Small- and large-scale eradication of invasive fish and fish parasites in freshwater systems in Norway

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Abstract In July 2016, the European Union adopted a list of invasive alien species of concern, and at present there are two freshwater fish species on the list. Member states are obliged to prevent further spread and to perform rapid eradication when problem species are discovered at new sites, but continental EU member states have limited experience with eradication of fish. Eradications are more likely to succeed if the invasive species is confined to insular habitats. Freshwater invasives can be regarded as island invasives, since their habitats have boundaries against shorelines, saline waters, waterfalls and dams, and these boundaries make eradications possible. CFT Legumine® containing rotenone is the only legal piscicide in the EU, and Norway has used CFT Legumine® in eradication efforts for many years. Species that have been introduced outside their native range and have been successfully eradicated include minnow (*Phoxinus phoxinus*), roach (*Rutilus rutilus*), pike (*Esox lucius*), common whitefish (*Coregonus lavaretus*), and the salmon parasite *Gyrodactylus salaris*. This manuscript summarises the eradication efforts of invasive fish species and fish parasite species during the last two decades in Norway, covering eradications from such diverse habitats as small ponds, lakes, marshlands, small streams and large rivers. An estimated £100 million has been spent in the *Gyrodactylus salaris* eradication programme. Costs of invasive fish eradications are given, ranging from less than £10,000 to more than £200,000. There are no known invasive fish eradication failures in Norway in the last 20 years. A summary of the efforts in Norway can be an aid for planning control and eradication measures of invasive fish species in other countries.

Keywords: CFT Legumine, fish control, *Gyrodactylus salaris*, IAS, rotenone

INTRODUCTION

Alien invasive fish species are a global problem (Gozlan, et al., 2010). Eradication is more likely to succeed if the invasive species is confined to insular habitats. Freshwater invasives can be regarded as island invasives, since their habitats have boundaries against shorelines, saline waters, waterfalls and dams, and these boundaries make eradications possible.

The EU requires member states to rapidly implement measures, including eradications, against invasive alien species. In July 2016 the EU adopted a list of invasive alien species of European Union concern that requires control or eradication (<http://data.europa.eu/eli/reg_impl/2016/1141/oj>). This list includes two fish species, topmouth gudgeon (*Pseudorasboras parva*) and Amur sleeper (*Perccottus glenii*), and new species can be added. Transfer of knowledge is therefore essential as many EU countries have little experience with such operations. In Europe, successful eradications against invasive freshwater fish have been done in Spain (Fernandez-Delgado, 2009), England (Britton, et al., 2010) and Norway.

The Norwegian Veterinary Institute has extensive knowledge of fish eradication through their work on behalf of the Norwegian Environment Agency. A simplified way to look at historic immigration routes for freshwater species to Norway is that all indigenous freshwater fish species can be found in south-eastern Norway, while the rest of the country has very few indigenous species, making most south-eastern species, e.g. all cyprinids and pike (*Esox lucius*), domestic exotic in other parts of the country (Huitfeldt-Kaas,1918). Exotic invasive fish are North-American salmonids, imported for aquaculture and improvements of wild stocks, and cyprinids from the European continent (Hesthagen & Sandlund, 2016). One of the most severe threats to an indigenous fish species was the introduction of the salmon fluke *Gyrodactylus salaris*, which in a worst-case scenario could lead to local extinction of Atlantic salmon (*Salmo salar*) populations. Norwegian authorities have committed to eradicate the salmon fluke from Norwegian rivers, and the Norwegian Veterinary Institute is in charge of the project planning and eradication campaigns. The experiences from these campaigns against *G. salaris* are used in other operations against invasive freshwater fish species.

The piscicide rotenone has been used for fish control and eradication for more than 70 years (McClay, 2000). Rotenone is a natural product isolated from roots of tropical plants in the pea family *Leguminosae*, and it is highly toxic to fish (Ling, 2003). The rotenone product used in Europe is CFT Legumine® (CFT L). It is the only piscicide currently under assessment of the Biocidal Product Regulation (BPR, Regulation (EU) 528/2012), and thus the only piscicide legal for use in Europe. The effect of rotenone on non-target organisms has been extensively studied (Ling, 2003; Vinson, et al., 2010; Finlayson, et al., 2010a; Dalu, et al., 2015) and, even if some invertebrate taxa are very sensitive, the general findings from Norway are that most taxa recolonise treated areas within a year (Fjellheim, 2004; Kjærstad, et al., 2015).

