hematopoitic necrosis or infectious hematopoietic necrosis Infectious pancreatic necrosis or IPNV or Infectious salmon anaemia or ISAV or isavirus* or Salmonid alphavirus or alpha virus* or alphavirus or Piscine orthoreovirus or Piscine myocarditis or PMCV or Salmon gill pox* or (salmon adj2 gill pox*) or Viral nervous necrosis or (viral adj2 nervous necrosis) or (chum salmon adj2 virus*) or chum salmon reovirus* or (Oncorhynchus masou adj2 virus*) or ((reoviridae or reovirus*) adj2 infection*)).kf,tw.	4341
4	2 or 3	9476
5	1 and 4	1

Embase <1974 to 2019 January 23>
Date: 24.01.2019

Number of hits: 0

#	Searches	Results
1	(Oncorhynchus gorbuscha or pink salmon or gorbuscha or humpback salmon or Salmo gorbuscha).kw,tw.	266
2	viral hemorrhagic septicemia/ or infectious hematopoietic necrosis virus/ or infectious pancreatic necrosis/ or isavirus/ or Alphavirus infection/ or Orthoreovirus/ or Reoviridae/ or poxvirus infection/ or reovirus infection/	3500
3	(Viral haemorrhagic septicaemia or Infectious hematopoitic necrosis or Infectious pancreatic necrosis or Infectious salmon anaemia or isavirus* or Salmonid alphavirus or alpha virus* or alphavirus or Piscine orthoreovirus or Piscine myocarditis or carditis or myocarditides or Salmon gill pox* or (salmon adj2 gill	6336

	pox*) or Viral nervous necrosis or (viral adj2 nervous necrosis) or (chum salmon adj2 virus*) or chum salmon reovirus* or (Oncorhynchus masou adj2 virus*) or ((reoviridae or reovirus*) adj2 infection*)).kw,tw.	
4	2 or 3	9242
5	1 and 4	0

Web of Science
Date: 24.01.2019

Number of hits: 5

# 3	5	#2 AND #1 *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=All years*
# 2	5449	TS=("Viral haemorrhagic septicaemia" OR "viral hemorrhagic septicemia" OR "viral haemorrhagic septicemia" OR "Infectious hematopoitic necrosis" OR "infectious hematopoietic necrosis" OR "Infectious pancreatic necrosis" OR "Infectious salmon anaemia" OR "isavirus*" OR "Salmonid alphavirus" OR "alpha virus*" OR "alphavirus" OR "Piscine orthoreovirus" OR "Piscine myocarditis" OR PMCV OR "Salmon gill pox*" OR (salmon NEAR/2 "gill pox*") OR "Viral nervous necrosis" OR (viral NEAR/2 "nervous necrosis") OR ("chum salmon" NEAR/2 virus*) OR "chum salmon reovirus*" OR ("Oncorhynchus masou" NEAR/2 virus*) OR ((reoviridae or reovirus*) NEAR/2 infection*)) *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=All years*
# 1	1181	TS=("Oncorhynchus gorbuscha" OR "pink salmon" OR "humpback salmon" OR "Salmo gorbuscha" OR gorbuscha) *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=All years*

SCOPUS
Date: 24.01.2019

Number of hits: 6

(TITLE-ABS-KEY ("Oncorhynchus gorbuscha" OR "pink salmon" OR "humpback salmon" OR "Salmo gorbuscha" OR gorbuscha)) AND ((TITLE-ABS-KEY ("Viral haemorrhagic septicaemia" OR "viral hemorrhagic septicemia" OR "viral haemorrhagic septicemia" OR "Infectious hematopoitic necrosis" OR "infectious hematopoietic necrosis" OR "Infectious pancreatic necrosis" OR "Infectious salmon anaemia") OR TITLE-ABS-KEY ("isavirus*" OR "Salmonid alphavirus" OR "alpha virus*" OR "alphavirus" OR "Piscine orthoreovirus" OR "Piscine myocarditis" OR pmcv OR "Salmon gill pox*") OR TITLE-ABS-KEY ((salmon W/2 "gill pox*") OR "Viral nervous necrosis" OR (viral W/2 "nervous necrosis") OR ("chum salmon" W/2 virus*) OR "chum salmon reovirus*" OR ("Oncorhynchus masou" W/2 virus*) OR ((reoviridae OR reovirus*) W/2 infection*))))
Antall treff: 6

