**Project no. SSPE-CT-2003-502329**

**PANDA**

Permanent network to strengthen expertise on infectious diseases of aquaculture species and scientific advice to EU policy

Coordination Action

Scientific support to policies

# Work Package 2
# Risk analysis of exotic, emerging and re-emerging disease hazards

## Annex 10: *Gyrodactylus salaris* qualitative risk assessment

Start date of project: 01/01/04 Duration: 44 months

Dr Barry Hill,
Centre for Environment, Fisheries and Aquaculture Science
United Kingdom

Revision [1.0]

| **Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)** | | |
|---|---|---|
| **Dissemination Level** | | |
| **PU** | Public | PU |
| **PP** | Restricted to other programme participants (including the Commission Services) | |
| **RE** | Restricted to a group specified by the consortium (including the Commission Services) | |
| **CO** | Confidential, only for members of the consortium (including the Commission Services) | |

# Table of Contents

# *Gyrodactylus salaris* qualitative risk assessment

## *Gyrodactylus salaris* TOR

To undertake a risk assessment for *Gyrodactylus salaris* (Gs) ahead of a Commission decision to modify the existing trade measures to prevent the introduction of Gs with fish imports via intra-Community trade and imports from third countries. The Commission agreed to accept the outcome of a PANDA RA on this and amend the measures if the report recommends so, with any new measures to take effect from 1 May 2005.

The Commission's proposals include allowing susceptible species originating in coastal farms to be traded freely into Gs-free zones without testing for the presence of Gs on the grounds that a publication just out shows that at a salinity of 25ppt the parasite is killed within 15 min.

The assessment was based on the preventive measures set out in the draft legislation (SANCO 10024) (i.e. a restricted risk analysis) and was essentially be used to determine whether the measures as they stand reduce the risk of Gs transmission to an acceptable (i.e. negligible) level.

### Original terms of reference

1) Qualitatively assess the risk of the introduction of *G. salaris* to uninfected territories within the EU with the movement of live salmonids from coastal farms which are under the supervision of the competent authority and:

a) situated in an coastal zone with a salinity below 25 parts per thousand, and where all water catchment areas draining into the estuary are declared free of *G. salaris* OR

b) situated in a coastal zone where the seawater has a salinity of more than 25 parts per thousand and no live fish of the susceptible species have been introduced during the previous 14 days

2) Based on the results of the risk assessment make recommendations, if necessary, to reduce the risk of *G. salaris* to a negligible level.

### Revised terms of reference

1) Qualitatively assess the risk of the introduction and establishment of *G. salaris* in uninfected territories within the EU by the movement of live species susceptible to *G. salaris* from coastal waters at various salinities.

2) Make recommendations for measures to reduce the risk of *G. salaris* introduction and establishment associated with the movement of live species susceptible to *G. salaris* from coastal waters at various salinities.

### Outcome

The assessment determined that the measures would reduce the risk of *Gs* transmission to an acceptable (i.e. negligible) level. The main conclusions were that species of fish, the surveillance and biosecurity in *Gs*-free farm sites and rivers and the salinity of coastal farm sites supplying and receiving live fish were the main factors determining the risk of *Gs* transfer with the movement of live fish. The report was made available on the PANDA website and it was subsequently published as a scientific paper in the journal Aquaculture (Peeler *et al*., 2006).

### Reference

Peeler, E., Thrush, M., Paisley, L. and Rodgers, C. 2006. An assessment of the risk of spreading the fish parasite *Gyrodactylus salaris* to uninfected territories in the

European Union with the movement of live Atlantic salmon (*Salmo salar*) from coastal waters. *Aquaculture*, 258:187-197.

# A qualitative assessment of the risk of the spread of the fish parasite *Gyrodactylus salaris* to uninfected European territories with the movement of live fish from coastal waters

***confidential draft for discussion only***

Edmund Peeler[1], Mark Thrush[1], Larry Paisley[2] and Chris Rodgers[3]

[1]Centre for Environment, Fisheries and Aquaculture Science, Weymouth, UK, DT4 7QN
[2]Danish Institute for Food and Veterinary Research, Department of Epidemiology and Risk Assessment, Mørkhøj Bygade 19, DK-2860 Søborg, Denmark
[3] Aquaculture Centre-IRTA, Ctra. Poble Nou, s/n., P.O. Box 200, 43540 San Carlos de la Ràpita, Tarragona, Spain.

# 1 Terms of reference

1) Qualitatively assess the risk of the introduction and establishment of *G. salaris* in uninfected territories within the EU by the movement of live species susceptible to *G. salaris* from coastal waters of varying salinity.

2) Make recommendations for measures to reduce the risk of *G. salaris* introduction and establishment associated with the movement of live species susceptible to *G. salaris* from coastal waters of varying salinity.

# 2 Summary

A scenario tree of events necessary for the introduction of the *G. salaris* with the importation of live fish from coastal waters was constructed; relevant information was identified, and the probability of each step assessed. Salinity at the site of origin, destination and during transport are the most important factors influencing the likelihood of *G. salaris* spread. Salinity, and other factors, will vary considerably between sites and, therefore, it is not meaningful to produce an overall assessment of risk. Nevertheless, the scenario tree provides a framework for further, quantitative assessments of *G. salaris* spread with the movement of a known consignment between identified locations. It is possible to conclude that Atlantic salmon originating from coastal sites where salinity is greater than 25 ‰ presents a negligible risk of introduction, mainly because survival of the parasite at this salinity is approximately 22 hours (temperature 1.4$^0$C). Parasites might be alive on recently introduced fish, but transportation in full strength seawater (33 ‰) reduces the risk of introduction to a negligible level. Fish from coastal zones where salinity is less than 25 ‰ and where rivers draining into the region have been declared free of *G. salaris* present a higher risk of introduction, which will be reduced to negligible if the fish are transported in seawater. Since reproduction and the survival of *G. salaris* are negatively associated with increasing salinity, the risk of introduction of *G. salaris* is lower for movements of live Atlantic salmon from coastal zones, where rivers draining the estuaries have been declared *G. salaris* free, compared with movements from freshwater which have been declared *G. salaris* free. Therefore, the EC decision 2004/453/EC did not create routes with a higher level of risk of *G. salaris* spread, compared with existing routes. This work demonstrates how qualitative risk assessment can be used to in support of decision-making.

