	Council	CNL(23)60
NASCO	*The status of Atlantic salmon stocks in Iceland* *Past and present management actions to mitigate the effect of climate change on Atlantic salmon*	Agenda item: 7a)

The status of Atlantic salmon stocks in Iceland
Past and present management actions to mitigate the effect of climate change on Atlantic salmon

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Introduction

Five native species of freshwater fishes are found in Iceland. Three species of salmonids, Atlantic salmon (*Salmo salar*), brown trout (*Salmo trutta*) and Arctic charr (*Salvelinus alpinus*). The other two are, European eel (*Anquilla anquilla*), and three-spined sticklebacks (*Gasterosteus aculeatus*). Arctic charr and brown trout can have both resident and migratory components. Atlantic salmon, Arctic charr and brown trout have stocks in both rivers and lakes that are being harvested in Iceland. In the most recent years European flounder (*Platichthys flesus*) has been common, mostly at river estuaries, and pink salmon (*Oncorhynchus gorbuscha*) is rapidly increasing in numbers and distribution (Gudbergsson and Antonsson 1996, Gudbergsson 2015).

From the first settlement in the 9th century, salmon fishing has been highly evaluated as food resource. In the first law, written in the year 1200, it is stated that fishing trap fence were only allowed out to 2/3 of a river width to allow migrating fish to pass to the upper regions of the river.

The fishing rights belong to the owner of the land adjacent to the rivers. The landowners are usually farmers. All the landowners of the fishing rights, in a river system, have by law to form a fishery association, which manages the exploitation of the fish stocks, within the frame set by the law. Most commonly the rivers fishery association rent or leases the fishing rights to angling syndicates, angling clubs or directly to anglers. The entire riverbank is accessible to the limited number of rod fishermen that have fishing permit each day.

The fishing season for salmon in Icelandic rivers is at the maximum of 105 days in the period from 20th of May to 30th of September. In rivers where salmon fishery is mainly based on release of hatchery reared salmon smolts (ocean ranching) the fishing season can be extended to 120 days and throughout October with permission from the Directorate of Fisheries (Fiskistofa). The daily fishing period is 12 hours for seven days a week for a total of 84 hours each week. In most Icelandic rivers, rod and line is the only fishing gear allowed. A limited number of rods are allowed in each river. The old historic limit for conservation was attained by limiting the fishing effort in terms of number of rods. For the decision, taken by the Directorate of Fisheries, one fish per rod per day was used as a rule of thumb. In most rivers fishing effort has remained almost unchanged from 1970, while changes in the numbers of landed catch have at the same time been going down as many river associations apply catch & release of all salmon in their harvest plans. Each fishery association needs to make a harvest plan that outlines the management strategy to sustainable fishery. The management plan needs approval by the Directorate of Fisheries after a review by the Marine and Freshwater Research Institute (MRFI).

Net fishery is almost exclusively bound to the large glacial rivers where angling possibilities are limited due to turbid water. In the net fishery, gillnets are the most common fishing method.

The weekly net fishing period lasts from Tuesday morning at 10 AM to Friday evening at 10 PM. The weekly fishing period in net fisheries is 84 hours, the same number of hours as the weekly fishing opening is in the rod fishery. The weekend closure, in the net fishery, is to reduce fishing effort and enhance fish migration to the river upper regions and tributaries.

There has been a general ban, by law, on ocean salmon fishing in Icelandic waters since 1932. An exception to that were five localities (farms) in West Iceland with coastal fishery. At these localities coastal gillnets set from land were used. These fishing rights were permanently bought out in 1997 by fishery associations in nearby rivers and with governmental support. This was possible since salmon caught by anglers are of much higher economic value than salmon caught in the net fishery. All salmon harvested in Iceland is in freshwater and mostly based on exploitation of a single stock.

Lease of net fishing rights by owners of rod fishing rights in clear water tributaries have been practised in the Hvita River system in Borgarfjordur, SW-Iceland since 1991 (32 years). The net lease is based on an agreement where the fishery associations to clear water tributaries pays 8-10% of the income value from rod fishing licences to the net owners of net fishing rights for not fishing. The net lease has reduced the net catch and increased the rod catch by 28-35% (Einarsson and Gudbergsson 2003).

