

**T5.6: Fish disease case study
– *Gyrodactylus salaris***

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Abstract:

The fish parasite *Gyrodactylus salaris* has been endemic for many years in fish in the Baltic watershed in Sweden, Finland and Russia. Fish in these rivers have immunity to its harmful effects. Since 1975, it has spread into Norway, Denmark and Germany. In Norway, it has killed salmon in 46 rivers and has caused economic damage put at \$500 million. At present, it can only be eradicated by using chemicals to remove all the fish from a river system, which has been done in 26 Norwegian rivers. It has been transmitted by the transport of fish for farming and sport, and represents the most significant exotic disease threat to salmon in the UK. The epidemic brings with it important lessons, including the need for care when animals are moved to new environments, and the requirement for less destructive eradication technology and better detection. It is simple to detect the disease in farmed salmon, but it causes no clinical signs in rainbow trout.

This review has been commissioned as part of the UK Government's Foresight project, Infectious Diseases: preparing for the future. The views expressed do not represent the policy of any Government or organisation.

Introduction

Gyrodactylus salaris is a freshwater parasite of salmon. Gyrodactylids attach to the surface of their host by means of hooks and feed on host tissue. They are viviparous, and can reproduce both sexually and asexually. *G. salaris* was first identified as a harmless commensal parasite of Atlantic salmon in the Baltic watershed (Malmberg 1957). But in East Atlantic stocks of Atlantic salmon, those spawning in rivers that drain into the Atlantic ocean, it is a serious parasite of juvenile salmon (parr). It multiplies unchecked by an immune response, and death normally results (Bakke et al. 1990).

G. salaris was first identified in Norway in 1975 (Johnsen and Jensen 1991). It had probably been introduced via salmon parr imported from Sweden (Mo 1994). *G. salaris* infection has resulted in the collapse of wild salmon populations in 45 Norwegian rivers (T.A. Mo, personal communication). The average density of parr in infected rivers is reduced by 86%, leading to an annual loss of 250–500 metric tonnes of salmon. The total cost *G. salaris* in Norway exceeds US\$500 million (Bakke et al. 2004). *G. salaris* has also spread to Atlantic salmon in the River Keret (an Arctic White Sea Atlantic salmon stock) in Russia (Prusov et al., 1998) and to the west coast of Sweden (Bakke et al. 2002) through the movement of infected fish. The parasite is probably widespread in Europe. Outside its original distribution in the Baltic watershed (OIE 2003b), its presence has been confirmed in Denmark, Germany and Spain (reviewed by Bakke et al. 2002).

The parasite is easily controlled in a farm through formalin baths. But elimination from a wild population is considerably more problematic. Chemical destruction of all fish life within a river catchment is the only proven method of control. The parasite is listed by the World Organisation for Animal Health (Office International des Épizooties – OIE) in the *Aquatic Animal Code* (OIE 2003a). It is a notifiable disease in the UK under the Fish Disease Act 1983, but has never been recorded in the UK. However, the salmon population of the UK is highly likely to be as susceptible to *G. salaris* as Norwegian stocks (Bakke and MacKenzie 1992; MacKenzie 1993), making it serious threat.

Sources of *G. salaris*

Host range

G. salaris reproduces and survives permanently only on Atlantic salmon, rainbow trout (*Oncorhynchus mykiss*) (Bakke et al. 1991b) and Atlantic salmon X brown or sea trout (*Salmo trutta*) hybrids (Bakke et al. 1999). However, it can live for periods of 7–150 days on other salmonid and non-salmonid species including eels (*Anguilla anguilla*), where infection exhibits a maximum duration of eight days (Bakke et al. 1991a). Under laboratory conditions, the parasite survives longest (about 200 days) on arctic char (*Salvelinus alpinus*) (Bakke et al. 1996), although in the natural environment long-term persistence on this host is very unlikely (Bakke et al. 2002). Limited reproduction also takes place on brown trout (*Salmo trutta*) (Jansen and

Bakke 1995) and grayling (*Thymallus thymallus*) (Soleng and Bakke 2001). *G. salaris* rapidly detaches from a dead host and is highly efficient at finding a new one (Soleng et al. 1999a). But the parasite is not harmful to these species. Natural and experimental infection have only been recorded as causing clinical signs in Atlantic salmon.