## 3 Introduction

*Gyrodactylus salaris* is a viviparous, monogenean freshwater parasite of Atlantic salmon (*Salmo salar*) that naturally infects some Baltic stocks of Atlantic salmon without causing clinical disease. However, in Atlantic stocks *G. salaris* is a serious parasite of pre-smolts; it multiplies unchecked by an immune response and death normally results (Bakke et al., 1990b). *G. salaris* was introduced into Norway, probably via salmon parr imported from Sweden in the early 1970's (Mo, 1994), and has resulted in the collapse of wild salmon populations in 46 Norwegian rivers, with 24 rivers currently infected (Mo, T.A, pers. comm.). In Norway, elimination of the parasite has been achieved in 16 rivers by the chemical destruction of all fish life using rotenone, an organic pesticide (a further five rivers are under surveillance following treatment). The parasite is listed by the Office International des Epizooties (O.I.E.) in the Aquatic Animal Code (O.I.E., 2003a).

## 4 Material and methods

There are five stages to a complete import risk analysis (O.I.E., 2001): i) hazard identification, ii) release assessment (description of pathways necessary for introduction), iii) exposure assessment (description of pathways necessary for the exposure of aquatic species in the importing territory to the introduced exotic pathogen), iv) consequence assessment (identification of the consequences of disease introduction and establishment), and v) risk management (policies to reduce likelihood of introduction and mitigate the consequences).

The hazard is defined in the terms of reference; in brief it is the introduction of *G. salaris* to uninfected territories with the movement of live fish from coastal waters. A scenario tree describing the series of events necessary for the hazard to occur was constructed (Figure 1.) but only the release and exposure stages of a complete import risk analysis (IRA) have been addressed in this paper. The geographical distribution of the parasite and its biophysical properties and host range are discussed and used to assess the likelihood that the hazard occurs.

## 5 Marine aquaculture in Europe

Atlantic salmon and rainbow trout (*Oncorhynchus mykiss*) dominate aquacultural finfish production in Northern Europe. The main European salmon producers are Norway and Scotland, whilst rainbow trout are produced in many European countries.

Atlantic salmon fry are produced in freshwater hatcheries where they grow until approximately 70 g at which point they undergo physiological, morphological and behavioural changes to prepare them for the marine phase of their existence. This is called smoltification and the fish are referred to as smolts. Smolts are moved to seawater cages where they continue to grow until reaching slaughter weight (often referred to as "ongrowing"). Sea cages are usually located in sheltered locations (e.g. sea lochs or fjords). Selected fish are grown on beyond slaughter weight for use as broodstock. Broodstock are returned to freshwater for spawning, when the gametes are "stripped" from the fish. The majority of rainbow trout production takes place entirely within freshwater but juveniles above 100 g in weight can survive in seawater and limited marine production takes place in Norway, Denmark and Scotland.

# 6 Host range

*G. salaris* reproduces and survives permanently only on Atlantic salmon, rainbow trout (*Oncorhychus mykiss*) (Bakke et al., 1991) and Atlantic salmon X brown or sea trout (*Salmo trutta*) hybrids (Bakke et al., 1999). However, it can live for periods of 7-50 days on other salmonid and non-salmonid species (Appendix 1) including eels (*Anguilla anguilla*) (maximum duration of infection eight days) (Bakke and Jansen, 1991). The parasite survives longest (50 days) on brown trout (*Salmo trutta*) (Jansen and Bakke, 1995) and grayling (*Thymallus thymallus)* (Soleng and Bakke, 2001) on which limited reproduction is possible. *G. salaris* rapidly detaches from a dead host and is highly efficient at finding a new host (Soleng et al., 1999a). *G. salaris* causes clinical disease  only in Atlantic salmon.

# 7 Geographic distribution and prevalence

## 7.1 Geographic distribution

*G. salaris* was originally found in some Baltic stocks of Atlantic salmon in western Sweden, northern Finland and northern Russia. Recent work as demonstrated that some Baltic stocks are susceptible to *G. salaris*, though not to the same degree as Atlantic stocks (Bakke et al., 2004; Dalgaard et al., 2003), which may indicate a patchy distribution throughout its original geographic distribution. It has been introduced to Norway (46 rivers have been infected and currently 24 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 it is generally agreed that the parasite found was a different 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 (*Oncorhynchus mykiss*) (Bakke and Harris, 1998) and it is likely to be present in more countries than currently known (O.I.E., 2003b). Surveys to substantiate freedom from *G. salaris* have been conducted only in the UK, Ireland, some river catchments in Finland and France (Lautraite et al., 1999).

### 7.2 Farm level prevalence

There are no published data on the prevalence of *G. salaris* in Swedish fish farms, however, in Finland, where Baltic salmon are also farmed, *G. salaris* was found in 39% of all freshwater salmon farms (Haenninen et al., 1995). *G. salaris* was found on rainbow trout in four of five farms surveyed in Denmark (Buchmann and Bresciani, 1997). A more recent survey found *G. salaris* in seven of 11 Danish rainbow trout farms, however, only 15 fish were sampled from each farm (Nielsen and Buchmann, 2001).

### 7.3 Within farm / river prevalence

Studies of *G. salaris* in wild Norwegian salmon populations have generally found high prevalences. A study in one Norwegian river over a four year period (Appleby and Mo, 1997) found a prevalence of 100% on year classes throughout the study period, except during winter and spring of 1992, when the prevalence declined to 0-40%. The mean abundance peaked in autumn at between 400 - 1300 parasites/ fish (Appleby and Mo, 1997). Mo (1992) found prevalence to be 100% on yearlings and older parr in a Norwegian river (Batnfjordselva) except in the winter when the water temperature had fallen to 0 degrees for 2-3 months. Soleng et al (1998) found the prevalence of *G. salaris* was 71% in migrating smolts in the Drammensfjord. A study of *G. salaris* over 6-7 years on four Baltic Finish Atlantic salmon farms found that the prevalence ranged from 9-18% for salmon yearlings and smolts. The experience in Norway is that the prevalence of *G. salaris* in farmed rainbow trout populations may only be 5% and many individuals may have only 1 or 2 parasites (T.A. Mo, pers. comm.).

# 8 Biophysical characteristics of *G. salaris*

## 8.1 Introduction

*G. salaris* has a short, direct life-cycle, produces live young, is highly fecund (Harris et al., 1994; Jansen and Bakke, 1991) and a single individual can cause an epidemic. Although phylogenetically *G. salaris* is a macroparasite, its life cycle is similar to a micro-parasite (e.g. a virus or bacterium). *G. salaris* rapidly detaches from a dead host and is highly efficient at finding a new host (Soleng et al., 1999a). It can survive for 6-7 days off the host in low water temperatures but is killed by desiccation, freezing or elevated temperatures (one hour survival at above 60°C) (Mo, 1987).