Enhancement actions taken to increase population size of Atlantic salmon

The geology of Iceland is relatively young. Rivers in Iceland are of various origin including, spring-fed rivers, direct run- off rivers and glacier rivers and waterfalls are numerous. At present 78 fish passages have been built, which opens up 900 km, resulting in a total of 3000 km of river length accessible for anadromous fish in Iceland. The construction of fish ladders has, with only few exceptions been successful in increasing population size of salmon, angling opportunities, and economic value of the angling fishery in Iceland.

Enhancement programs

Enhancement of salmon has been practiced in Iceland for the past century. Initially with fry from hatcheries and later (after 1960) with parr and smolts. In the latest years enhancement is mainly by utilizing areas above waterfalls by moving adults for spawning or stocking with parr or eggs. By the operation eggs are moved from lower part of rivers to unreachable upper parts but does not add to the spawning stock. Ocean ranching for harvest with rod and line is practiced in few rivers at the south coast of Iceland. The operations are mainly bound to two rivers, rivers with poor nursery areas not supporting wild salmon, but good angling opportunities. Annually 500 thousand smolts are released in each of the rivers giving from six to ten thousand fish caught annually with rod and line. The ocean ranching increases the total number of salmon caught in the angling fishery in Iceland by 20 to 25%.

Water temperature and salmonids thermal optima

The Marine and Freshwater Research Institute (MRFI) has, for the past 20 years, operated a net of temperature loggers in more than fifty rivers in Iceland. Information from the Icelandic Meteorological Office show an increase in annual average air temperature for the past twenty to thirty years. The temperature increase is mainly shown during wintertime and is reflected by the in-river water temperature that shows higher water temperature in spring and autumn while summer temperature has been more stable. There is a strong relationship between spring temperature and the size of juvenile salmon measured in the annual autumn surveys. The optimal water temperature differs for the three salmonids species, with salmon tolerating the highest temperature out of the three and Arctic charr the lowest with brown trout being intermediate. The long-term measurements around Iceland seldomly reach the upper temperature limits for salmon but may in some cases have constrained the cold adapted Arctic

charr. Higher temperature has been observed to result in many different physiological changes in salmonids such as changes in growth rate, time of spawning, egg hatching time and emergence of larvae (Jonsson and Jonsson 2010). In some rivers in Iceland, mostly in the south and west, higher spring temperature has indirectly contributed to changes in age-at-smolting by increasing juvenile growth rate. This can be observed by analysing scales from returning adults, as well as from smolt traps in one of our ICES index rivers, Ellidaar.

Furthermore, there are indications that higher water temperatures may have indirect negative effects on salmon. For example, a recent study on the Proliferative Kidney Disease indicated a very high proportion of infections among salmonids in Iceland but since the symptoms need temperature above 15°C to develop majority of the individuals were not affected by the infection (Kristmundsson *et al.* 2011; 2023). The PKD disease has caused severe mortality in rivers in Northern-Norway (Sterud *et al.* 2007) and with such high numbers of infected individuals in the studied rivers and lakes it should be considered likely to have negative effects on salmon populations with increasing water temperatures expected with climate change.

Wild salmon in Iceland

The average number of wild salmon migrating into Icelandic rivers is close to 80 thousand fish in the period from 1971 to 2021 (Figure 1). A declining trend are seen for the whole time-series with a period of higher fluctuations and some of the lowest numbers in the most recent years. This high fluctuation between years can clearly be seen from 2012 to 2015.