Geographical distribution

The original geographical distribution of *G. salaris* is the Baltic watershed of western Sweden, northern Finland and northern Russia. It has been introduced to Norway, where 45 rivers have been infected and currently 19 remain infected, Denmark (Buchmann and Bresciani 1997; Nielsen and Buchmann 2001) and Germany (Cunningham et al. 2003). Reports of *G. salaris* in France (Johnston et al. 1996) have been disputed and the parasite was classified as a new species, *G. teuchis* (Lautraite et al. 1999). Similarly, reports of *G. salaris* in Spain and Portugal (Johnston et al. 1996) may also have been due to misidentification. However, the parasite has probably been spread widely within Europe with the movement of live rainbow trout from Baltic countries (Bakke and Harris 1998), and it is likely to be present in more countries than we currently realise (OIE 2003b). Surveys to substantiate freedom from *G. salaris* have been conducted in the UK, Ireland and certain river catchments in Finland and France (Lautraite et al. 1999).

***G. salaris* in Norway**

The disease caused by *G. salaris* can be directly attributed to the development of aquaculture and, in particular, the human movement of fish for farming. Salmon farming expanded rapidly in the early 1970s, when a shortage of home-produced juveniles led to the importation of salmon from Swedish hatcheries. The Scandinavian mountains separate Atlantic salmon populations in Sweden and Norway, and mixing of the two populations could only occur via human intervention. It is likely that the parasite was introduced more than once. Atlantic salmon in one Norwegian river has been attributed to a known introduction of Swedish salmon in 1975 (Johnsen and Jensen 1991). Illegal imports of rainbow trout are thought to have introduced the parasite to another river (T.A. Mo, personal communication). The spread of *G. salaris* in Norway has largely been attributed to the movement of fish for stocking and is discussed below in the section on pathways.

In 1983, *G. salaris* was declared a notifiable disease in Norway, some ten years after its introduction and when the parasite had infected fish in 32 rivers. For a number of years following the identification of *G. salaris*, it was argued that the parasite was a secondary infection and the primary cause was acid rain, fungal infections or an unidentified pathogen. This debate delayed making the disease notifiable. In 1985, the parasite was present in six salmon and 35 rainbow trout hatcheries. Infected hatcheries were destocked to eliminate the infection. Four measures have been put in place to minimise the likelihood that a freshwater rainbow trout farm would become infected and to minimise the likelihood of transmission of the parasite from farmed to wild salmon populations. The water intake must be above the level where

anadromous fish – those that migrate up rivers from the sea to breed – are found, or the inflow must be treated with ultraviolet (UV) light or ozone: the outflow must be into seawater or be filtered through a 40µm mesh. Hatcheries can only supply seawater production units within the same epidemiological zone¹ or freshwater sites within the same river catchment, and all rainbow trout on-growing units must be fallowed annually for an unspecified period. In addition, stocking rainbow trout into rivers or lakes for recreational angling was banned.

Elimination of *G. salaris*

G. salaris can be controlled in salmon and rainbow trout farms by formalin baths but complete eradication requires destocking. The only proven method of control of *G. salaris* in wild salmon populations is the elimination of all fish from a river using rotenone. Rotenone is a naturally occurring chemical with insecticidal, acaricidal (mite-killing) and piscicidal properties. It is obtained from the roots of several tropical and subtropical plant species belonging to the genus *Lonchocarpus* or *Derris*. The parasite has been eliminated from 15 Norwegian rivers and a further 11 have been treated and are under surveillance, while 19 rivers remain infected. The elimination of all fish and invertebrates from a river catchment can cause severe ecological impacts. Rotenone breaks down relatively quickly – its toxicity is lost over 5–6 days. But its metabolites are very stable. Despite a long history of use as an agricultural acaricide and for ‘pest fish’ control in the US, the available ecotoxicological data is limited and insufficient for its approval to current requirements. However, there was little protest in Norway against the use of the chemical.

