Effects of climate change on some anadromous salmonids in the northern hemisphere

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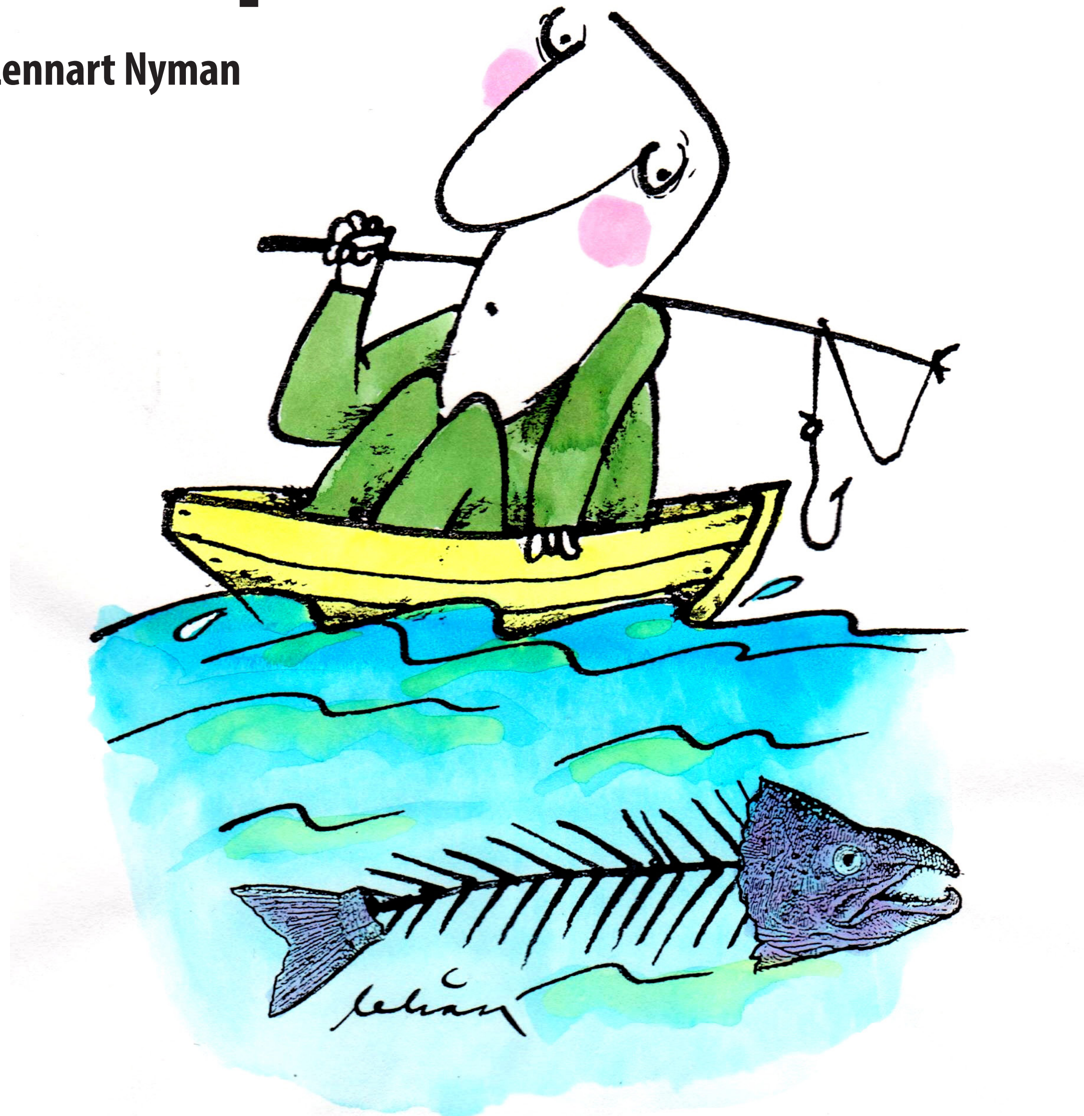

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About the author:

Lennart Nyman is a scientist and environmentalist from Sweden who has worked for some 50 years studying various aspects of the Baltic ecosystem and other marine, freshwater and terrestrial ecosystems worldwide. He has served for many years as Conservation Director with WWF Sweden, and prior to that in various roles, including Director of the Institute of Freshwater Research at Drottningholm, Sweden. He has been a member of numerous national and international boards, committees and societies on environmental issues.