Two different solutions of CFT L have been used in the described treatments. The first CFT L formula used contained 2.5% rotenone and the synergist piperonylbutoxid (PBO). Since PBO did not have the desired synergic effect (Finlayson, et al., 2010a), the manufacturer made a change in the product in 2012. The new product omitted PBO and increased rotenone content to 3.3%. As of 2013, all treatments described have used the 3.3% solution.

The objective of this manuscript is to present all rotenone treatments against invasive freshwater fish species in Norway the last 20 years, and a short summary of the still ongoing eradication campaign against the salmon fluke. None of the invasive fish species eradications are previously published. Only lake volumes are described in detail, but the treatment area also includes adjacent streams, pools and marshlands, to ensure that no fish survives in temporary locations. The work of treating these surroundings varies depending on the site, but the amount of CFT L used in these areas is small compared to the amount used in lakes. A map is included for the geographical location of the invasive fish species eradications (Fig. 1). Costs are included to give an idea about the cost of invasive fish eradications (Table 1). The following descriptions can be an aid for planning control and eradication measures of invasive fish species in the EU and for other stakeholders.

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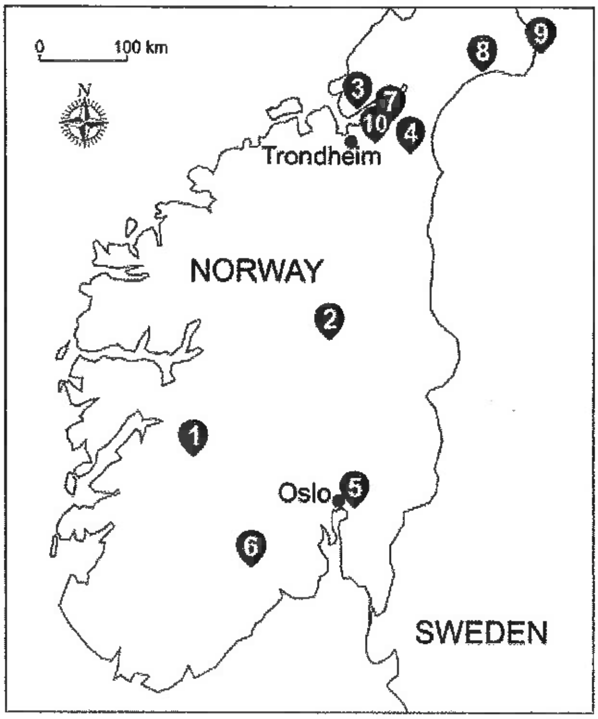

Fig. 1 Geographical location of invasive fish eradications. 1) Hardangervidda, 2) Sør-Fron, 3) Lake Ålmotjønna, 4) Lake Alsettjønna, 5) Lake Lille Mortetjern, 6) Telemark Canal, 7) Lake Vikerauntjønna, 8) Lake Klokkartjønna, 9) Gäddede (in Sweden) 10) Bymarka.

OVERVIEW OF ERADICATION OF INVASIVE FISH AND FISH PARASITES IN FRESHWATER SYSTEMS IN NORWAY

Salmon fluke (*Gyrodactylus salaris*) in rivers and lakes in Norway

The salmon fluke *G. salaris* is a freshwater salmon ectoparasite indigenous to the Baltic region, and an exotic invasive species in Norway that was first detected in the 1970s. *G. salaris* is one of the most severe threats against Norwegian Atlantic salmon (Anon., 2016), It has been introduced via fish transports from Sweden, and distributed in Norwegian rivers through stocking from salmon hatcheries. Norwegian Atlantic salmon populations are highly susceptible to the parasite, with up to 95 % mortality for salmon fry and parr (Johnsen & Jensen, 1991). Rainbow trout (*Oncorhynchus mykiss*) and Arctic char (*Salvelinus alpinus*) can also host the salmon fluke. It has been found in 50 rivers in Norway, and rotenone treatments aim to eradicate the Atlantic salmon from infected river systems since the parasite cannot survive without its host. The salinity of the fjords acts as a barrier for dispersion of the salmon fluke, providing defined borders for the treatment area (Soleng & Bakke, 1997). Extensive operations to preserve and re-establish local strains of Atlantic salmon and sea trout (*Salmo trutta*) are performed before, during and after eradications (O'Reilly & Doyle, 2007). Forty-three rivers throughout Norway have been treated and the salmon fluke has so far been successfully eradicated from 31 rivers. Meanwhile, 12 rivers are still under post-treatment surveillance awaiting confirmation of eradication. The rivers differ in size but eradication campaigns have included 42 km long rivers in rugged terrain (Sandodden, et al., 2018) and 10 rivers in the same fjord system in the Vefsna region, where River Vefsna had a discharge of 200 m^3/s on the day of treatment (Stensli & Bardal, 2014). Also, in the Vefsna region, the salmon fluke infested Arctic char in three lakes. In total these lakes covered more than 18 km^2, two of them 65 m deep. The Vefsna region was one of the largest rotenone treatments ever performed, for both lake and riverine systems (Stensli & Bardal, 2014). Confirmation of eradication was attained in the rivers of the Vefsna region in 2017. The lakes in the same region still await eradication confirmation because of a different procedure for eradication confirmation.