Attempts have been made to develop therapeutic compounds that kill *G. salaris* without harming the hosts or other aquatic life. This has proved difficult, especially as any treatment must completely eliminate the parasite. However, the use of aluminium has produced encouraging results (Soleng et al. 1999b). It has been found that salmon can survive for 12 months or more at aluminium concentrations that kill *G. salaris* in three days. However, the presence of other metals, particularly magnesium, reduces the concentration of free aluminium ions. The water pH is also important. In many Norwegian rivers, the use of aluminium would require the pH of the river to be lowered to 6.2 to release sufficient free ions, which can be achieved with sulphuric acid. The treatment of tributaries with aluminium may be difficult, and aluminium treatment may have to be accompanied by the use of fish barriers. These prevent upstream migration so all anadromous fish, including salmon, are eliminated within a few years. During August 2004, aluminium was used to treat stretches of a river. To date *G. salaris* has not reappeared. But surveillance will continue for some months before the trial is declared a success.

¹ A group of neighbouring rivers emptying into the same fjord where salinity can fall below 25 parts per thousand (ppt)

European Union legislation

The EU has recognised the threat posed by *G. salaris* to member states whose salmon populations are free of the parasite. In 1993, the EU awarded the UK and Ireland *G.-salaris*-free status. This permitted imports of live salmonids to be restricted to areas of equivalent health status (this legislation was replaced by EC decision 2004/453). Elsewhere in Europe, only two river catchments in Finland have been recognised as *G.-salaris*-free.

Pathways of spread

G. salaris is a freshwater parasite and survives only hours in water of moderate salinity (i.e. less than 20ppt). Therefore carcasses harvested from seawater sites do not present a significant pathway for its spread (Peeler and Thrush 2004). Similarly, the movement of live Atlantic salmon from seawater sites poses a negligible risk (Peeler et al. submitted for publication). The movement of live Atlantic salmon and rainbow trout from freshwater sites is the most important route of spread of *G. salaris*, both across international borders and between river catchments² within countries (Peeler et al. 2004). The movement of fish, especially the upstream migration of Atlantic salmon (Soleng et al. 1998), and currents will spread *G. salaris* within a river catchment. In Norway, it spread throughout an entire river catchment within two years of the parasite first being detected (Johnsen and Jensen 1991).

In Norway, a strong association between the distribution of *G. salaris* in wild salmon populations and known deliveries of fish from infected hatcheries to rivers has been shown (Johnsen and Jensen 1991). The distribution of *G. salaris* in mainland Europe has largely been attributed to the movement of infected rainbow trout from Finland (Bakke and Harris 1998). As we have seen, *G. salaris* can survive on species of fish other than Atlantic salmon and rainbow trout, although not permanently since reproduction does not take place or is limited. For example, the movement of brown trout from sites that also keep rainbow trout is a potentially important pathway for its spread. European eels can carry the parasite for up to seven days (Bakke et al. 1991a). Eels are known to travel up to 2km overland, and thus may spread *G. salaris* between river catchments. Anglers are known to move fish between rivers to populate nearby rivers or lakes with prize specimens or for live baiting. Since *G. salaris* can survive off the host for up to seven days in moist cool conditions (Mo 1987), the parasite could be spread mechanically on objects such as an angler's keep net. In some places, only a few kilometres separate Norwegian rivers with susceptible Atlantic salmon populations from easterly-flowing Baltic watershed rivers. Anglers could spread the parasite by moving between these rivers.

Work by Soleng et al. (1998) in Norway demonstrated the potential for sea-running juvenile stages of Atlantic salmon to disperse *G. salaris*. Those

² Defined as a river and its tributaries that collect water from a single drainage basin, and its associated still waters and fish farms.

authors suggested that the parasite may be spread if juvenile Atlantic salmon which have migrated into low-salinity water in estuaries or fjords do not swim out to sea but instead migrate back into freshwater and enter a river other than their natal river. At some times of the year, the salinity in fjords may be low enough to allow migrating salmon to spread the parasite between rivers emptying into the same fjord. Alternatively, infected juvenile Atlantic salmon might transmit the infection to other fish species (for example, those that inhabit the lower parts of rivers) that move between rivers in low-salinity estuarine water. They might also infect sea trout prematurely returning to freshwater, possibly due to heavy sea lice (*Lepeophtheirus salmonis*) infections.

