The Salmon Killer *Gyrodactylus salaris* in Norway

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Pathogenic strains of the salmon parasite Gyrodactylus salaris has since the seventies infected 50 Norwegian rivers and 39 hatcheries and freshwater stocks with salmonids. This article presents the history of and control of the parasite in wild salmonids in Norway.

Gyrodactylus salaris is originally a low- or non-pathogenic parasite of salmon in the Baltic Sea which during and shortly after the ice ages formed an isolated refuge for freshwater. The salmon in these water-ways were, therefore, objects for a co-evolution with *G. salaris* and this has resulted in partial resistance. It has been concluded that *G. salaris* has been imported to Norway by anthropogenic means at least four times from the Baltic region. If not treated, the infection will most probably lead to total extinction of the local salmon stock (Anon 2014).

The first observation in Norway was in 1975 after substantial salmon mortality at the Akvaforsk fish hatchery in Sunndalsøra, Møre and Romsdal County (Bergsjø & Vassvik 1977). Five years later, a "Gyrodactylus committee" concluded that *G. salaris* was non-indigenous, probably newly established, spread via hatcheries, restocking and subsequently fish migration through brackish water in estuaries (Johnsen & Jensen 1991; Bakke et al. 2007).

The epizootie in Norway is related to the Atlantic salmon, *Salmo salar*. Nevertheless, it has been shown that two other species of salmonids play a part in the disease´s maintenance and spreading. The rainbow trout (*Oncorhynchus mykiss*) has been shown to be a carrier species on many of the inflicted farms and some of the rivers, but with low intensity on each fish (Bakke et al., 1991; Mo 1991). Later it has also been shown that some stocks of arctic char (*Salvelinus alpinus*) have the same property (Robertsen et al., 2007; Hytterød et al., 2011) and this has led to the necessary treatment of three lakes in the Nordland County (Stensli & Bardal 2014). Other species may potentially function as vectors over a limited distance or time.

Methods of control and eradication

The chemical of choice for eradication of *G. salaris* is rotenone ($C_{23}H_{22}O_6$, commercial solution CFT-Legumine with 3,3% active rotenone), which is an isoflavonoid from the roots of certain leguminous plants. Since this chemical has limited solubility in water, different solvents have been added. Rotenone will not affect mammals, birds or amphibians, but it is non-specific to aquatic organisms breathing through gills. While highly toxic to fish and invertebrates, researchers have not detected any invertebrate species eradicated by treatments (Arnekleiv et al. 1997; Fjellheim 2004; Eriksen et al. 2009; Arnekleiv et al. 2015; Vinson et al. 2010). A fish-killer, the rotenone principle used is well known in the control of contagious diseases in terrestrial animals – get rid of the host and you also get rid of the pest – stamping out.

During the eighties, treatments were often successful. The rivers were mostly small and easily mapped, but in the nineties problems arose since some vital waterways still contained *G. salaris* after treatment (Lærdalselva, Skibotnelva, Rauma and Steinkjerelva). This fact led to a total review and thorough scrutiny of the methods used (Johnsen et al. 2008). The results of this was

extensive amendments to the methods used. The equipment used for administrating rotenone was improved with the use of boats and pumps, the concentration of rotenone was raised, full-scale simulation of treatments using the tracer dye rhodamine WT (http://www.turnerdesigns.com/t2/doc/MSDS/998-0122.pdf) to document achieved concentrations pretreatment, a field laboratory was established to record and monitor the delivered concentration and distribution of rotenone (Sandvik et al., 2018). A full treatment was carried through and repeated the next year, on site field trips by experts on upwelling to detect problematic in-river upwelling areas, concentrated rotenone was produced for places with upwelling of ground-water, the mapping of all tributaries and pipelines to the rivers was far more meticulously done using GPS waypoints and electronic maps. The new methods applied are described in (Sandodden et al., 2018).

Although rotenone has been the chemical of choice for most of the treatments through the years, laboratory trials with acidic aluminium in a collaborative project by the Norwegian Water Research Institute (NIVA), The University of Oslo (UiO) and The Norwegian Veterinary Institute showed positive results. This method kills the parasites at concentration that is not lethal to the fish. Full-scale trials with this method were therefore carried out with promising results. The main river and all tributaries are treated with sulfuric acid in combination with aluminium sulfate to a pH of 5,5 - 6,0 and a concentration of 20-40 µg inorganic aluminium/l. These water chemical conditions are kept for two 14 days periods the same autumn, and the same procedure is repeated the next year. Since the toxic effect of acidic aluminium is gradually reduced in stagnant water, smaller tributaries, stony shores and pipelines, are treated with rotenone.