Minnow (*Phoxinus phoxinus*) in Hardangervidda National Park

The minnow is indigenous to south-eastern Norway, but has been introduced to most parts of the country. It is believed that minnow has been spread through the use of live bait and also accidentally released, mistaken as brown trout (*Salmo trutta*) fry. Minnow have been present at Hardangervidda for decades. Minnows can multiply to high numbers and food competition has had a negative impact on local fish stocks and birdlife. Minnows are not present in western watercourses at Hardangervidda National Park, a high altitude, tree-less plateau in southwest Norway, but were found up to the water divide in several places. The risk of further dispersion across

Table 1 Year of treatment, location and target species, with approximate volume of lakes, litres of CFT L used and approximate cost of treatment.

Year	Location	Target species	Volume (1,000 m^3)	CFT L volume used (l)[a]	Cost (£1,000)
1999	Hardangervidda	Minnow		137	30–50
2005	Sør-Fron	Rainbow trout	5.6	7.5	<10
2008	Lake Ålmotjønna	Roach	120	180	10
2008	Lake Alsettjønna	Common whitefish	84	90	10
2009	Lake Lille Mortetjern	Roach	2.9	4.5	10
2012	Telemark Canal	Pike		100	30–50
2013	Hardangervidda	Minnow	640	805	>100
2014	Telemark Canal	Pike		22	10
2014	Lake Vikerauntjønna	Roach	188	293	10–30
2015	Lake Klokkartjønna	Lake trout	675	670	30–50
2016	Gäddede	Several species		8	10
2016	Bymarka	Roach	2,500	4,000	>200

a) CFT L used also includes CFT L in streams, pools and marshlands surrounding the lakes.

the water divide was regarded as imminent. A successful treatment was conducted in 1999–2000 in the area around Stigstuv (Tønset & Bakkeli, 2000), which is set at the east-west water divide at Hardangervidda National Park. Fish barriers were built to create a buffer zone towards the water divide. Minnows were found in the buffer zone again 10 years later, most likely because the barriers were not working properly. In flooding periods the water level downstream from the barrier could rise and thus level out the height difference. The barriers were adjusted in 2013 prior to a new treatment of the Stigstuv area. The treatment area comprised 40 ponds/small lakes, streams and marshes within an area of 2 km^2. Total water coverage of the ponds/small lakes was 140,000 m^2, with depths of up to 4 m and average depths of 0.5–1 m. The treatment was performed during four days in August 2013 by 16 people. Target dose was 1 ppm CFT L, and a total of 225 l of CFT L was used.

In addition, Lake Hætjørna, another site on Hardangervidda, also was treated due to minnow invasion. Two new barriers had been built, one in the inlet and one in the outlet, making the lake a buffer zone without minnows. Twelve people treated the lake, ponds and marshes in the surrounding area in two days, just prior to the treatment at Stigstuv. Lake Hætjørna covers an area of 0.2 km^2, with an estimated mean depth of 2.5 m and maximum depth 8 m. The target dose was 1 ppm CFT L, and a total of 580 l of CFT L was used. No minnows were caught in hoop net surveys in 2014 and 2016. An environmental DNA survey found no traces of minnows at either site in 2016 (Fossøy, et al., 2017).