Appendix Ib Search: Pink salmon and bacteria

Ovid MEDLINE(R) Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid MEDLINE(R) <1946 to Present>

Date: 24.01.2019

Number of hits 2

#	Searches	Results
1	(Oncorhynchus gorbuscha or pink salmon or gorbuscha or humpback salmon or Salmo gorbuscha).kf,tw.	250
2	Aeromonas salmonicida/ or Flavobacteriaceae Infections/ or Flavobacteriaceae/ or Francisella/ or Piscirickettsia/ or PISCIRICKETTSIACEAE/ or PISCIRICKETTSIACEAE INFECTIONS/ or RICKETTSIACEAE/ or Yersinia ruckeri/ or Yersinia Infections/ or Yersinia/ or VIBRIO/ or VIBRIO INFECTIONS/	17787
3	(Renibacterium salmoninarum or Aeromonas salmonicida or Flavobacterium psychrophilum or Francisella or francisellaceae or Piscirickettsia or Piscirickettsiaceae or Rickettsiaceae or Yersinia ruckeri or vibrio or vibrioses or vibriosis).kf,tw.	28868
4	2 or 3	37361
5	1 and 4	2

Embase <1974 to 2019 January 23>
Date: 24.01.2019

Number of hits: 0

Searches	Results
(Oncorhynchus gorbuscha or pink salmon or gorbuscha or humpback salmon or Salmo gorbuscha).kw,tw.	266
renibacterium salmoninarum/ or aeromonas salmonicida/ or exp Flavobacteriaceae infection/ or flavobacteriaceae/ or Francisella/ or Piscirickettsia salmonis/ or Piscirickettsia/ or Piscirickettsiaceae/ or piscirickettsiosis/ or Rickettsiaceae/ or Rickettsiaceae infection/ or yersinia ruckeri/ or exp Yersinia infection/ or exp Vibrio/ or exp vibriosis/	42775
(Renibacterium salmoninarum or Aeromonas salmonicida or Flavobacterium psychrophilum or Francisella or francisellaceae or Piscirickettsia or Piscirickettsiaceae or Rickettsiaceae or Yersinia ruckeri or vibrio or vibrioses or vibriosis).kw,tw.	29921
2 or 3	51227
1 and 4	2

Web of Science
Date: 24.01.2019
Number of hits: 9

# 3	9	#2 AND #1
		Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=All years
# 2	38298	TS=("Renibacterium salmoninarum" OR "Aeromonas salmonicida" OR "Flavobacterium psychrophilum" OR Francisella OR francisellaceae OR Piscirickettsia OR Piscirickettsiaceae OR Rickettsiaceae OR "Yersinia ruckeri" OR vibrio OR vibrioses OR vibriosis)
		Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=All years
# 1	1181	TS=("Oncorhynchus gorbuscha" OR "pink salmon" OR "humpback salmon" OR "Salmo gorbuscha" OR gorbuscha)
		Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=All years

Scopus
Date: 24.01.2019

Number of hits: 6

(TITLE-ABS-KEY ("Oncorhynchus gorbuscha" OR "pink salmon" OR "humpback salmon" OR "Salmo gorbuscha" OR gorbuscha)) AND (TITLE-ABS-KEY ("Renibacterium salmoninarum" OR "Aeromonas salmonicida" OR "Flavobacterium psychrophilum" OR francisella OR francisellaceae OR piscirickettsia OR piscirickettsiaceae OR rickettsiaceae OR "Yersinia ruckeri" OR vibrio OR vibrioses OR vibriosis))
Antall: 15

Appendix Ic Search: Pink salmon and parasites

Ovid MEDLINE(R) Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid MEDLINE(R) <1946 to Present>