There is evidence that *G. salaris* has spread to a number of rivers in Norway through migration of juveniles have become infected by this route (reviewed by Mo (1994)). Neighbouring rivers that are at risk from the spread of *G. salaris* by migrating salmon are classified into epidemiological zones. The salinity of water separating zones does not fall below 25ppt. If more than one river in a zone has infected fish, treatment of all infected rivers would take place at the same time. An assessment of the risk of inter-river transmission of *G. salaris* by migrating smolts was undertaken to quantify the increased risk created by stocking an infected river with smolts (Høgåsen and Brun 2003). With one major exception, stocking juvenile salmon into rivers known to carry infected fish is not permitted.

Other potential routes for the spread of the parasites between river catchments include effluent discharge from a fish-processing plant, the movement of staff, vehicles and equipment between farm sites, canoes and boats, and fish-eating birds (Peeler et al. 2004).

Outcomes

Following the outbreak of *G. salaris* in Norway, some work was done to investigate the relative susceptibility of east Atlantic strains, which spawn in Norwegian rivers and rivers draining into the western European coast, and of Baltic strains of Atlantic salmon, which spawn in rivers draining into the Baltic (Bakke et al. 1990). The picture seemed clear. The parasite multiplied unchecked on east Atlantic strains of salmon, while Baltic strains exhibited acquired and innate resistance and were able to limit infections. Detection of the parasite within the Baltic watershed has not been associated with clinical disease (Malmberg and Malmberg 1993). Further work demonstrated that Atlantic salmon from Scotland were as susceptible to *G. salaris* as Norwegian stocks (MacKenzie 1993).

However, recent studies reveal a more complex picture. Firstly, considerable variation in individual susceptibility exists. Fish can be characterised as: susceptible, in which case the population of *G. salaris* grows until the fish dies; responding, where the population of *G. salaris* grows for a few weeks but the infection is non-pathogenic and the fish may cure itself spontaneously; or innately resistant, when the population of *G. salaris* fails to grow (Bakke et al. 2002). Within east Atlantic salmon populations, relatively few individuals are

innately resistant. But a significant proportion of some populations can respond, although they take longer to do so than Baltic strains (Bakke et al. 2002).

Relatively few Baltic stocks have been tested. A Baltic strain from Sweden was found to be relatively susceptible to *G. salaris*, though less susceptible than a Scottish strain (Dalgaard et al. 2003). A recent paper found the susceptibility of a Baltic Atlantic salmon strain to be comparable with an east Atlantic Norwegian salmon strain (Bakke et al. 2004). Despite the limited testing of east Atlantic salmon stocks outside Norway, the evidence suggests that salmon in the UK, Ireland, Iceland, Spain and France are susceptible to *G. salaris*. The abundance and importance, both economic and cultural, of Atlantic salmon varies greatly between these countries. Recreational angling for Atlantic salmon in Iceland, Ireland and the UK is an important source of income in rural areas. Atlantic salmon populations in Spain and France are fewer in number, less abundant and economically not as important as for the UK, Ireland and Iceland. This difference in the perceived value of salmon is reflected in the attitude towards *G. salaris* adopted by the governments of these countries, which have made few efforts to protect their salmon from *G. salaris*.

The impact of the introduction of *G. salaris* will be determined primarily by the geographical distribution of the parasite, and, in particular, the number of rivers affected. Effective surveillance and identification have a critical role to play in ensuring early detection and thus in the rapid implementation of control measures and effective contact tracing following detection of the first case.

While rotenone has been used successfully in Norway, its use would be controversial in the UK. There is a lack of ecotoxicological data on which to assess its environmental impact. The elimination of all fish and invertebrates would have serious ecological impacts and would be strongly resisted by coarse fish and sea trout recreational angling interests. By contrast, the Norwegian rivers that have been treated had low biomass and supported salmon and trout but few other fish species. The probability of success in large complex river systems is also uncertain.