Rainbow trout (*Oncorhynchus mykiss*) in Sør-Fron

Sør-Fron is a municipality in Oppland County. Rainbow trout were found in four artificial ponds at a farm in Sør-Fron. Rainbow trout are indigenous to North-America, and have been exported worldwide for angling and fish farming. In Sør-Fron it had been released in these ponds, and netting in October 2000 confirmed their existence. Rainbow trout can host the salmon fluke and thus act as a vector for the parasite. There was risk of escape from the ponds during large floods in the nearby River Lågen. The ponds were treated with rotenone in October 2005. The volumes ranged from 350 to 3,750 m^3, and two people completed the job in one day. The target dose was 1 ppm CFT L, and a total of 7.5 l CFT L was used. On arrival, all ponds were covered with ice. Ice cover was broken before adding CFT L, and the dosage was increased slightly to compensate for the low water temperatures. Prior to treatment the number of fish was reduced through netting. There has been no programme for eradication confirmation, but there have been no later reports of rainbow trout in the ponds.

Roach (*Rutilus rutilus*) in Lake Ålmotjønna

Lake Ålmotjønna is situated in Rissa municipality in Sør-Trøndelag County. The roach is indigenous to south-eastern Norway, but alien to the Trøndelag region. It is believed that roach were released by anglers. Roach were discovered in Lake Ålmotjønna in the summer of 2007. The purpose of the treatment was to prevent further spread downstream to the large Lake Storvatnet, which could lead to a permanent foothold for roach in the region. The volume of Lake Ålmotjønna was 120,000 m^3, and average depth was 5 m. A rotenone treatment was conducted in August 2008. Two people worked for one day. Target dose was 1.5 ppm CFT L, and a total of 180 l CFT L was used. Only two dead roach were found post-treatment. Fish scale analysis revealed that the roach had been introduced at least five years prior to treatment, and apparently had not reproduced. There has been no programme for eradication confirmation, but there have been no later reports of roach in the lake.

Common whitefish (*Coregonus lavaretus*) in Lake Alsettjønna

Lake Alsettjønna is situated in Selbu municipality in Sør-Trøndelag County. The common whitefish is indigenous in south-eastern Norway and eastern watersheds, but alien to the region. Common whitefish was released in Lake Alsettjønna around 1875 as part of a wedding gift. The purpose of the treatment was to prevent further spread to the larger Lake Selbusjøen, which could lead to a permanent foothold for common whitefish in the region. Common whitefish is a food competitor of the indigenous brown trout and Arctic char and can be more effective in exploitation of food sources. It also has a large capacity for propagation. Increased rainfall in the catchment could, in the future, make the stream from Lake Alsettjønna habitable for common whitefish in flooding periods, leading it to spread to Lake Selbusjøen. A rotenone treatment was conducted in Lake Alsettjønna in August 2008. The volume was 84,000 m^3, and average depth was 4 m. Two people worked for one day. Target dose was 1 ppm CFT L, and a total of 90 l CFT L was used. There has been no programme for eradication confirmation, but there have been no later reports of common whitefish in the lake.

Roach (*Rutilus rutilus*) in Lake Lille Mortetjern

Lake Lille Mortetjern is situated in Nittedal municipality in Akershus County. The roach is indigenous to south-eastern Norway, where Lake Lille Mortetjern is situated, but fish had not been recorded in this lake before, making it ideal for amphibians. Roach are present in a neighbouring lake in walking distance, so suspicion is that it has been carried from there and released into Lille Mortetjern. Roach were discovered here in 2007. The lake is known for its rich population of amphibians. The endangered smooth newt (*Lissotriton vulgaris*), great crested newt (*Triturus cristatus*), and moor frog (*Rana arvalis*) can be found here. Since the discovery of roach in 2007, the population of amphibian larvae dwindled to a minimum due to roach predation (Kooij & Redford, 2012), and lack of recruitment threatened the long-term survival of the amphibians. For the first time in Norway, a rotenone treatment was conducted to benefit endangered amphibians. The lake is small, only 2,880 m^3, and rotenone treatment was performed in September 2009. Two people completed the treatment in one day. The target dose was 1.5 ppm CFT L, and a total of 4.5 l of CFT L was used. No mortality of amphibians was observed during treatment. The following spring, newts and frogs reproduced in high numbers (Kooij & Redford, 2012). Eradication of introduced fish in amphibian habitats can be done effectively with rotenone with apparently few negative effects on the amphibian population. It is recommended that treatments be carried out in the autumn when most adult amphibians and metamorphosed larvae have left their breeding habitat and water temperatures are still high enough for rapid rotenone degradation. No roach were detected in biodiversity surveys after the treatment.