Date: 24.01.2019

Number of hits: 41

#	Searches	Results
1	(Oncorhynchus gorbuscha or pink salmon or gorbuscha or humpback salmon or Salmo gorbuscha).kf,tw.	250
2	Naegleria/ or ACANTHAMOEBA/ or COCCIDIA/ or EIMERIIDAE/ or exp CRYPTOSPORIDIUM/ or exp EIMERIA/ or SOSPORA/ or LOMA/ or GLUGEA/ or PLEISTOPHORA/ or MYXOBOLUS/ or ANISAKIS/ or DIPHYLLOBOTHRIUM/ or COPEPODA/ or ARGULOIDA/	16920
3	(Paramoeba peruran* or Thecamoeba or Trinema or Naegleria or Acanthamoeba or Hartmanella or Vahlkampfia or Vexillifera or Ichthyobodo necator or Cryptobia salmositica or Trypanoplasma salmositica or Spironucleus or Chilodonella or Ichthyophthirius multifiliis or Capriniana spp or Ambiphyra or Riboscyphidia orTrichodina truttae or Coccidia or Eimeriidae or Calyptospora or Cryptosporidium or Eimeria or Epieimeria or Goussia or Isospora or Desmozoon lepeophtherii or Paranucleospora theridion or Microsporidium rhabdophilia or Nucleospora or Loma* or Ichthyosporidium or Microfilum or Microgemma or Nosemoides or Spraguea or Tetramicra or Glugea* or Heterosporis or Pleistophora* or Kabatana or Dermocystidium salmonis or Ichthyophonus hoferi or Sphaerothecum destruens or Henneguya salminicola or Henneguya zschokkei or Parvicapsula pseudobranchicola or Ceratomyxa shasta or Myxobolus cerebrali* or Kudoa thyrsites or Chloromyxum truttae or Hoferellus or Myxobilatus or Palliatus or Sphaerospora or Wardia or Ceratomyxa shasta or Tetracapsuloides bryosalmonae or Anisakidae or Anisakis simplex or Pseudoterranova decipiens or Eubothrium crassum or Diphyllobothrium or Ligula intestinalis or Proteocephalus longicollis or Nanophyetus salmincola or Diplostomum spathaceum or Cryptocotyle lingua or Sanguinicola or Acanthocephalus or Echinorhynchus or Metechinorhynchus or Pomphorhynchus or Pomphorhynchus or Lepeophtheirus salmoni* or Caligus clemensi or Caligus rogercresseyi or Argulus foliaceus).kf,tw.	24614
4	2 or 3	28630
5	1 and 4	41

Embase <1974 to 2019 January 23>
Date: 24.01.2019

Number of hits 42

#	Searches	Results
1	(Oncorhynchus gorbuscha or pink salmon or gorbuscha or humpback salmon or Salmo gorbuscha).kw,tw.	266
2	Naegleria/ or ACANTHAMOEBA/ or COCCIDIA/ or EIMERIIDAE/ or exp CRYPTOSPORIDIUM/ or exp EIMERIA/ or SOSPORA/ or LOMA/ or GLUGEA/ or PLEISTOPHORA/ or MYXOBOLUS/ or ANISAKIS/ or Anisakis simplex/ or DIPHYLLOBOTHRIUM/ or COPEPODA/ or ARGULOIDA/ or thecamoeba/ or Hartmannella/ or Vahlkampfia/ or ichthyophthiriasis/ or Pseudoterranova decipiens/ or Acanthocephalus/ or Gyrodactylus salaris/	23072
3	(Paramoeba peruran* or Thecamoeba or Trinema or Naegleria or Acanthamoeba or Hartmanella or Vahlkampfia or Vexillifera or Ichthyobodo necator or Cryptobia salmositica or Trypanoplasma salmositica or Spironucleus or Chilodonella or Ichthyophthirius multifiliis or Capriniana spp or Ambiphyra or Riboscyphidia orTrichodina truttae or Coccidia or Eimeriidae or Calyptospora or Cryptosporidium or Eimeria or Epieimeria or Goussia or Isospora or Desmozoon lepeophtherii or Paranucleospora theridion or Microsporidium rhabdophilia or Nucleospora or Loma* or Ichthyosporidium or Microfilum or Microgemma or Nosemoides or Spraguea or Tetramicra or Glugea* or Heterosporis or Pleistophora* or Kabatana or Dermocystidium salmonis or Ichthyophonus hoferi or Sphaerothecum destruens or Henneguya salminicola or Henneguya zschokkei or Parvicapsula pseudobranchicola or Ceratomyxa shasta or Myxobolus cerebral* or Kudoa thyrsites or Chloromyxum truttae or Hoferellus or Myxobilatus or Palliatus or Sphaerospora or Wardia or Ceratomyxa shasta or Tetracapsuloides bryosalmonae or Anisakidae or Anisakis simplex or Pseudoterranova decipiens or Eubothrium crassum or Diphyllobothrium or Ligula intestinalis or Proteocephalus longicollis or Nanophyetus salmincola or Diplostomum spathaceum or Cryptocotyle lingua or Sanguinicola or Acanthocephalus or Echinorhynchus or Metechinorhynchus or Pomphorhynchus or Pomphorhynchus or Lepeophtheirus salmoni* or Caligus clemensi or Caligus rogercresseyi or Argulus foliaceus).kw,tw.	25892
4	2 or 3	33171
5	1 and 4	42