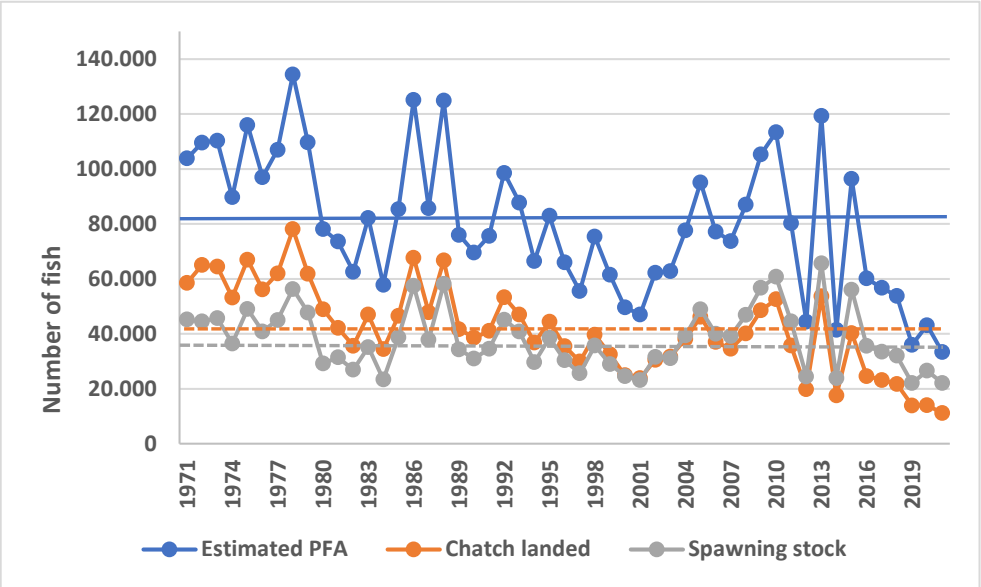

Figure 1. Estimated pre fishery abundance (PFA) of wild salmon in Icelandic rivers, catch and spawning stock from 1971 to 2021.

Sea age composition

The salmon stock in Iceland consists of one sea winter (1SW) and two sea winter salmon (2SW). Longer sea age than 2SW is very rare and repeated spawning is in low proportions.

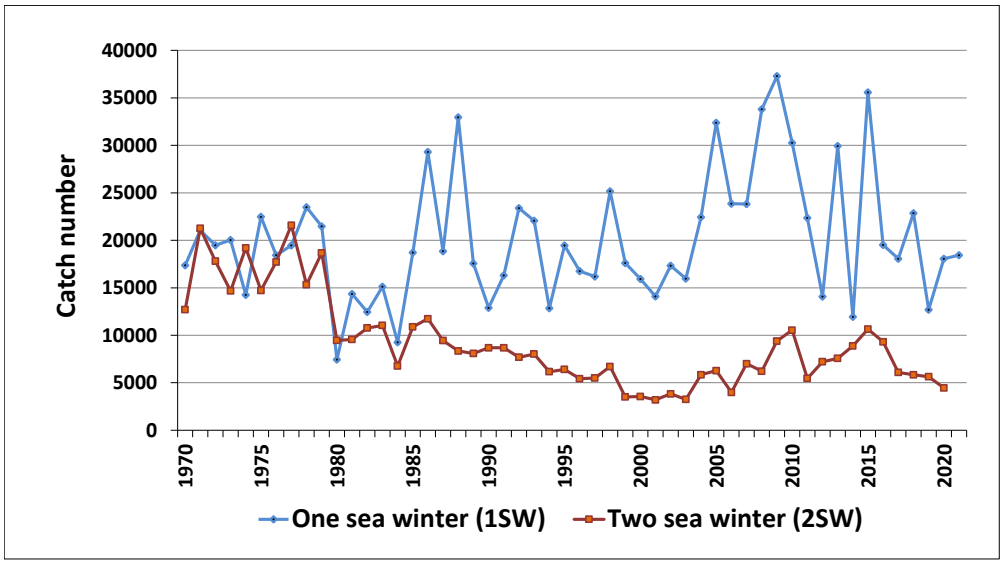

Figure 2. The number of one sea winter (1SW) and two sea winter (2SW) salmon in the angling fishery of wild salmon in Icelandic rivers 1970-2021, shown for the same smolt cohort.

In the 1970's 48% of the angling catches of wild salmon was 2SW salmon. After a very cold period in the early 1980's a clear decline was seen in both stock components. The 2SW stock component did not recover like the 1SW and was down to 19% of the total catch at the average from 2000 to 2010 (Thordardottir and Gudbergsson 2022).

In 2000 a **management action** was taken in cooperation between the Institute of Freshwater Fisheries, the Federation of Icelandic River Owners and the Association of Angling Clubs to encourage catch and release of 2SW salmon. The management action involved changing the fishing regulations to mandatory release of large salmon (>69 cm) a size group which is almost entirely comprised of 2SW salmon. It needs to be noted that the genetic inheritance of sea age, as later described by Barson *et al*. (2015), was not known at that time. In the light of Barson *et al.* (2015) findings these actions can be regarded as successful and a clear sign of recovery of the 2SW can be seen and from 2010 to 2020 (Figure 3).