Pike (*Esox lucius*) in the Telemark Canal

The Telemark Canal connects the coast of Telemark County with the inland by means of eight sluice stations on a stretch of 105 km. The pike is indigenous to south-eastern Norway but is alien to the Telemark region. Pike were released in the lower parts of the watercourse about 200 years ago. Pike are a voracious predator with the potential to severely decimate indigenous populations of fish. Over the last century, pike have spread upstream. Further upstream are large lakes with populations of large brown trout and river pearl mussel (*Margaritafera margaritafera*) that could be severely affected by invasive pike. Pike were found between Kjeldal and Hogga sluice, Hogga being the critical last sluice before entering the large lake system. This led to permission for rotenone treatment between Hogga and Kjeldal sluice, and the building of an electric fish barrier in the side canal leading up to Kjeldal sluice to prevent pike from being sluiced upstream together with boat traffic. The goal was to stop the pike at Kjeldal sluice, creating a pike free buffer zone up to Hogga sluice. A rotenone treatment was carried out between Hogga and Kjeldal sluice in October 2011, a stretch of about 1 km, to eradicate pike and restore the buffer zone. The river segment between the sluices was drained, and five people treated the remaining pools in one day. The target dose was 1 ppm CFT L, and 100 l of CFT L was used. An electric fish barrier was established in 2012, at the side canal leading up to Kjeldal sluice, to stop further spread.

The Norwegian Veterinary Institute conducted a new treatment at Kjeldal sluice in April 2014, this time only in the side sluice canal downstream of the area treated in 2011. The electric fish barrier in the side canal had been shut down during the winter season in 2013 due to maintenance work. Therefore, it was necessary to prevent the pike that had passed the non-functional electric barrier during winter from entering the previously treated area upstream of Kjeldal sluice before the boat sluices were opened for the season start. The side canal was 220 m long, 3 m deep and 17 m wide. One person did the job in one day, and a total of 22 l of CFT L was used. The target dose was increased to 1.5 ppm CFT L to compensate for water leaking through the sluice gates. Netting has been conducted in the rotenone-treated areas over several years, and no pike have been found.

Roach in Lake Vikerauntjønna

Lake Vikerauntjønna is situated in Trondheim municipality in Sør-Trøndelag County. The roach is indigenous to south-eastern Norway, but alien to this region. It is believed that roach had been released, and the source was other lakes with an alien population of roach in the same municipality, in Bymarka. A dense population of roach was detected in Lake Vikerauntjønna in 2013. It is located only 250 m from Trondheim municipality's main potable water source, Lake Jonsvatnet. There was a concern that roach could adversely affect water quality. The two lakes belong to separate catchments, but the risk of further spread to Lake Jonsvatnet was considered to be high due to the small distance between the lakes. Rotenone treatment was considered as the only measure that would eradicate the roach. Lake Vikerauntjønna covers an area of 0.04 km^2 with a water volume of 188,000 m^3 and maximum depth of 17 m. Treatment was conducted in September 2014 by five people in one day. The target dose was 1.5 ppm CFT L, and a total of 293 l of CFT L was used. Fish scale analysis revealed that the roach had been introduced for the first time around 2007, and possibly new introductions in following years too. No roach were detected in biodiversity surveys after the treatment.

Lake trout (*Salvelinus namaycush*) in Lake Klokkartjønna

Lake Klokkartjønna is situated in Blåfjella-Skjækerfjella National Park in Nord-Trøndelag County. The lake trout is indigenous to North-America but has been imported to Scandinavia for fish farming and angling purposes. The first records of release in Norway are from the 1970s (Hesthagen & Sandlund, 2016). In Lake Klokkartjønna the introduction could have come from source populations in Sweden, since lake trout are more common across the border, but no one knows for sure. A first finding of lake trout in Lake Klokkartjønna was recorded in the autumn of 2010. Lake trout are considered to be a threat to natural habitats, ecosystems, and indigenous fish populations. The risk of spread downstream to adjacent lakes was considered high, and permission for rotenone treatment was granted. Lake Klokkartjønna covers an area of 0.14 km^2 with an estimated volume of 675,000 m^3. Eradication was performed in July 2015, and eight people participated over two days. The target dose was 1 ppm CFT L, and a total of 670 l of CFT L was used. No lake trout have been found through post-treatment netting.