After developing the method through a series of treatments in several rivers, the method was applied in one of the most famous salmon-rivers in Norway in 2011 and 2012, the river Lærdalselva (Hindar et al., 2014). In October 2017, a five year post treatment surveillance program was completed with no sign of the parasite (Hytterød et al., 2018), and the Minister of the Environment could declare the river free of *G. salaris.*

Researchers have during the last couple of years tested chlorine in the same manner as with aluminium, and with promising results (Hagen et al., 2014, 2018). The bulk of the water may not be manipulated with other chemicals as had to be done with acidification to get the proper effect with aluminium and the concentration needed is in the same area as to chlorinate pot-water. Larger-scale tests are now under planning and may result in a less expensive, non-lethal method to eradicate *G. salaris* in the future.

Stock preservation

Since the salmon-populations of the infected rivers have been on the verge of extinction, it has for many years been necessary to preserve the stock in living and cryopreserved systems, so-called gene-banks. All in all, 23 stocks of salmon, eight stocks of trout and two stocks of anadromous arctic char have been taken care of in this manner

Regulation and legislation

Introduction and spreading of *G. salaris* is the most important and most significant human-inflicted threat to Norwegian wild salmon stocks. Containment and eradication of this threat have therefore been a priority to Norwegian authorities. Although expensive, it has been calculated that the benefit for the society is four to ten times the cost of the eradication-campaigns. The economic loss for the community as a whole is estimated to 4 billion NOK since the introduction to the country (Anon 2014). Without the eradication program the parasite would spread even further and faster, therefore the cost would increase even more.

Measures against *G. salaris* in Norway are based on regulations managed by two authorities, the Norwegian Food Safety Authority and the Norwegian Environmental Authority. These agencies have been instructed to form a National Committee for the administration of the different tasks, and have been responsible for the construction of action plans, the last one from 2014 covering 2014-2016 (Anon 2014). The agencies have also ordered a multitude of reports on different aspects of the overall problem, mostly from the Norwegian Veterinary Institute, the Norwegian Institute of Natural Research and the Norwegian Institute of Water Research. In the early years, the treatments were low budget treatments, led, planned and performed by the regional County Governor. They started with the smaller creeks, to harvest experience on full-scale treatments, but with reduced environmental impact. As the rivers to be treated became larger, more complex, and the numbers of infected watercourses in an affected region increased, the need of building competence over time became more apparent. Therefore, in 1996, the Norwegian Veterinary Institute was appointed to be in charge of planning, mapping, and performing the treatments on behalf of the Norwegian Environmental Authority. In each infected region, the treatments would be executed by the Norwegian Veterinary Institute, supervised by a regional council and led by the regional County Governor. This was done to ensure that the experience harvested during treatments in one region was used to improve the treatments in the next region. In 2007 the Norwegian Veterinary Institute was given the role as a National Competence Center for Chemical Treatments against *G. salaris*,

The regulations allow fishing and other water-activity in the infected parts of the rivers only after application, and granted permission follows with mandatory disinfection of fishing gear and the like when removed from the waters. Moreover, folders and posters with warnings and advice are spread along the waterways in question and through stake-holders in the region.

Political aspects

The plans and accomplishment of the eradication processes have often led to opposition to the program from groups of locals. National environmental NGOs have also been active, sometimes calling the treatments actions of crime. This tendency has been less noticeable the last years. Open meetings have therefore been necessary to bring forward all aspects of the treatments.

By the National Surveillance Program of *G. salaris* in 60-80 selected non-infected rivers for some years, Norway has achieved free status pertaining to the parasite. Imports of salmonids must, therefore, come with the official declaration that they come from stocks with the same state (Anon 2016).

Following detection of *G. salaris* from a new river, the Food Safety Authority let carry through an epidemiological surveillance program trying to detect where the infection had its roots. A third form of monitoring, “mapping”-surveillance, is carried out before treatments to estimate where in the river-body the parasite is located.

Today’s status

Today, of the initially 50 infected rivers, a total of 32 rivers are declared *G. salaris*-free, and only seven remain infected. The rest, 11 rivers, are under surveillance after treatment and will hopefully be declared free of the parasite during the next 4 years. (Sandodden et al. 2015; Adolfsen et al. 2017).

In one of the two remaining regions, Sunndalen/Driva, a migration barrier has been built to shorten the necessary treatment area from 90 km to 25 km. After 5-7 years all fingerlings will have smoltified and left the upper parts of the river and treatment of the lower part can be done.

For the last remaining region, Drammen, work is in progress for determining if it at all is possible to treat the infected rivers. Report form the working committee was delivered 15th of May 2018 with the conclusion that treatment is possible by all the three methods (Hindar et al., 2018).

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