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Introduction

Salmonid fishes all originate in the Northern hemisphese. Most species occur both as freshwater, landlocked or anadromous populations, where the latter spawn and evolve as juveniles in fresh water and then swim downstream to the ocean where they grow until they are ready to migrate back to freshwater habitats like brooks, rivers or lakes to spawn and thus complete their life cycle.

This report deals with salmonid species of two genera only, viz. ***Oncorhynchus*** (Fig. 1) and ***Salmo*** (Fig. 2), the species of which normally exist as anadromous populations, even if numerous populations occur as landlocked or streamdwelling. This means that I have excluded other salmonid genera and species, like the chars, huchens, whitefish and grayling, but even these latter species are subjected to the same hardships of climate change as the Pacific salmons (***Oncorhynchus***) and the Atlantic salmon (***Salmo salar***, including also the European anadromous brown trout – ***Salmo trutta***).

Fig. 1 Spawning migration of Sockeye salmon (Oncorhynchus nerka) (http://www2.laiwanette.net/fountain/wp-content/uploads/2015/07/vancouverobserver.comsitesvancouverobserver.comfilesimagesarticlebodyhero-optimized-low.jpg)

Fig. 2 Spawning pair of Atlantic salmon (Salmo salar) – female above. (http://keyassets.timeincuk.net/inspirewp/live/wp-content/uploads/sites/3/2015/05/Atlantic-salmon-630x400.jpg)

All species described in this report have been and are of immense economic importance to the peoples and countries where they occur naturally and also in countries where some of them have been introduced. In the former group of countries the fish are both caught commercially and by sportfishermen and are very important in aquaculture. In the latter group of countries where these fish have been introduced and sometimes have formed selfsustaining populations, they are also of great economic importance, mainly to anglers. The latter group include such countries as New Zealand (McDowall, 1994), Chile (Tveterås, et al. 2014) and southern Argentina (Schneider, 2016). Sea-run European brown trout have also established selfsustaining anadromous populations in Argentina.

Where do these salmonids live?

Pacific salmon occur in coastal (marine) and/or river waters from Alaska, western Canada and eastern Russia in the north to Taiwan and Mexico in the south (Fig. 3). I have only considered the 7 species of ***Oncorhynchus*** that are mainly anadromous, but this genus contains at least 12 recognized species (Behnke 2002). The Atlantic salmon (Fig. 4) and the indigenous anadromous brown trout occur on the high seas, and in coastal and river waters of the North Atlantic roughly from the White Sea in western Russia and in western Europe down to Portugal (salmon) and both species also occurring in Icelandic waters, but to the west of Iceland only salmon, in Greenland – one river only, and in numerous lakes and rivers in eastern Canada and a few rivers in New England. Introduction of European brown trout has resulted in a few established anadromous brown trout populations in Newfoundland, Canada.