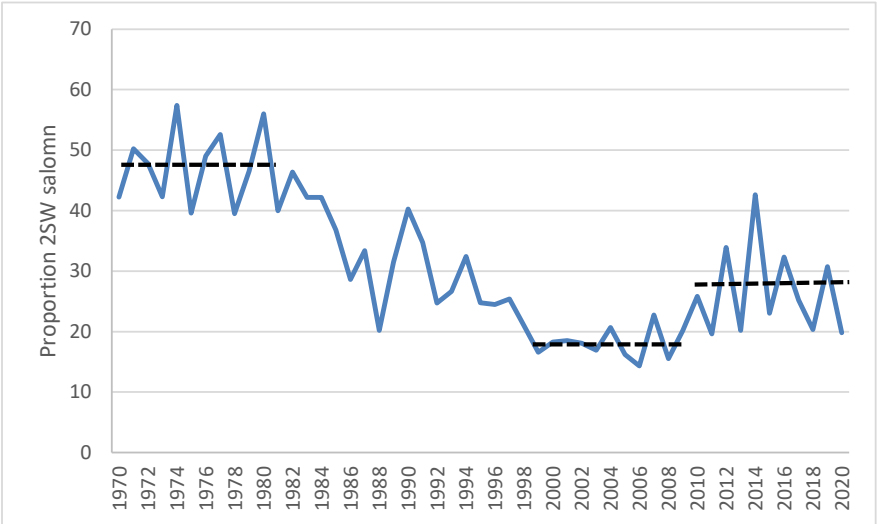

Figure 3. The proportion of two sea winter salmon in the angling catches in Icelandic rivers from 1970 to 2020. The average proportions were 48% from 1970-1980, 19% form 2000-2010 and 28% from 2010-2020.

Furthermore, to decrease the fishing pressure on the 2SW salmon in the few rivers that net fisheries were still in operation a **management action** in which a delay of the opening of the net-fishery to the end of June, was taken. The purpose is to allow the 2SW fish, which usually

arrive earlier then the 1SW, to migrate up rivers to clear water tributaries and lower the fishing pressure on that component.

Catch and release is mandatory for all salmon catches in numerous Icelandic rivers and for the past few years more than 80% of all wild 2SW salmon and 50% of the 1SW salmon are released in the angling fishery. As can be seen on Figure 1, catch and release has led to increase the spawning stock and the number of eggs spawned annually.

Case study on rivers in NE-Iceland show that the after catch and release commenced the juvenile densities has increased (Figure 4) (Bardarson *et al*. 2017). The smolt production has increased and helped to keep the number of migrating adult fish although the ocean mortality of salmon has increased in general in the North Atlantic (ICES 2023).