## 8.2 Salinity and temperature

Soleng and Bakke (1997) exposed groups of 12 hatchery-reared Atlantic salmon parr, infected with *G. salaris*, to varying salinities and different temperatures (1.4°C, 6°C and 12°C). They found that the parasite survived in full strength salinity (>33 ‰) for approximately 20 minutes, but at 5 ‰ the parasite reproduced and increased in number (Soleng and Bakke, 1997). For salinities between 7.5 and 20 ‰ survival time declined from 38 days to 16 hours, respectively (at 6°C) (Soleng and Bakke, 1997) (Appendix 2, Table A2a). The range of survival times was relatively narrow (Appendix 2. Table A2a). At salinities from 7.5 to 20 ‰ survival time and abundance declined with increasing temperature (1.4°C to 12°C). Work by Soleng et al., (1998) largely confirmed these results, however, after exposure to 33 ‰ salinity for 30 minutes 3 of 7 fish were still infected with *G. salaris* and after being returned to freshwater, and the number of parasites on one fish increased. No fish exposed to 33 ‰ for 60 minutes were infected when examined after 7 days in freshwater (Soleng et al., 1999a).

## 8.3 Disinfection

*G. salaris* is killed by aluminium sulphate at 202 μg $1^{-1}$ (Poleo et al., 2004; Soleng et al., 1999b), and most disinfectants (e.g. 0.5% Virkon ® S, Antec International, Sudbury, Suffolk, UK; Mo, T.A., pers. comm.).

# 9 Release and exposure assessments

The series of events that would lead to the introduction of *G. salaris* to uninfected territories through the movement of live fish from coastal sites are set out in Figure 1. The initiating event will be a *G. salaris* infection in freshwater that spreads to coastal farms. The movement of live infected fish from a coastal farm to an uninfected territory and the subsequent establishment of the parasite in a susceptible population completes the series of events. In Figure 1. the pathways are broken down into a series of small steps so that all the factors that might influence the probability of *G. salaris* transmission can be identified. P1 – P11 describe the release assessment and P12 – P20 the exposure assessment for introduction into a coastal site. The physical relationship between freshwater and coastal fish production sites is illustrated in Figure 2.

## 9.1 Host species

The risks associated with the pathways of introduction in Figure 1. vary with different host species because duration of survival varies considerably between species (see Appendix 2.). Only farmed Atlantic salmon, and to a lesser extent rainbow trout, will be moved from freshwater to seawater (at smoltification), hence risks P1- P3 (Figure 1.) only apply to these species. Similarly, it is only the broodstock of these species that will be moved from seawater to freshwater (P19 and P20) for stripping (see section 4).

Figure 1. Scenario tree for the introduction of *G. salaris* from coastal sites

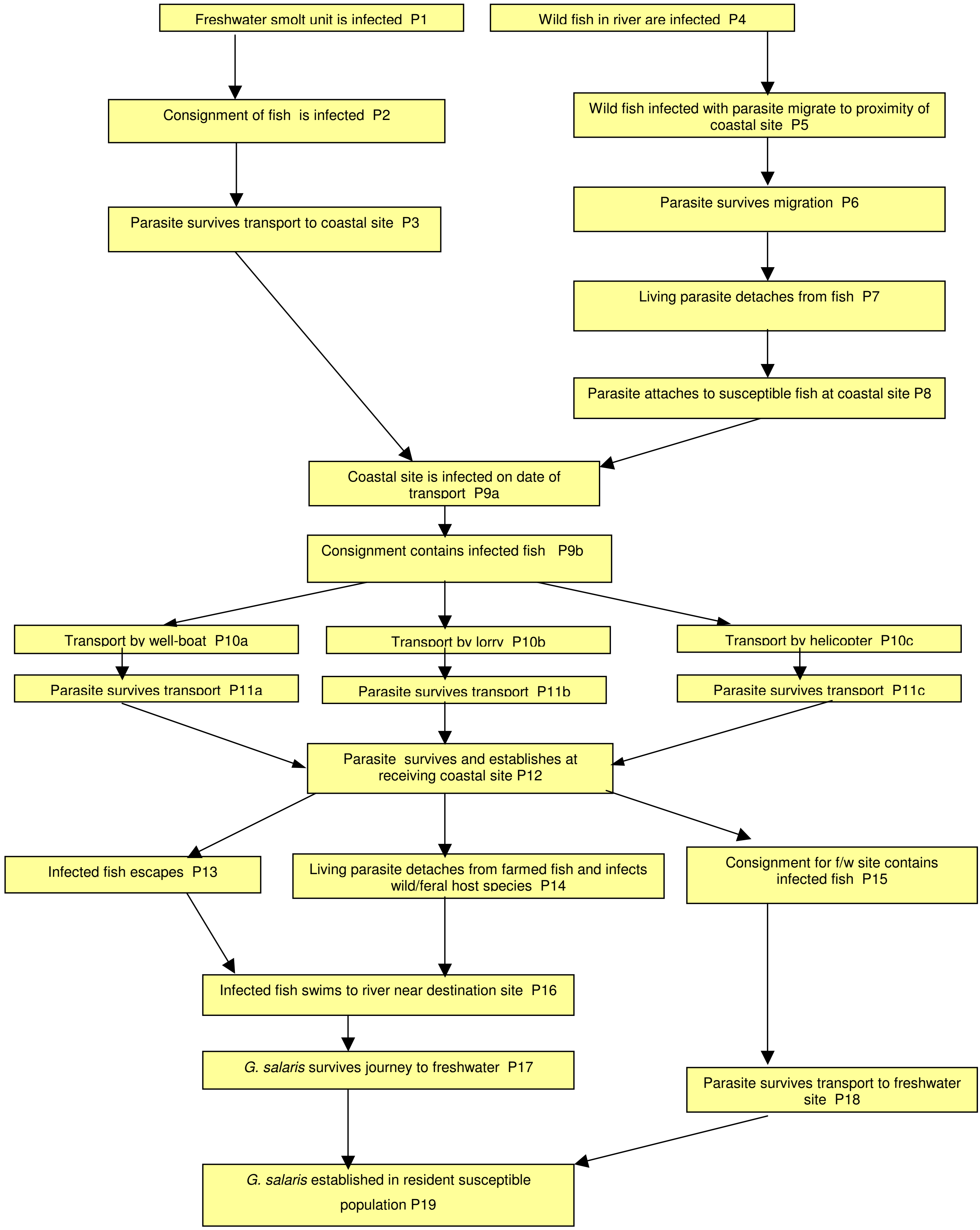
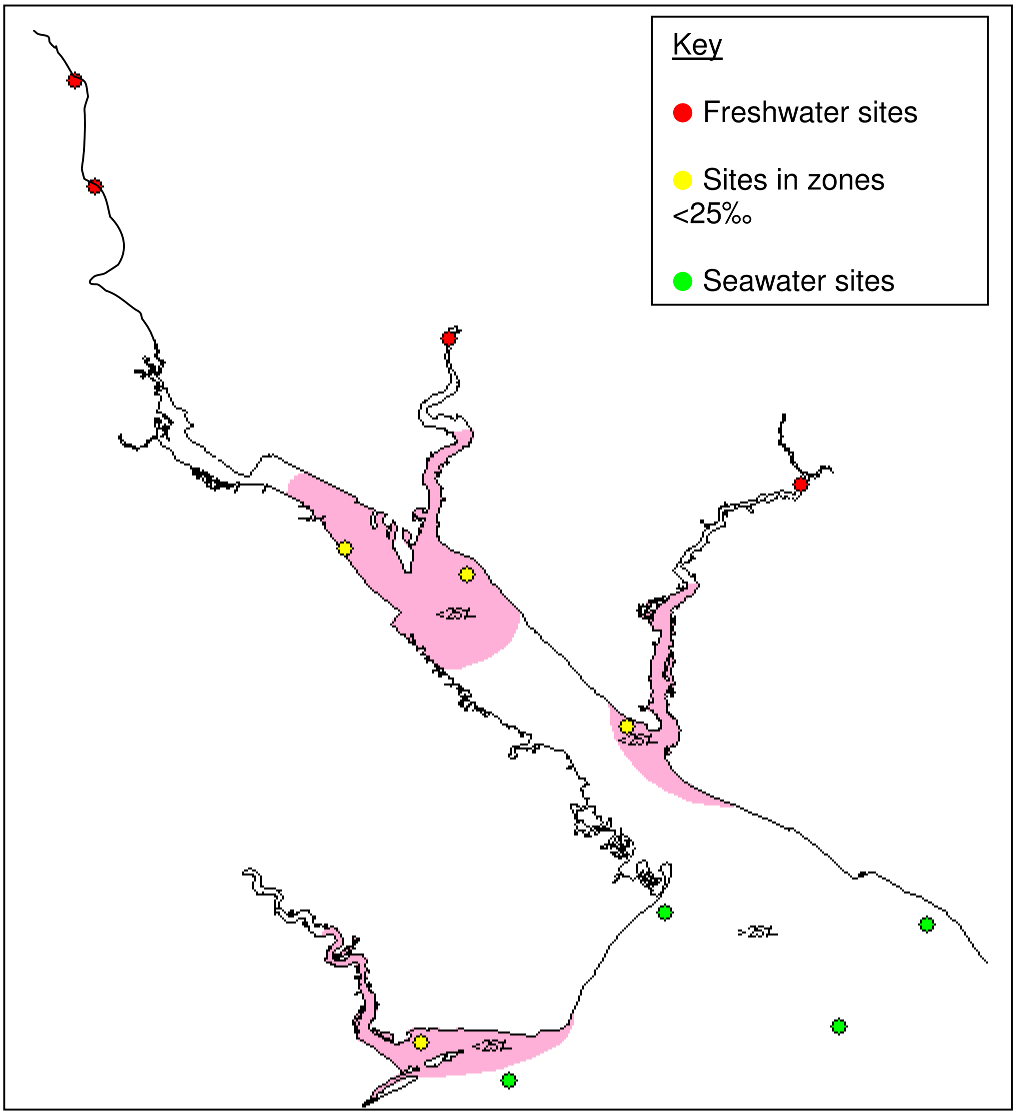