Web of Science

Date: 24.01.2019

Number of hits 117

#3	117	#2 AND #1 *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=All years*
#2	32989	TS=("Paramoeba peruran*" OR Thecamoeba OR Trinema OR Naegleria OR Acanthamoeba OR Hartmanella OR Vahlkampfia OR Vexillifera OR "Ichthyobodo necator" OR "Cryptobia salmositica" OR "Trypanoplasma salmositica" OR

		Spironucleus OR Chilodonella OR "Ichthyophthirius multifiliis" OR "Capriniana spp" OR Ambiphyra OR Riboscyphidia OR "Trichodina truttae" OR Coccidia OR Eimeriidae OR Calyptospora OR Cryptosporidium OR Eimeria OR Epieimeria OR Goussia OR Isospora OR "Desmozoon lepeophtherii" OR "Paranucleospora theridion" OR "Microsporidium rhabdophilia" OR Nucleospora OR Loma* OR Ichthyosporidium OR Microfilum OR Microgemma OR Nosemoides OR Spraguea OR Tetramicra OR Glugea* OR Heterosporis OR Pleistophora* OR Kabatana OR "Dermocystidium salmonis" OR "Ichthyophonus hoferi" OR "Sphaerothecum destruens" OR "Henneguya salminicola" OR "Henneguya zschokkei" OR "Parvicapsula pseudobranchicola" OR "Ceratomyxa shasta" OR "Myxobolus cerebrali*" OR "Kudoa thyrsites" OR "Chloromyxum truttae" OR Hoferellus OR Myxobilatus OR Palliatus OR Sphaerospora OR Wardia OR "Ceratomyxa shasta" OR "Tetracapsuloides bryosalmonae" OR Anisakidae OR "Anisakis simplex" OR "Pseudoterranova decipiens" OR "Eubothrium crassum" OR Diphyllobothrium OR "Ligula intestinalis" OR "Proteocephalus longicollis" OR "Nanophyetus salmincola" OR "Diplostomum spathaceum" OR "Cryptocotyle lingua" OR Sanguinicola OR Acanthocephalus OR Echinorhynchus OR Metechinorhynchus OR Pomphorhynchus OR Pomphorhynchus OR "Lepeophtheirus salmoni*" OR "Caligus clemensi" OR "Caligus rogercresseyi" OR "Argulus foliaceus") *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=All years*
#1	1181	TS=("Oncorhynchus gorbuscha" OR "pink salmon" OR "humpback salmon" OR "Salmo gorbuscha" OR gorbuscha) *Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=All years*

Appendix II

Appendix IIa Naturally occurring freshwater fishes in Norway.

English name	Norwegian name	Scientific name
River lamprey	Elveniøye	*Lampetra fluviatilis*
Brook lamprey	Bekkeniøye	*L. planeri*
Arctic lamprey	Arktisk niøye	*L. camtschaticum*
Sea lamprey	Havniøye	*Petromyzon marinus*
European eel	Ål	*Anguilla anguilla*
Atlantic salmon	Laks	*Salmo salar*
Brown trout	Aure	*Salmo trutta*
Arctic char	Røye	*Salvelinus alpinus*
European whitefish	Sik	*Coregonus lavaretus*
Vendace	Lagesild	*C. albula*
European grayling	Harr	*Thymallus thymallus*
Smelt	Krøkle	*Osmerus eperlanus*
Roach	Mort	*Rutilus rutilus*
Common dace	Gullbust	*Leuciscus leuciscus*
Orfe	Vederbuk	*L. idus*
Common chub	Stam	*L. cephalus*
Asp	Asp	*Aspius aspius*
Common rudd	Sørv	*Scardinius erythrophthalmus*
Common minnow	Ørekyt	*Phoxinus phoxinus*
Crucian carp	Karuss	*Carassius carassius*
Bleak	Laue	*Alburnus alburnus*
Bream	Brasme	*Abramis brama*
Silver bream	Flire	*Blicca bjoerkna*
Pike	Gjedde	*Esox lucius*
Burbot	Lake	*Lota lota*
Ninespined stickleback	Nipigget stingsild	*Pungitius pungitius*
Threespined stickleback	Trepigget stingsild	*Gasterosteus aculeatus*
Alpine bullhead	Steinsmett	*Cottus poecilopus*
Common bullhead	Hvitfinnet steinulke	*C. gobio*