Several species at hydroelectric power plant in Gäddede

Gäddede hydroelectric power plant is situated in Sweden in Strømsund municipality in Jämtland County close to the Norwegian border. The power plant separates two lakes with different fish species due to a natural fish barrier. The upstream lake contained only indigenous brown trout and Arctic char whilst the lower lake also hosted pike, common whitefish, burbot (*Lota lota*), and rainbow trout. It was unwanted for any of these fish species to be spread upwards in the waterway. It is not possible for fish to pass upstream through the power plant, but a planned maintenance shutdown in 2016 could enable fish to pass the turbines and later rise up above the dam into the upper lake. As a precautionary measure, permission for rotenone treatment in the stagnant ponds on both sides of hydro power turbines was given. The volumes of the ponds ranged from 150 to 2,500 m^3, and eradication was performed in June 2016. Two people did the job in one day. A high dose of 3 ppm CFT L was used to compensate for fresh water leaking into the isolated ponds. A total of 8 l CFT L was used. There has been no programme for eradication confirmation. Dead fish were found during treatment in the ponds.

Roach in seven lakes in Bymarka

Bymarka is on the outskirts of Trondheim city in Sør-Trøndelag County. The roach is an invasive species in the region and was released in the 1880s to three small lakes in the same watercourse. From the 1960s to the 1980s roach were spread to three neighbouring lakes, and were found in another four lakes from 1998 to 2013. It was suspected that the roach population in Bymarka was the source of spread. When roach were found in Lake Vikerauntjønna, close to the Trondheim municipality's main potable water source, plans for treatment of the lakes in Bymarka were put forward. The main reasons were a concern for the roach to adversely affect potable water quality, a wish to permanently eradicate this blacklisted species from the region, and to contribute to conservation of natural fish stocks and biodiversity. Rotenone treatment was considered to be the only measure that could eradicate roach from these lakes. Several of the lakes have a dam, and an attempt to eradicate roach through dewatering in 2004 failed. One lake was 17,000 m^3 and 10 m deep, while the six other lakes ranged from 412,000 to 615,000 m^3, with maximum depths of 10–17 m. In September 2016, treatment was performed by a crew of 14 people for four days. A total of 4,000 l of CFT L was used and, as before, the target dose was 1.5 ppm CFT L. Populations of invasive pike in the lakes were eradicated simultaneously. No roach were detected in a biodiversity survey after the treatment.

DISCUSSION

Rotenone treatments are not without controversy, but most times invasive fish eradications are welcomed. The general public's acceptance of rotenone treatments in Norway might be a result of the absence of failure, thus strengthening the understanding for rotenone as a necessary and effective tool in the fight against invasive freshwater fish. The description of rotenone treatments does not include method, but relevant method can be found in Sandodden, et al. (2018). A standard operating procedure for the use of rotenone in fish management is given by Finlayson, et al. (2010b). For rotenone analysis, an on-site determination of rotenone has been developed by the Norwegian Veterinary Institute (Sandvik, et al., 2018).

The Norwegian Environment Agency is in the process of writing an action plan, which will identify and prioritise measures against invasive freshwater fish. This will lift the coordination of possible eradication measures from county level to national level, making top prioritised measures easier to identify. Forthcoming eradication projects are mostly for domestic invasive pike. The *G. salaris* eradication campaign will continue, and is now at an intermediate planning stage with the next eradication, at the earliest, in 2022.

Costs of treatments

Costs are not easy to describe uniformly. Eradication projects have had different levels of participation from the County Governor, and work hours are usually the main expense in these smaller eradications. The cost consists of the Norwegian Veterinary Institute's planning and preparations and expenses with treatments, including hired crew. The cost does not include pre- and post-treatment biodiversity surveys, cost of CFT L, and County Manager expenses. Eradication of *G. salaris* is not included in the table, but the cost of the eradication campaign so far is estimated to be about £100 million.

Eradication confirmation

The *G. salaris* eradication campaign includes a surveillance programme for eradication confirmation, but no parallel surveillance programme exists for invasive freshwater fish. Eradication confirmations are based on the absence of new detections by biodiversity surveys, local netting and angling. Successful restocking of indigenous fish also indicates the absence of the introduced species. Net trapping and environmental DNA surveys are other possible ways to document the outcome of a treatment but there is, at present, no national set of rules for eradication confirmation. However, there are no examples from Norway, during the past 20 years, of failed rotenone-based eradication attempts against invasive freshwater fish.

This may be because all eradications are assigned for planning and execution to a national competence group for rotenone treatment, which gives continuity-based experience and knowledge. Secondly, smaller lentic waters are less complicated treatments due to longer time for adequate mixing of rotenone and thus ensuring lethal concentration in all parts of the lake, which should leave the target fish no opportunities to accidently avoid lethal exposure. Large-scale lotic waters systems are also possible to succeed in, proven by the *G. salaris* eradication campaign.

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