Figure 2. Location of freshwater and coastal fish production sites



## 9.2 Freshwater production unit infected (P1)

### 9.2.1 Background

*G. salaris* may spread if fish are sourced from a freshwater production site that is incorrectly considered free of the parasite. It is possible that a site may incorrectly be granted disease free status or *G. salaris* may have been introduced into a previously free site. The risk of *G. salaris* introduction into *G. salaris* approved free sites will depend on the risk of exposure and the biosecurity measures in place. Information used to assess the probability

An estimate of the risk of exposure can be obtained from historic data. During 2002 in Norway a salmon hatchery became infected with *G. salaris* and the parasite spread to two other hatcheries. These were the first hatcheries to become infected since 1987 (Mo et al., 2004). There are approximately 291 salmon hatcheries in Norway (register held by the Ministry of Fisheries). A farm can be incorrectly granted *G. salaris* free status if the parasite was not detected in samples taken to demonstrate freedom. The lower prevalence and abundance in rainbow trout, compared with Atlantic salmon populations, increases the risk of failing to identify the parasite in this species.

Biosecurity measures will vary greatly between countries depending *inter alia* on the perceived threat of exposure. Measures taken in Norway for freshwater rainbow trout farms include the following: i) water intake must be above the level where anadromous fish are found, or the inflow must be treated with ultra-violet (UV) light or ozone, ii) the outflow must be into seawater or filtered through a 40µm mesh, iii) hatcheries can only supply seawater production units within the same epidemiological zone or freshwater sites within the same river catchment, and iv) ongrowing units must be fallowed annually. Salmon hatcheries must also source water where migratory populations of anadromous fish (e.g. Atlantic salmon) are absent.

#### *9.2.1.1 Detection and infection status*

*G. salaris* will cause obvious clinical signs (increased mucous production, change in behaviour and mortality) in Atlantic salmon smolts and high prevalence and abundance (see section 6.3), thus detection is likely to be rapid. However, *G. salaris* infection in a Norwegian hatchery in 2002 led to two secondary cases. By contrast *G.*

*salaris* infections of rainbow trout cause no clinical signs, prevalence and abundance can be low and thus detection by passive surveillance is very unlikely, thus large numbers of fish must be sampled to achieve a high probability of detecting the disease.

#### *9.2.1.2 Conclusion*

The risk of *G. salaris* infection in a freshwater unit will vary greatly between farms and rivers. The risk for an individual farm will depend on biosecurity and, in particular, on the volume of introduced live fish. Farms within multi-catchment *G. salaris* free territories have an inherently lower risk, compared with farms surrounded by infected rivers. The risk is also higher for rainbow trout units, compared with Atlantic salmon, because the likelihood of detection is considerably lower.

## 9.3 Consignment of fish is infected (P2)

### 9.3.1 Background

The potential for transmission from the freshwater site exists for the period until the parasite is detected (and thus will depend on thus the probability of detection and the sensitivity of any surveillance or testing).

### 9.3.2 Information used to assess the probability

The probability that a consignment of fish (Atlantic salmon or rainbow trout) is infected will be proportional to the prevalence of infection in the population from which the consignment is drawn and the size of the consignment. Prevalence will increase with time from first introduction until a stable state is reached. The prevalence in farmed Atlantic salmon will be higher than rainbow trout (see section 6.2).

### 9.3.3 Conclusion

The probability that a consignment is infected can only be assessed on an individual site basis. Detection is likely to be more rapid in Atlantic salmon but the probability that a consignment is infected is high for Atlantic salmon compared with rainbow trout due to the higher prevalence.