English name	Norwegian name	Scientific name
Fourhorn sculpin	Hornulke	*Myoxocephalus quadricornis*
Perch	Abbor	*Perca fluviatilis*
Ruffe	Hork	*Gymnocephalus cernuus*
Pikeperch	Gjørs	*Sander lucioperca*

Appendix IIb Freshwater fish species introduced to Norwegian waters and with documented successful breeding.

English name	Norwegian name	Scientific name
Goldfish	Gullfisk	Carassius auratus
Common gudgeon	Sandkryper	Gobio gobio
Belica	Regnlaue	Leucaspius delineatus
Common carp	Karpe	Cyprinus carpio
Tench	Suter	Tinca tinca
Pumpkinseed	Rødgjellet solabbor	Lepomis gibbosus
Brown bullhead	Dvergmalle	Ameiurus nebulosus
Pink salmon	Pukkellaks	Oncorhynchus gorbuscha
Rainbow trout	Regnbueaure	Oncorhynchus mykiss
Brook trout	Bekkerøye	Salvelinus fontinalis
Lake trout	Canadarøye	Salvelinus namaycush

Appendix III

Catches of pink salmon in Norway (categorical), Tana and Neiden rivers (numbers), and Northwest Russia (number of 100s), and stocking of fry introduced from the Pacific and locally produced (number of 100,000s).

Year	Top year Norway	Alternative Norway	Tana catch (no.)	Neiden catch (no.)	Russian catch (no. hundreds)	Russian introduced fry stocking (no. hundred thousands)	Russian local fry stocking (no. hundred thousands)	Per-mille catch (year t) from imported fry stocking in Russia (year (t-1))	Per-mille catch (year t) from imported AND local fry stocking in Russia (year (t-1))
	1=yes, 0=no	2=much, 1=medium, 0=little	Norway+ Finland	Norway+ Finland	From table 1, Niemelä et al. 2016	From table 1, Niemelä et al. 2016	From table 1, Niemelä et al. 2016		
1957						35			
1958						62			
1959						154			
1960	1	2			763	144		4,95	4,95
1961	0	0			28	104	0,1	0,19	0,19
1962	0	0			1	343	2,1	0,01	0,01
1963	0	0			0	237	0	0,00	0,00
1964	0	0			19	359		0,08	0,08
1965	1	2			478		0,4	1,33	1,33
1966	0	0			0		0,3		0,00
1967	0	0			24				80,00
1968	0	0			0	50			
1969	0	0			1	60		0,02	0,02
1970	0	0			4	73		0,07	0,07
1971	1	2			278	40	0	3,81	3,81
1972	0	0			17	42	0	0,43	0,43
1973	1	2			1436	35	0	34,19	34,19
1974	0	0	234		99		9,4	2,83	2,83
1975	1	2	177		1039	34	0		110,53
1976	0	0	668		26	50	1,5	0,76	0,76
1977	1	1	2420		1077	47	0	21,54	20,91
1978	0	0	40		35	49	6,8	0,74	0,74
1979	0	0	370		226	44		4,61	4,05
1980	0	0	9		0,4		0,7	0,01	0,01
1981	0	0	0		1,3	31			1,86
1982	0	0	0		0,3	2,4		0,01	0,01
1983	0	0	60		0,4			0,17	0,17