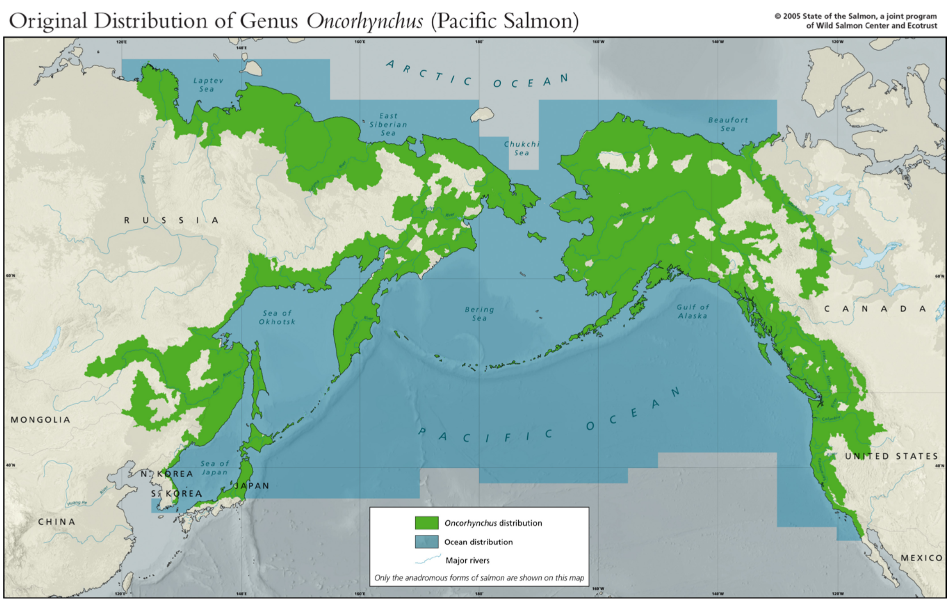

Fig. 3 Historical Pacific salmon distribution (https://thefisheriesblog.files.wordpress.com/2014/06/pacific-salmon-distribution.jpg)

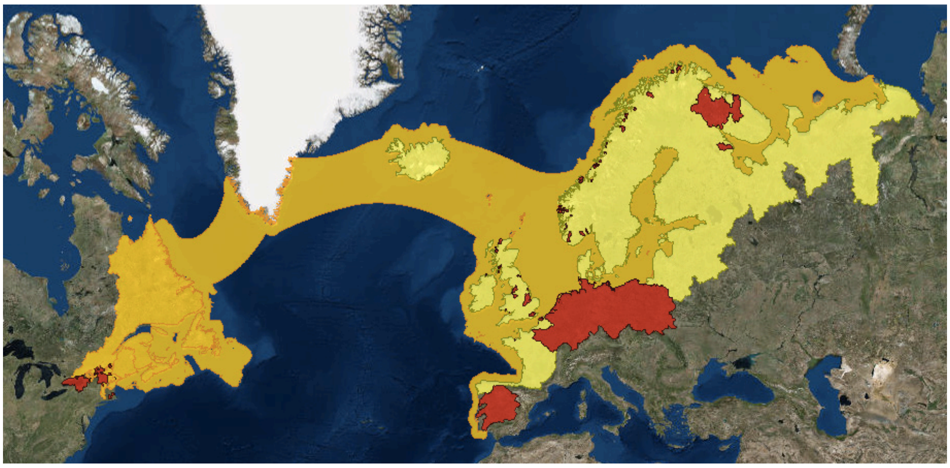

Fig. 4 Historical Atlantic salmon distribution (http://www.alternet.org/files/screen_shot_2016-03-08_at_7.44.36_pm.png)

Salmonid biology

All anadromous salmon (of both genera) spawn in fresh water. The majority of species are fall spawners and their fertilized eggs require some three to eight months to hatch and develop into juveniles. A few species spawn in spring and require only a few weeks before the eggs hatch. When they are young and remain in running water these salmonids forage on small crustaceans, insects and even plankton, but when they have returned to sea they become typical predators, often depending on schooling small fish like herrings, sand lance, capelin, and juveniles of many other species. In addition, Pacific salmon also prey on e.g. euphasiids, pteropods and squid (Karpenko et al., 2007).

After hatching the juveniles still depend on their yolk-sacs for several weeks, and eventually the juveniles begin their dowstream migration during which time they develop their tolerance to salt water. Depending on the species and habitat juveniles remain in the river from a few months up to seven years.

Also, depending on the species their growth period, maturation process and time of return to fresh water to spawn may vary between one and seven years (Rand, 2009).

Salmonids and climate change

In addition to their economic importance these fish also have important ecological roles in their environments, particularly in the freshwater phase where they many times are dominant species on which both the aquatic and terrestrial ecosystems surrounding their native streams depend. The latter fact refers mainly to the Pacific salmon. Two areas with native salmonid species are of special interest because of large-scale threats to the species. These areas are dealt with separately below, the Baltic Sea and the state of California, USA.