## 9.4 Parasite survives transport to coastal site (P3)

### 9.4.1 Background

At smoltification Atlantic salmon and rainbow trout are transported to seawater sites for ongrowing (see section 4).

### 9.4.2 Information used to assess the probability

Atlantic salmon and rainbow trout smolts are generally transported in freshwater. Conditions of transport will favour the survival of the parasite. Transport in seawater greater than 7.5 ‰ will reduce the level of infection, and at high salinities (>20 ‰) may eliminate the infection completely (see section 6.2 and Appendix 2.).

### 9.4.3 Conclusion

Under normal circumstances smolts are transported in freshwater thus the probability of *G. salaris* survival can be assumed to be 100%.

## 9.5 Wild fish infected in freshwater (P4)

### 9.5.1 Background

The migration of wild fish from freshwater to marine sites is a potential route of spread. A river may be known to have infected salmonids populations, have *G. salaris* free status or an unknown status.

### 9.5.2 Information used to assess the probability

*G. salaris* can only be permanently present in rivers with farmed or wild populations of Atlantic salmon, rainbow trout or Atlantic salmon X brown trout hybrids.

The geographic distribution of *G. salaris* in Europe is not well documented outside of the Baltic, thus the *G. salaris* status of many rivers is unknown (see section 6.1).

Under EU legislation, member states (MS) can apply to have river catchments or territories recognised as *G. salaris* free (Commission Decision 2004/453/EC). However, a river approved as *G. salaris* free may be infected if the status was granted incorrectly (5% probability if sampling was chosen to detect *G. salaris* with 95% probability) or has become infected since gaining approval (and the infection gone undetected). The risk of *G. salaris* infection in these rivers will depend on the biosecurity measures in place to prevent the anthropogenic introduction of the parasite. The main risk of introduction is the movement of live infected fish, however, other routes of transmission exist (Peeler et al., 2004) and include movement of vehicles, people and equipment between fish farms on different catchments. In Norway, anglers are obliged to disinfect their angling equipment after use in an infected river. Altantic salmon migrating through low salinity water can spread the parasite (Soleng et al., 1998). A recent New Scientist article (Bazichuk, 2004) reported a significant level of sea trout X Atlantic salmon hybrid parr in a Norwegian river infected with *G. salaris*. These hybrids permanently carry *G. salaris* without clinical signs and might be more likely to migrate between rivers than Atlantic salmon. In Norway, a salinity of 25 ‰ is considered a sufficient barrier to prevent spread of *G. salaris* through fish migration between rivers, and therefore, rivers connected by water in fjords of less than 25 ‰ are considered as a single epidemiological unit for control purposes (T.A. Mo, pers. comm.).

Farmed Atlantic salmon will act as sentinels for the presence of the parasite in the wild population. In the absence of farm sites and where there is no active surveillance programme, the first sign of *G. salaris* infection may be a decline in the Atlantic salmon population.

### 9.5.3 Conclusion

In some respects P4 is similar to P1: i) the risk of exposure will vary greatly between locations, and ii) rivers in *G. salaris* free multi-catchment territories have an inherently lower risk compared with river surrounded by infected rivers.

## 9.6 Wild fish infected with parasites migrate to coastal sites (P5)

### 9.6.1 Background

The probability that infected wild fish migrate from freshwater to coastal farm sites will vary greatly with species and season.

### 9.6.2 Information used to assess the probability

Atlantic salmon smolts will migrate into coastal water from estuaries in the spring. Some species such as flounder (*Platichthys flesus*) are known to migrate on a daily basis from estuarine to coastal waters (*G. salaris* can infect flounder for up to three days - (Soleng and Bakke, 1998). Wild fish are known to be attracted to sea cages to scavenge on waste feed.

The likelihood that the fish are infected will depend on the prevalence of infection, which in turn depends on a number of additional factors, particularly species (see section 5 and Appendix 1.). There are no data on which to assess the likelihood of infection of non salmonids (e.g. flounder and saithe) in rivers with infected salmonid populations.

#### 9.6.3 Conclusion

The migration of wild Atlantic salmon to marine cages presents the main threat of spread. It is very possible that wild salmon may be attracted to scavenge at cages but insufficient data exists on which to assess this risk.

### 9.7 Parasite survives migration on wild fish (P6)

#### 9.7.1 Information used to assess the probability

The survival of the parasite during migration will depend on i) the time taken for the migratory fish species to reach the coastal site (a function of distance and speed at which they swim); ii) the salinity and temperature of the water (see section 6.2 and Appendix 2), and iii) the behaviour of the fish, particularly the depth at which the fish swim (salinity increases with depth).

Høgåsen and Brun (2003) used a mean swimming speed of 5.8 km/ 24hr, based on unpublished research and assumed that salmon travelled in the upper 3-metre layer (based on expert opinion) where salinity is lowest (see Appendix 3). Other work has demonstrated that whilst salmon mainly travel in the upper water layers they also make small vertical dives (Doving et al., 1985).

#### 9.7.2 Conclusion

P6 can only be assessed on a site specific basis when geographic and salinity information is available.

### 9.8 Living parasite detaches from wild fish (P7) and attaches to a susceptible farmed fish at a coastal site (P8)

#### 9.8.1 Background

Wild fish arriving at a marine seacage may infect farmed fish through the release of live young in the vicinity of the cages or through host-switching.

#### 9.8.2 Information used to assess the probability

*G. salaris* is a highly fecund parasite and, therefore, the release of live young is possible. However, reproduction ceases at salinities greater than 7.5 ‰ (see section 3 and Appendix 2).

*G. salaris* is known to switch hosts as a survival mechanism and method of dispersal (Bakke and Jansen, 1991). Thus, a *G. salaris* parasite on a non-salmonids species (on which they cannot reproduce e.g. flounder) may be likely to detach if alternative hosts are present. *G. salaris* is highly efficient at seeking new hosts, therefore, there is a reasonable probability that a detached parasite will find a new host, especially given the host density of farmed fish.

#### 9.8.3 Conclusion

The risk of transmission from wild Atlantic salmon is probably moderate where salinity is less than 7.5 ‰ and low at salinities greater than 7.5 ‰. Host-switching is a likely mechanism of transmission from a wild non-salmonid species to a farmed salmonids, and presents a moderate risk.

### 9.9 Coastal site infected at time fish are transported (P9a)

#### 9.9.1 Background

Following introduction of *G. salaris* into a site there is a period during which live movements from the site may be infected.

#### 9.9.2 Information used to assess the probability

The site will remain infected until the parasite i) is eliminated because they cannot survive permanently on the host (i.e. marine fish species), ii) killed by the level of salinity (see section 7.2 and Appendix 2), or iii) is detected (depends on the species infected and the level of active surveillance).