1984	0	0	0					
1985	0	0	4			4		
1986	0	0	23		0	10		0,00	0,00
1987	0	0	26		25,4	1		2,54	2,54
1988	0	0	6		0			0,00	0,00
1989	0	0	291		335			
1990	0	0	35		0	unknown (but 4 mill.eggs)	0,7		
1991	**1**	**1**	895		661			
1992	0	0	100		0			
1993	1	1	532		316			
1994	0	0	54		0		3,2	
1995	1	1	216		296				92,50
1996	0	0	40		0		5,5	
1997	**1**	**1**	438		983				178,73
1998	0	0	62		0		5	
1999	1	1	193		232	16,5	9,7		46,40
2000	1	1	485		81			4,91	3,09
2001	1	1	451		1560			
2002	1	1	224		11			
2003	1	1	245		483			
2004	0	0	99					
2005	1	1	593					
2006	0	0	32					
2007	1	1	601	61				
2008	0	0	50	4				
2009	0	0	81	12				
2010	0	0	9	1				
2011	0	0	28	8				
2012	0	0	16	15				
2013	0	0	36	6				
2014	0	0	75	6				
2015	0	0	74	9				
2016	0	0	42	38				
2017	1	2	2862	193				
2018	0	0	2	7				
2019	1	2	1277	400				

Appendix IV

List of potentially relevant parasites related to Pacific salmon

PROTOZOA
- *Paramoeba perurans* (amoebic gill disease)
- *Thecamoeba* spp. ?
- Trinema spp.
- *Naegleria* spp.
- *Acanthamoeba* spp.
- *Hartmanella* spp.
- *Vahlkampfia* spp.
- *Vexillifera* spp.
- *Ichthyobodo necator*
- *Cryptobia (Trypanoplasma) salmositica?*
- *Spironucleus* spp. (*perurans/salmonis*)
- *Chilodonella* spp.
- *Ichthyophthirius multifiliis*
- Different groups of peritrichs such as *Capriniana* spp., *Ambiphyra* spp., *Riboscyphidia* spp., *Trichodina truttae* and other groups and species
- Coccidia (Eimeriidae) such as *Calyptospora* spp., *Cryptosporidium* spp., *Eimeria* spp., *Epieimeria* spp., *Goussia* spp. and *Isospora* spp.

Microsporidia (various species and genera including, but not limited to):
- *Desmozoon lepeophtherii*
- *Paranucleospora theridion*
- *Microsporidium rhabdophilia*
- *Nucleospora*
- *Loma*
- *Ichthyosporidium*
- *Microfilum,*
- *Microgemma*
- *Nosemoides*
- *Spraguea*
- *Tetramicra,*
- *Glugea*
- *Heterosporis*
- *Pleistophora*
- *Kabatana*

Mesomycetozoea
- *Dermocystidium salmonis*
- *Ichthyophonus hoferi*
- *Sphaerothecum destruen*

CNIDARIA

Myxozoa (various species, including, but not limited to):
- *Henneguya salminicola*
- *Henneguya zschokkei*
- *Parvicapsula pseudobranchicola*

- *Ceratomyxa shasta*
- *Myxobolus cerebralis*
- *Kudoa thyrsites*
- *Chloromyxum truttae* (and other species)
- *Hoferellus* spp*.*
- *Myxobilatus* spp*.*
- *Palliatus* spp*.*
- *Sphaerospora* spp*.*
- *Wardia* spp*.*
- *Ceratomyxa shasta* (and other species??)
- *Tetracapsuloides bryosalmonae*

HELMINTHS
Nematodes
Anisakidae such as *Anisakis simplex*, *Pseudoterranova*

Cestodes
- *Eubothrium crassum* (and other species)
- *Diphyllobothrium* spp.
- *Ligula intestinalis*
- *Proteocephalus longicollis*

Trematodes
- *Nanophyetus salmincola*
- *Diplostomum spathaceum*
- *Cryptocotyle lingua*
- *Sanguinicola* spp.

Acanthocephala
- *Acanthocephalus*
- *Echinorhynchus*
- *Metechinorhynchus*
- *Pomphorhynchus*

MONOGENEANS
Gyrodactylus salaris

CRUSTACEA
- *Lepeophtheirus salmonis* (salmon louse)
- *Caligus* spp. (e.g., *C. clemensi, C. rogercresseyi*)
- *Argulus* spp. (e.g., *A. foliaceus*)