This makes it unlikely that the large-scale use of rotenone would be permitted in the UK. Once the parasite was established in a river system in the UK, eradication may have to wait for the development of more environmentally acceptable methods. A river system carrying infected stock in wild or farmed salmonid populations, or both, is a potential source of infection to other farms and rivers. Measures would be taken in the UK to prevent a farm moving fish from an infected site. Destocking farms would have to be considered if they held the only infected populations in a river catchment.

Control of a *G. salaris* outbreak in the UK would need to balance the interests of the aquaculture industry against the risk of further spread of the parasite to uninfected salmon. Measures could be taken to minimise the spread of the parasite before its detection. For example, in Norway, rainbow trout cannot be stocked into rivers or lakes for recreational fishing or moved between farms in different catchments. These measures would minimise the spread of *G.*

salaris if it arrived. However, they would have a severe impact on the aquaculture industry and recreational fishing. Risk analysis methods can be used to inform decisions which balance the interests of aquaculture against wild fish interests. In Norway, quantitative analyses of the risk of introducing *G. salaris* to the Tana river through the operation of a salmon farming business (Paisley et al. 1999) and the increased risk of spread from a river stocked with salmon (Høgåsen and Brun 2003) have underpinned decision making.

A number of environmental factors will influence the likelihood of *G. salaris* becoming established in the UK if and when it is introduced. Salmon populations in a number of rivers in the UK are low compared with those in Norwegian rivers. A low population density may reduce the spread of the parasite and the probability of its establishment. The population dynamics of *G. salaris* are not well enough understood to estimate the impact of population density and distribution within a river and the presence of other transient host species. Mathematical models that integrate salmon behaviour and gyrodactylid epidemiology are required (Bakke and Harris 1998).

Detection and identification of *G. salaris*

Detection of *G. salaris*

G. salaris was probably detected in Norway within two years of its introduction (Johnsen and Jensen 1991). The parasite was detected in hatchery salmon in 1975 after a period of high mortality in parr. In the same year, the parasite was detected in a wild population. Infection in farmed salmon is likely to be detected rapidly because both prevalence (the percentage of fish infected) and abundance (the number of parasites per individual) are high, and because infection results in clinical disease and mortality.

The parasite may not be detected in wild salmon until dead fish, often with high levels of fungal infections, are found on the river bank. This may happen only months after its first introduction, depending on water temperature, chemistry and the population size. In rivers with an abundant salmon population, fish deaths are more likely to be obvious. They will be detected, for example, by anglers, more readily than in rivers with sparser salmon stocks. In these rivers, the first sign of *G. salaris* may be a decline in the salmon population detected by routine population monitoring. The prevalence and abundance of infection in wild populations can vary with water chemistry, temperature, salinity and other factors (Appleby and Mo 1997; Soleng and Bakke 1997). The presence of the parasite may be missed on dead fish with light infections of *G. salaris* when death may have resulted from secondary infections. In higher-intensity infection (up to 10,000 parasites per juvenile salmon (Mo 1992)) the osmotic disruption caused by perforation of the epidermis is likely to be the direct cause of death, and detection of the parasite will be more likely.

The detection of *G. salaris* in countries with farmed rainbow trout but few, if any, wild salmon populations will be considerably more problematic.

Examples include Denmark, Germany, France and Spain. As the parasite causes no clinical signs in rainbow trout, the farmer will be unaware of the infection. *G. salaris* will only be detected in rainbow trout populations through active surveillance. The prevalence may be extremely low, generally less than 5%; single parasite infections are common and the parasite may be attached anywhere on the fish (OIE 2003b).

While Atlantic salmon populations can still be found in 89 of the 180 river catchments in England and Wales, they are absent from 62 catchments where rainbow trout are farmed (Peeler et al. 2004). However, the salmon populations are only considered to be at a healthy level in 33% of rivers, while in 14% of rivers they are critically low (WWF 2001). This means that the parasite could be widely spread by the movement of live rainbow trout between farms before dead salmon are noticed (Peeler et al. 2004).