#### 9.9.3 Conclusion

For Atlantic salmon and trout the duration of infection will mainly depend on the salinity at the site (infection could be permanent at salinities <7.5 ‰). Detection is likely to be delayed for rainbow trout compared with Atlantic salmon, owing to the lack of clinical signs and low abundance of infection on the former (see section 6.3).

### 9.10 Consignment contains infected fish (P9b)

#### 9.10.1 Information used to assess the probability

The probability that the consignment contains at least one infected fish depends on the prevalence of infection in the target populations and the size of the consignment (number of fish).

### 9.10.2 Conclusion

At salinities greater than 7.5 ‰ the parasite cannot reproduce and thus only very limited spread will occur through host swapping; prevalence, therefore, will be low and the probability that the consignment is infected would remain low. At lower salinities prevalence will be moderate to high in Atlantic salmon populations.

## 9.11 Transport by well-boat from a coastal site and parasite survival (P10a / P11a)

### 9.11.1 Background

Well-boats are the main form of transport for moving live fish over long journeys (often lasting several days).

### 9.11.2 Information used to assess the probability

Water in well boats can be re-circulated and oxygenated for short periods (e.g. during bad weather or when in close proximity to farm sites). In the open sea, water is exchanged at a high rate. Well-boats would be used to move Atlantic salmon smolts from Norway to other countries (e.g. Scotland). The exposure of the smolts to full-strength seawater for the duration of the journey would ensure that all *G. salaris* parasites are killed and flushed out of the transport hold.

Surface waters in the Baltic sea have salinities ranging from 3-10 ‰[1], so conditions in well-boats operating exclusively between sites in this region will not eradicate *G. salaris* parasites present on the fish.

### 9.11.3 Conclusion

The duration of the journey and the salinity of the water used for transportation will determine the survival of the parasite. *G. salaris* will probably not survive the majority of well-boat journeys.

## 9.12 Transport by lorry from a coastal site and parasite survival (P10b / P11b)

### 9.12.1 Information used to assess the probability

The water used as a transport medium for fish transported by lorry from any coastal site is likely to originate from the coastal site. Journey times for live fish movements made by lorry are likely to be of short to medium duration (minimum 1hour accounting for loading / unloading; maximum 24 hours).

[1] www.fishbase.org

9.12.2 Conclusion

Transport by lorry effectively increases the exposure time of *G. salaris* parasites to the level of salinity at the coastal site by up to 24 hours. Thus parasites that are alive on transported fish may die during transport, depending on salinity.

## 9.13 Transport by helicopter from a coastal site and parasite survival (P10c / P11c)

9.13.1 Background

Helicopters are mainly used to transport Atlantic salmon smolts from freshwater to coastal sites, although, they could be used to transport fish between coastal sites.

9.13.2 Information used to assess the probability

The water used as a transport medium for fish transported by helicopter from any coastal site is likely to originate from the coastal site. The journey times are very short, ranging from 3 to 15 minutes.

9.13.3 Conclusion

Given the short journey time *G. salaris* survival is unlikely to be significantly affected.

## 9.14 Parasite survives and establishes at the destination farm (P12)

9.14.1 Background

For *G. salaris* to spread to an uninfected area, introduced fish must first infect the resident farmed population at the destination, before spreading to other wild and farmed populations is possible.

9.14.2 Information used to assess the probability of establishment at site of introduction

The probability of establishment at the site of introduction will depend mainly on i) the presence of a susceptible host (i.e. Atlantic salmon and / or rainbow trout), and ii) salinity and water temperate (see section 6.2 and Appendix 2).

9.14.3 Conclusion

The probability of establishment in freshwater or low salinity (≤7.5 ‰) sites is very high (assuming Atlantic salmon or rainbow trout are present). At higher salinities (where reproduction does not take place) the parasite will only persist for a period of hours or days (see Appendix 2).

## 9.15 Infected fish escape (P13) or a living parasite detaches from the fish and attaches to a wild or feral host species (P14)

### 9.15.1 Background

The pathways of spread in Figure 1 assume that the receiving site is a coastal site where salinity is > 7.5 ‰ (the very large majority of live fish movements from seawater will be to seawater). The parasite has a limited amount of time to find and infect a host in freshwater. Freshwater and low salinity (≤7.5 ‰) sites will remain infected until the parasite is detected (through active or passive surveillance) and action is taken to eliminate it (i.e. destocking).

### 9.15.2 Information used to assess the probability

In coastal sites the probability that the free living parasites detaches from infected fish and infects a wild or feral fish of a host species depends on the duration of infection (which depends on the salinity at the site and on previous exposure to water of salinity >7.5 ‰) and density of wild fish around the cages. The infection pressure will be low when the salinity is >7.5 ‰ because no live young will be produced. Wild or escaped farmed fish are likely to be found in the vicinity of sea cages scavenging waste feed. Similarly, at salinities >7.5 ‰ there is only a short window of opportunity for an infected fish to escape before the parasite perishes. The probability that an escaped fish is infected is proportional to the prevalence of infection (which will be low when salinity is >7.5 ‰). Farmed salmon are known to escape when bad weather or seals damage sea cages.

### 9.15.3 Conclusion

P13 ranges from moderate to negligible depending on the salinity of the site.

## 9.16 Movements of infected fish from seawater to freshwater (P15)

### 9.16.1 Background

Only small numbers of Atlantic salmon broodstock are likely to be moved from seawater to freshwater sites for stripping (see section 4).

### 9.16.2 Information used to assess the probability

Broodstock can only become infected with *G. salaris* if they have come into contact with introduced infected fish. The risk of *G. salaris* transmission will depend mainly on the salinity of the site of origin (see section 4 and Appendix 2).

The probability that the fish moved from a coastal site will be infected when moved will depend on the prevalence of infection at the site. The prevalence will depend on the salinity at the site and the duration of infection at the site.

#### 9.16.3 Conclusion

Broodstock are unlikely to come into contact with infected introduced fish and will be kept at coastal sites where salinity is considerably higher than 7.5 ‰. P15 is therefore extremely low to negligible.

### 9.17 Infected fish swims to an estuary near destination site (P16)

#### 9.17.1 Background

For *G. salaris* to spread from a coastal farm an infected fish (escaped or wild) must swim to fresh or low salinity water where the parasite can reproduce and establish in a population rainbow trout or Atlantic salmon.

#### 9.17.2 Information used to assess the probability

The probability that an infected fish swims to an estuary will depend mainly on the species infected. As mentioned under P5 some species, such as flounder, migrate on a daily basis from estuaries to the open sea. Mature Atlantic salmon will migrate during the autumn towards estuaries to spawn in freshwater.

#### 9.17.3 Conclusion

P16 carries a moderate level of risk depending on the species and time of year.