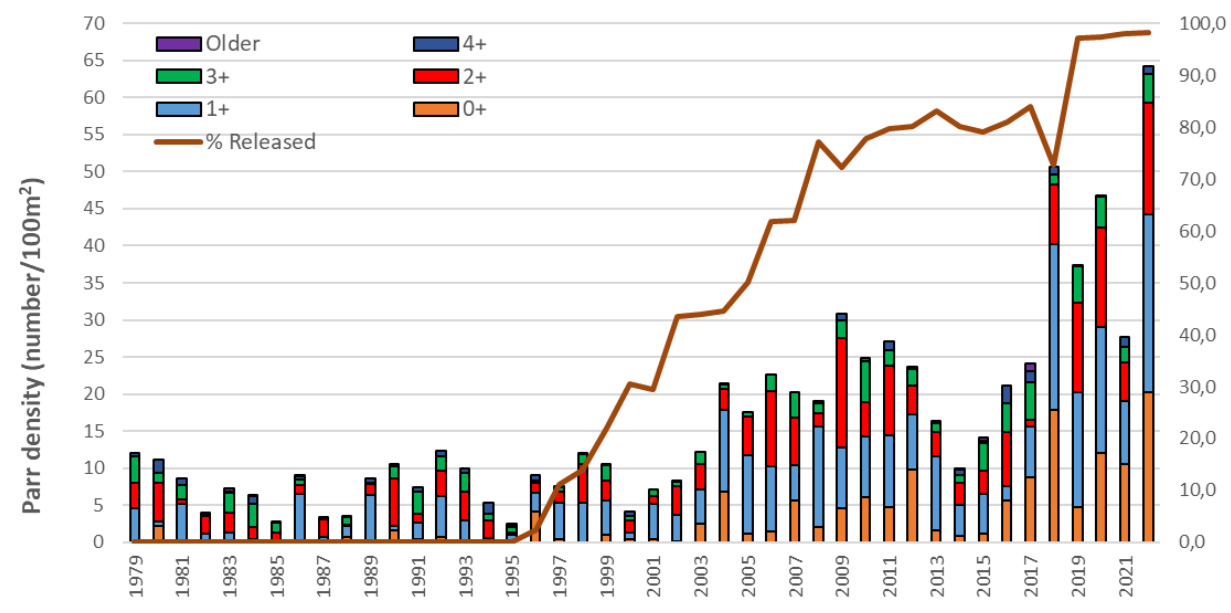

Figure 4. The proportion of catch and release and densities of juvenile salmon in river Selá in NE Iceland.

Ice-free winters – higher predation pressure

Warmer winters has led to longer ice-free periods of rivers in Iceland. This opens for predation on salmon juveniles. In river predation, especially during the smolt run, is likely to be a bigger problem than previously anticipated. MRFI has installed three, pit-tag antennas, in the ICES index river Vesturdalsá, in NE-Iceland to investigate parr migrations and mortality during the smolt run. For the past three years the smolt mortality has on a five km at the lower part of the river has been from 44% and 65% (Bardarson *et al.* 2023). In river mortality has also been seen in other rivers (Flávio *et al.* 2020). The study in river Vesturdalsá will continue in the coming years for further estimation of in-river mortality and for further understanding of the reason for the mortality.

Less snow fall during winter can also result in less river runoff during vulnerable periods in the life-cycle of salmons such as during the smolt runs and it can even end with a severe drought in smaller rivers. This was for example the case in many of the salmon rivers in West of Iceland with some experiencing severe drought that have been linked to worse recruitment then was expected based on the size of the spawning cohorts in the rivers (Gudmundsdottir *et al.* 2023.).

The **management action** taken by the river fishery association in river Vesturdalsá and other rivers in the area is to overwatch the rivers especially during the smolt run and scare away bird predators and to minimize the abundance of the invasive American mink (*Mustela vision*) which is an introduced alien species in Icelandic environment.

Pink salmon

The first pink salmon was caught in Iceland 1960. Since then, pink salmon have been periodically reported in the catch and almost exclusively males. The males have distinctive humpback, and it is likely that the female pink salmon has been mis-identified as sea-run Arctic charr. From 2015 the number of pink salmon caught in Icelandic rivers has been increasing and are now being reported in many Icelandic rivers. Furthermore, pink salmon smolts have been caught indicating successive spawning and reproduction (Skóra *et al*. in prep). The impacts of pink salmon on the ecology of Icelandic salmon rivers are still not known. It is likely that the sudden increase in number and distribution of pink salmon may be related to climate change (Irvine and Fukuwaka 2011). It is also a burning question why pink salmon is doing well in the North Atlantic at the same time the Atlantic salmon is struggling as the two species reside in the same marine area and utilizing to large extent the same food items.

Local fishery associations are willing to remove pink salmon from their rivers and by that delay the colonisation of pink salmon in their rivers.

A **management action** has been taken by the Ministry of Food, Agriculture and Fisheries to give the fishing associations permit for fishing pink salmon in rivers with seins and nets, an equipment that otherwise would be illegal to use. A proposed change to the Salmon, trout and charr fishing act is now going through parliamentary procedure in the Icelandic parliament. It is regarded likely that necessary changes to the act will be agreed and in place before the fishing season.

In summary

The question asked by NASCO regarding management actions undertaken to mitigate the negative impacts of climate change was a wakeup call for the parties involved in research and management of Atlantic salmon in Iceland. Partly, this is because climate related changes, in relation to salmon stocks, is currently not having affects that are considered substantial. Although warmer climate can be welcomed by people living in cold northern countries, climate change can have negative impacts on the environment including harvested fish stocks. Seeing the negative effects that warmer climate is having on salmon populations across the North-Atlantic, especially in the southern part, it is of high importance for Iceland to closely follow lessons learnt in other countries. The invite to take part in the discussions on the topic within the NASCO community is therefore welcomed. Furthermore, we surely hope that the political decision taken by the minister of Food, Agriculture and Fisheries to re-join NASCO will be a good step for salmon research and sustainable management of the country’s valuable salmon resources.

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