Identification of *G. salaris*

The identification of *G. salaris* is based on the shape and size of its body parts, such as marginal hooks and anchors (OIE 2003b). *G. salaris* is one of a number of gyrodactylids that infect salmonid fish. Morphologically, it is only subtly different from other species of gyrodactylids (Cunningham 2002). Good preparation of specimens and a high level of expertise and experience are essential for distinguishing *G. salaris* from other species of gyrodactylids. There is considerable variation in morphology between *G. salaris* from different locations, which may be due to reproductive isolation (Cunningham 2002). Seasonal variation in the opisthaptor hard parts also occurs (Mo 1991). The problems associated with identifying *G. salaris* by light microscopy have led to considerable advances in morphometric techniques. Scanning electron microscopy (SEM) has been used. Statistical analysis of morphometric measurements obtained via light and SEM has resulted in a computer-based imaging system capable of distinguishing different species of gyrodactylids with a high level of accuracy. This system is currently used at the National Fish Diseases Reference Laboratory in Weymouth (Shinn et al. 2000).

Molecular techniques (polymerase chain reaction (PCR), and DNA sequencing) have been developed for *G. salaris* diagnosis (Cunningham et al. 1995; Cunningham and Mo 1997; Cunningham et al. 2003). Initially, restriction fragment length polymorphism (RFLP) and probe techniques based on ribosomal RNA genes were developed (reviewed by Cunningham (2002)). The drawback of these techniques is that only a small proportion of the DNA is amplified. The original report of *G. salaris*, based on DNA probes and morphology in France (Johnston et al. 1996) was later found to be a new species of gyrodactylid now called *G. teuchis* (Lautraite 2000; Cunningham et al. 2001). Genetically and morphologically, *G. teuchis* is very similar to *G. salaris*. Nucleotide sequencing was needed to distinguish these two species (Cunningham et al. 2001). Similarly, *G. salaris* and *G. thymallii* are genetically extremely similar. It is necessary to sequence the intergenetic spacer to differentiate the two species (Cunningham 2002). Thus, while PCR techniques can be used to identify *G. salaris*, *G. truttae* and *G. derjavini*, sequencing would be required to discriminate between *G. thymallii* or *G. teuchis* from *G.*

salaris. Distinguishing between *G. salaris* and other gyrodactylids requires an investment in training, DNA technology and bespoke image recognition software.

The identification of *G. salaris* on rainbow trout is especially problematic. Its low prevalence and abundance mean that a large sample of trout (more than 150) would be needed to generate a high level of confidence (over 95%) that the parasite was not present in a farmed population. In the event of a *G. salaris* outbreak, it would be necessary to discover the disease status of rainbow trout farms suspected of selling or receiving infected fish, established through contact chasing. Examining 150 fish per farm would take 12.5 person-hours at a rate of 5 minutes per fish. This step in identification is likely to severely constrain efforts to map the distribution of the parasite.

Prior to mortalities of salmon in Norway associated with *G. salaris*, the parasite had been considered to be of low significance. Little work had been carried out to establish its distribution. An import risk analysis for the movement of salmon from Sweden to Norway is unlikely to have been effective since *G. salaris* would not have been an identified hazard.

Within the EU, only Ireland and the UK have taken action to prevent the introduction of the parasite. Both have wild salmon populations of high economic and cultural value. Both countries enjoy high fish health, in part due to their island status but also because of a ban on the import of live salmonids dating back to 1937 (Fish Diseases Act). The 1937 legislation was enacted after an enquiry into an outbreak of furunculosis concluded that the disease had been introduced to the UK by the importation of live trout from Germany. This measure has protected the UK from viral diseases that were present across Europe such as viral haemorrhagic septicaemia and infectious haematopoietic necrosis. In effect, the Fish Disease Act also prevented the introduction of *G. salaris* before it was a recognised hazard.

The distribution of *G. salaris* in mainland Europe is not well established. The status of France and Spain, both countries with wild Atlantic salmon populations, is unknown. Countries in continental Europe do not have the same inherent level of biosecurity nor the same incentives to protect their salmon populations as the UK and Ireland. The majority of salmon populations in Denmark and Germany have disappeared as a result of pollution and barriers to migration such as dams. Nevertheless, France and Spain do have Atlantic salmon populations that are highly likely to be susceptible to *G. salaris*. Germany has plans to restore Atlantic salmon to the Rhine and Meuse (WWF 2001), which could be thwarted by the presence of *G. salaris* (Bakke and Harris 1998). Salmon historically occurred in nine Danish rivers, and are now found at very reduced levels in only three. *G. salaris* has not been implicated in the decline of wild Atlantic salmon in Denmark, but the parasite is widespread in farmed rainbow trout.