### 9.18 *G. salaris* survives migration to freshwater (P17)

#### 9.18.1 Information used to assess the probability

The same considerations apply to the survival of *G. salaris* on fish migrating to freshwater as from freshwater (P6), i.e. time, salinity, fish behaviour.

#### 9.18.2 Conclusion

Any viable parasites remaining on infected fish are likely to have been exposed to seawater of salinity >7.5 ‰ for some time. The additional time required for the journey to freshwater will further reduce the likelihood of survival. P17 carries an extremely low to moderate level of probability depending on salinity.

### 9.19 Parasite survives journey to freshwater (P18)

9.19.1 <u>Information used to assess the probability</u>

Survival during transport will primarily depend on the duration of the journey and the salinity of water in which the fish are transported (see sections 8.11 – 8.13).

9.19.2 <u>Conclusion</u>

Broodstock will be moved over relatively short distances from coastal farms to freshwater sites and thus P18 is likely to be high.

### 9.20 *G. salaris* becomes established in resident population of susceptible species (P19)

9.20.1 <u>Background</u>

Once the parasite is introduced into freshwater it can only become permanently established in rivers with Atlantic salmon, rainbow trout or Atlantic salmon X brown trout hybrids.

9.20.2 <u>Information used to assess the probability</u>

For *G. salaris* to become established in a river, following introduction, an infected fish must on average infect more than one other fish (the reproductive ratio, $R_0$, >1). P19 will in part depend on the density of the susceptible host population in the river. Infection is more likely to establish when the index case is an Atlantic salmon (salmon X brown trout hybrids) or rainbow trout; on other species establishment will depend on the parasite swapping to a more favourable host species.

9.20.3 <u>Conclusion</u>

An infected Atlantic salmon or rainbow trout is likely to remain permanently infected and infective. Thus the probability that the disease establishes following introduction of an infected salmon or trout is moderate to high.

## 10 Factors determining the risk of *G. salaris* transmission with the movement of live fish from coastal waters

From the sections above and Figure 1, the factors that influence the likelihood of *G. salaris* transmission with the movement of live fish from coastal waters of varying salinities have been identified (Table 1).

**Table 1. Factors affecting the likelihood of *G. salaris* transmission with the movement of live fish from coastal waters of varying salinity**

| | |
|---|---|
| | **Release assessment (introduction)** |
| 1. | biosecurity measures preventing introduction of *G. salaris* into approved free freshwater zones draining into a coastal area |
| 2. | species of farmed fish at coastal farm site |
| 3. | surveillance for *G. salaris* in approved *G. salaris* free freshwater zone |
| 4. | volume of movement of live farmed fish from freshwater to coastal farm sites |
| 5. | species and population level of wild fish in approved freshwater zones |
| 6. | distance from mouth of river to coastal farm sites |
| 7. | speed and depth at which wild fish swim to coastal site |
| 8. | maximum salinity of water separating coastal farm sites from mouth of the river |
| 9. | salinity at coastal farm site |
| 10. | water temperature at coastal farm site |
| 11. | surveillance for *G. salaris* at coastal farm site |
| 12. | volume of movements of live fish from the site (number and size of consignments) |
| 13. | method of transport of live fish from coastal farms site |
| 14. | duration of transport and salinity of water used in transport |
| | **Exposure assessment (establishment)** |
| 15. | salinity at receiving site |
| 16. | water temperature at receiving site |
| 17. | surveillance for *G. salaris* at receiving site |
| 18. | anthropogenic movement of fish from receiving site to freshwater sites |
| 19. | species and population level of wild and feral fish around the receiving site |
| 20. | distance from receiving site to freshwater |
| 21. | maximum salinity of water separating receiving site from freshwater |
| 22. | species present and population level in rivers nearest receiving site |

Live salmonid imports inevitably present the most serious threat of introduction of *G. salaris* because the parasite will multiple on salmonids hosts and the fish will be introduced into a farmed aquatic environment where the parasite may spread to other fish. The importance of this route has been recognised in EU legislation that has allowed MS to gain approval for *G. salaris* free zones, and restrict the importation of live salmonids to regions of equivalent status.

Two key factors stand out from the list of factors influencing the risk of *G. salaris* transmission with the movement of live fish from coastal waters. Firstly, *G. salaris* can only be introduced into coastal sea sites if there are fish movements (natural or anthropogenic) from an infected freshwater river catchment. Biosecurity and effective surveillance are crucial to maintaining the *G. salaris* free status of freshwater zones. It is worth noting that the biosecurity of a *G. salaris* free territory consisting of many catchments, especially an island territory, is inherently higher than a *G. salaris* free catchment surrounded by infected rivers. Secondly, the survival of the parasite, once introduced in a coastal sea farm, will depend on the salinity. At salinities of up to 7.5 ‰ *G. salaris* can reproduce and the population will increase (see Appendix 2.). Thus, if the freshwater zones, connected to the coastal site through fish movements, are infected then coastal sites, where the salinity is less than 7.5 ‰, are highly likely to also be infected. At salinities greater than 7.5 ‰, the probability of infection will depend on the frequency of introduction and survival time of the parasite, which decreases with increasing salinity. The risk of transmission of *G. salaris* from sites where the salinity is greater than 7.5 ‰, is low because the parasite cannot reproduce (thus the prevalence remains low) and only transfers of fish from the site in the time period during which the parasite can survive could be infected (see Appendix 2.) . Similarly, the survival of the parasite during transport and at the destination site will depend on the salinity. If introduced to a freshwater site with the susceptible species present, the probability of establishment is very high, but in coastal sites the parasite has very limited time to reach freshwater and establish infection in a susceptible host species..

## 11 From qualitative to quantitative risk assessment

*G. salaris* can be introduced into a coastal site via a number of pathways (Figure 1). For each pathway introduction is contingent upon a number of events, hence the risk for each pathway is the product of the probabilities of every step in the pathway. The overall risk is the sum of the risks of each pathway. Figure 1 provides a framework for quantitative risk assessment. However, many of the factors identified in Table 1 will vary between locations. In particular, the risk of the initiating event (infection in a freshwater catchment) will vary greatly between catchments depending on the level of biosecurity and surveillance. Thus, a quantitative assessment, similar to that undertaken to assess the risk of *G. salaris* introduction into the Tana River, Norway (Paisley et al., 1999) is only possible for the assessment of the movement of a specific commodity between identified locations.