Effects in the freshwater habitats

Salmon are triggered by temperature increases (e.g. Rand, 2009, Nyman, 2015). As water temperature increases some direct impacts on salmon biology can be predicted. These can include physiological stress, increased depletion of energy resources and also increased susceptibility to disease. At extreme water temperatures in summer massive fish kills may occur. Increasing water temperatures may cause rapidly developing juveniles to enter the sea before their planktonic food source is available in sufficient density. Increased summer temperatures may also present a thermal barrier which may delay or even prevent spawning.

In addition, loss of snowpack and less precipitation falling as snow will mean reduced stream flows in summer, and lower water flows in summer will also cause water temperatures to exceed optimum teamperatures for most salmonids. Reduced water flows will also impact the spawning migration of mature fish. Increased water flow in winter, because most precipitation will occur as rain rather than snow, may also cause floods which will impact spawning habitats, by scouring river beds and causing physical damage to both salmon and trout eggs and young fish. It is likely to assume that the increasing input of fresh water will cause increasing sedimentation of river beds, which in turn will reduce the amount of gravel available for spawning redds.

Warmer and drier conditions in summer have already substantially increased the number of forest fires which may burn out root systems and contribute to increased erosion and siltation in nearby rivers.

Effects in marine habitats

Predicting some of the specific effects of climate change on salmon in their marine environment is very difficult. This is due in part to our limited knowledge of where the salmon are in the high seas, but also with the uncertainties how marine habitats at large will be affected. Warmer oceans will cause a northward shift in the range of salmon at sea, but probably more important are the effects of increased temperatures on the timing of new food webs, from planktonic species of importance to young fish to the higher levels of biological productivity. Disruptions of this timing may cause a scarcity of food in the salmon´s life cycle. Warmer ocean temperatures may also reduce the number of smaller fish, which could increase predation pressure on salmon.

Ocean acidification is a mounting problem impacting all levels of biological productivity in the oceans. The continued release of so called green-house gases, above all CO_2, is rapidly acidifying the ocean. The most direct effect is that some zooplankton and some shelled phytoplankton are rapidly losing their ability to build shells, and so are most reefbuilding corals and mussels, clams, starfish and urchins, which have trouble building shells in more acidic water (Ries, 2010). The larger zooplankton are fundamental to survival of young salmonids and of course to numerous other fishes in the ocean.

Sea-level rise caused by warmer water and melting of the large areas covered by continental ice sheets will inundate estuaries which is where most salmonids make their transition between the freshwater and marine phases of life.

Effects at the 2 degree level

All fish species generally adapt to environmental change through the slow process of evolution, by moving to an area with a more suitable climate or by the ability of certain genes to turn on/off based on different environmental conditions, e g by changing the timing of their downstream migration to a warming climate.

Even at the present temperature level, which approximates a 2 degree temperature (C) increase at northern salmon latitudes, Sumaila et al. (2015) predicted that sockeye salmon on the Pacific northwest coast of North America may suffer a decline by 2050 as a result of climate warming. The same year as Sumaila´s prediction it was estimated that exceedingly warm stream temperatures were to blame for the loss of an estimated 250,000 adult sockeye in the same area (Zuckerman, 2017). Also in 2017, this mortality figure was further increased (Brodbeck, 2017). She wrote that ”...the majority of the 500,000 migrating sockeye salmon in the Columbia River died while returning to their spawning grounds, an event many federal and state fisheries biologists attribute to unusually warm waters”.

Even if that study was performed on Pacific salmon, there is no reason to believe that Atlantic salmon would not react in the same manner (Nyman, 2015, Johnsson, 2017). Johnsson (ibid.) also states that salmon migrating between freshwater and oceans are important vectors of energy in the two ecosystems they inhabit. The occurrence of short-term heat waves will be most common in the southern areas of salmonid distribution, but a temperature increase will partly be compensated by new northern watersheds which now are too cold for most salmonids. Such an extension of northern distribution will probably require a long period of time to develop because of the strong homing behavior of salmonids.