The failure of European countries to protect their already threatened Atlantic salmon populations against *G. salaris* can in part be attributed to inadequate systems for monitoring the health status of wild fish populations and detecting the parasite if it is present. The cost and difficulty of identifying *G. salaris*

partly explain why so little has been done to protect the health status of wild salmon by establishing *G. salaris*-free zones, which are allowed under EC decision 2004/453. In addition, a *G. salaris*-free zone would restrict the movement of salmonids into the area, which might damage fish farming and recreational angling activities.

Improved detection and identification methods would help with mapping the present distribution of *G. salaris* in Europe and would assist the establishment of *G. salaris*-free zones to protect uninfected wild salmon populations. For countries known to be free of *G. salaris*, improved methods of detection in rainbow trout would improve the speed with which *G. salaris* outbreaks can be investigated and controlled.

The detection of new pathogens will inevitably rely on general surveillance, since by definition, targeted surveillance is directed at specific agents. Indeed, *G. salaris* was detected through investigation of mortality in a salmon farm. It is difficult now to judge how well the surveillance system worked. Countries free of *G. salaris* need to ensure surveillance systems are in place to rapidly detect the presence of the parasite.

Overview

Since the introduction of *G. salaris* to Norway in the early 1970s (Johnsen and Jensen 1991), considerable resources have been devoted to studying the parasite and, in particular, much progress has been made in developing effective methods of identification. Inevitably, most work has taken place in Norway (Mo 1994), and to a lesser extent, the UK, where *G. salaris* is regarded as the most important exotic disease threat to wild salmon (Peeler and Thrush 2004). The susceptibility of Atlantic salmon populations is more complicated than initially reported (Dalgaard et al. 2003; Bakke et al. 2004) and more research is needed to assess the threat that *G. salaris* presents to already vulnerable Atlantic salmon populations in the UK, Spain and France. However, existing evidence strongly indicates that *G. salaris* could effectively eliminate salmon from river systems in these countries.

A number of European countries have not taken advantage of EU legislation to protect their remaining, sparse Atlantic salmon populations from *G. salaris*. Problems associated with detection and identification probably deterred efforts to investigate the distribution of *G. salaris*, which is necessary for the establishment of *G. salaris*-free zones. Recent developments in both molecular (Cunningham 2002) and morphometric (Shinn et al. 2000, 2001; Cunningham 2002) approaches to identification facilitate survey work to discover the distribution of *G. salaris* in Europe. However, problems still exist in identifying the parasite on rainbow trout populations due to low prevalence and low abundance of infection. In the UK, this problem needs to be addressed in the context of contingency plans for *G. salaris*, which must include the design of surveys to detect the parasite in farmed rainbow trout as well as in wild salmon.

The spread of *G. salaris* between countries (Peeler and Thrush 2004), from farmed to wild fish (Paisley et al. 1999), and between rivers (Soleng et al. 1998; Høgåsen and Brun 2003) has been thoroughly investigated. These studies support policies to prevent the introduction of the disease to uninfected populations. *G. salaris* illustrates the dangers of unidentified hazards. Measures were not in place to prevent its spread to Norway because it was not considered a threat. Legislation to prevent the introduction of other diseases protected the UK and Ireland from *G. salaris*.

The development of improved methods for identification and detection, such as multi-arrays, would provide a tool for screening populations for known and putative pathogens before they are transported, and to accurately determine the health status of fish in the receiving waters. The ability to detect a range of known and putative pathogens in a single test would improve the safety of international trade in live fish.

Atlantic salmon are threatened in much of their original range (WWF 2001). This species has suffered from over-exploitation, pollution, the destruction of spawning grounds, and barriers to migration such as the construction of hydro-electric dams.

The spread of *G. salaris* by human movement of fish presents another serious threat to the survival and restoration of the species. Effective methods of identification and detection of *G. salaris* are critical to efforts to mitigate its spread and impact.

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First published April 2006. Department of Trade and Industry. www.dti.gov.uk

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