The California case study

Climate is the major overarching threat affecting salmonids in California (Moyle et al., 2017, where all pertinent information on this topic is taken). At the writing of this report, the commercial salmon fisheries were again closed for the 2017 season, and the northern part of the state is hopefully emerging from the historic droughts of 2012-2016, which saw significant negative impacts on salmonid populations at large. Fortyfive percent of California salmonids are likely to be extinct in the next 50 years. This includes 52 % of anadromous species and 30% of inland species. It is predicted that 100 years from now 23 of the 31 species (74%) are likely to be extinct if prresent conditions continue.

Climate change is the major threat afferting salmonids in California and is scored as a critical or high threat for 26 of the 31 species (87%). Other threats include lack of cold water, low and variable streamflows, constricted habitat, reduced habitat suitability and survival, food web alteration, and rising sea levels. Is there a way to reverse the extinction trend thus saving California´s salmonids?

The primary goal is of course to reverse global releases of carbon dioxide. In addition, we must protect the best of what habitats are left, and in particular restore and protect source waters. Also, restore productive and diverse habitats that were once productive but are now highly altered. In short, a return to resilience.

The Baltic Sea case study

Two anadromous salmonids occur in the Baltic Sea, the Atlantic/Baltic salmon (Salmo salar) and the brown trout (Salmo trutta). The salmon also occurs in landlocked populations in some of the larger lakes draining into the Baltic, and the brown trout is very common in most brooks and rivers of the region. The Baltic Sea is very different to the high-salinity Pacific Ocean where numerous species of salmon of the genus Oncorhynchus live. The Baltic Sea functions as a gigantic estuary, with a salinity cline of almost pure fresh water in the extreme north of the Gulf of Bothnia, changing gradually to almost marine conditions in the south-west. There is also a temperature cline, in general with higher temperatures (both in summer and winter) in the south than in northern parts of the Baltic. The northernmost part of the Baltic is ice-covered for months in winter, but there is rarely any ice cover in the south. These climatic differences have different impact on salmonid life, because the entire lifecycle of salmon and anadromous brown trout is triggered by temperature conditions. When entering the Baltic from the rivers they were born in they are favoured by temperatures in excess of 10 degrees C, and when young (smolts) in the Baltic their survival is highest at a temperature from 9-11C, and finally, when feeding and maturing in open water they avoid temperatures above 10C (Alm 1958). The decrease in salinity which is predicted to affect the Baltic basin will probably not have any direct impact on salmon/trout survival, there will be a reduced body of sufficiently cold water in the Baltic, which might lead to reduced availability of suitable prey. However, the most severe threat to their long-term survival is rising summer temperatures. Prolonged periods of high temperature may prove fatal, especially to small populations around the southern Baltic region (Nyman 2015). These conditions may occur even at present climate warming, and with a temperature increase of 3 to 4 degrees C in the north temperature conditions will be of the same magnitude as in the southern Baltic. It is vital that all proposals regarding habitat improvement and protection described above in the California case study be applied also in Baltic rivers.

Effects at the 4 degree level

If the present increase in acidification continues it can be estimated that global ocean surface temperature may rise some 4 degrees (C) above present level. This will change all aquatic ecosystems, freshwater and saline, at all biological levels – bottom fauna, aquatic flora and up to fishes, birds and marine mammals – and eventually also humans. Such changes are extremely complicated to predict in any detail but it is very likely that almost all anadromous salmonid populations will vanish, and even at higher latitudes few populations will have the ability to adapt within the short time span of just one century. The melting of permafrost areas in the north will release methane, an even more potent green-house gas than carbon dioxide, which will compound the negative effects of global warming both in terrestrial and aquatic ecosystems. It should also be pointed out that such a temperature increase will be augmented by a number of other human-induced threats to salmonids, like overfishing, habitat destruction, pollution, and obstruction of migratory routes. Surely, this suite of threats will all jeopardise the chance of survival of all salmonid stocks.

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