## 12 Acceptable risk and equivalence

The acceptable level of risk associated with the importation of a commodity is defined as the risk judged by an importing country to be compatible with the protection of public and animal (terrestrial and aquatic) health (O.I.E., 2003a). The Sanitary and Phytosanitary (SPS) agreement of the World Trade Organisation (WTO)[2] recognises that governments have the right to provide the level of protection that it deems appropriate. Setting the acceptable level of risk of disease introduction is, therefore, a political decision (Pharo, 2003); however, the SPS agreement requires that it is based on an objective and scientific assessment of the probability and likely consequences of introduction. The UK Department of Environment, Food and Rural Affairs (Defra) consider that the "Acceptable level of protection (ALOP) for legal trade to be permitted is a negligible risk of introducing list A (OIE disease listing)[3] diseases" and negligible is defined as "not worth considering; insignificant"[4]. The consequences of *G. salaris* introduction are potentially severe and in this paper it is assumed that the acceptable level or risk is negligible. The acceptable level of protection can be considered as the measures necessary to reduce the assessed level of risk to an acceptable level (Pharo, 2003). However, measures more stringent than those laid down by international guidelines must be supported by an import risk analysis.

The concept of equivalence is embedded in the SPS agreement. It is important that countries are consistent in applying the acceptable level of risk to different commodities. Australia was forced to change import restrictions on imports of salmon products because they were found to be inconsistent with the restrictions imposed on other fish products that carried similar risk (Trachtman, 1999).

---

[2] http://www.wto.org/english/docs_e/legal_e/15-sps.pdf
[3] Defined by the OIE as "Transmissible diseases that have the potential for very serious and rapid spread, irrespective of national borders, that are of serious socio-economic or public health consequence and that are of major importance in the international trade of animals and animal products".
[4] http://www.defra.gov.uk/animalh/diseases/monitoring/pdf/riskplan.pdf

# 13 EC Decision 2004/453/EC

In the EC Decision 2004/453/EC contains measures to prevent the spread of *G. salaris* to uninfected parts of the EU. Live fish of a susceptible species can be moved from freshwater catchments that have demonstrated freedom from *G. salaris* and have implemented measures to prevent its introduction. Live fish can also be moved from coastal sites provided that:

- it is under the supervision of the competent authority AND
- all introductions of susceptible species have come from a zone or farm certified free of *G. salaris* AND
- it is situated in an coastal zone with a salinity below 25 ‰ and all water catchment areas draining into the estuary are declared free of *G. salaris* OR
- it is situated in a coastal zone where the seawater has a salinity of more than 25 ‰ and no live fish of the susceptible species have been introduced during the previous 14 days.

Essentially, a freshwater *G. salarisi* free river catchment has been extended into the contiguous estuarine / coastal area and are separated by seawater of at least 25 ‰ (see Figure 2.). The basis for the legislation is that seawater of provides an effective barrier to *G. salaris* transmission. The survival time of *G. salaris* at 25 ‰ is less than 22 hours at optimal temperature (1.4°C) (Appendix 2). The risk that an infected Atlantic salmon may spread *G. salaris* by migrating through water of salinity less than 25 ‰ will depend on the distance separating estuaries and the speed at which salmon swim. The Norwegians set the salinity threshold for separating freshwater areas at 25 ‰.

## 13.1 Spread of *G. salaris* from coastal sites where salinity is <25 ‰ and all water catchment areas draining into the estuary are declared free of *G. salaris*

The probability that *G. salaris* is introduced into a coastal site of less than 25 ‰ through introduction of infected fish from freshwater sites depends on i) the likelihood of *G. salaris* introduction into freshwater part of the approved *G. salaris* free zone; ii) the time to first detection of the parasite, and iii) the frequency of movements of farmed fish from freshwater to coastal sites and the movement of wild fish between fresh and seawater within the *G. salaris* free zone.

Decision 2004/453/EC sets out minimum biosecurity measures to prevent the introduction of *G. salaris* into an approved free zone (Annex I) that include a system which ensures "the rapid recognition of signs suspicious of a disease". As discussed above, free territories, especially island territories have an inherently higher level of biosecurity compared with single catchments. The time to first detection will depend on either producers reporting the presence of the parasite or active sampling to detect the parasite. Producers are likely to notice clinical disease as a result of *G. salaris* infection in Atlantic salmon but not rainbow trout. The survival and establishment of the parasite once introduced into a coastal site depends upon the salinity. If a salmon remains infected having swum through water of 25 ‰ salinity, *G. salaris* has a higher probability of establishment in a freshwater population compared with farmed salmon in sea cages in the same zone. For the same host populations (i.e. Atlantic salmon or rainbow trout), abundance and prevalence of *G. salaris* will be higher in fresh compared with seawater. Movements from coastal sites will invariably be to other seawater sites, whilst freshwater movements will generally be to other freshwater sites. For these reasons the risk of spreading *G. salaris* with movements from coastal sites (where salinity <25 ‰ and all water catchment areas draining into the estuary are declared free of *G. salaris*) will be lower than the risk of movement from the freshwater part of the zone catchments declared free of *G. salaris*. The risk will be in large part determined by the probability of *G. salaris* infection in the freshwater catchment draining into the coastal area or connected to it through live fish movements (i.e. the initiating event).

## 13.2 Spread of *G. salaris* from coastal sites where the seawater has a salinity > 25 ‰ and no live fish of the susceptible species have been introduced in the 14 days prior to shipment

The probability of wild fish spreading the infection to coastal sites where salinity is greater than 25 ‰ is extremely low due to the low survival rate of the parasite during the migration. Since the introduction of infected fish is likely to be a very infrequent event, and given that no live fish would have been introduced during the 14 days prior to a shipment and survival of the parasite at 25 ‰ will be less than 22 hours (see Appendix 2), the combined probability that the site is infected at the time that live fish are moved from the site (P9a) and infected fish are in the consignment (P9b) can be considered as negligible. Survival of *G. salaris* in fish transported by well boats (P11a) can also be considered as negligible if exposed to full strength salinity.

Survival when transported by lorries or helicopter can be considered as moderate to high depending on the duration of transport. The risk of *G. salaris* spread with movement of live fish from seawater sites (where salinity is greater than 25 ‰) is negligible.

### 13.3 Survival and establishment of the parasite at site of destination (exposure assessment)

Survival and establishment of the parasite at the site of destination will depend primarily on the salinity at the site. At salinities less than 5 ‰ the parasite will easily reproduce and establish in the population to which the fish are introduced. At higher salinities the parasite has a period of days or hours (depending on salinity) to reach freshwater and establish infection. It can safely be assumed that if the salinity at the destination site has a salinity of greater than 25 ‰ the probability that it will establish, if introduced, is negligible.

## 14 Conclusion

The main conclusions of this risk assessment are that species of fish, the surveillance and biosecurity in *G. salaris* free farm sites and rivers and the salinity of coastal farm sites supplying and receiving live fish are the main factors deterimining the risk of *G. salaris* transfer with the movement of live fish. The level of risk will, therefore, depend greatly on the site of origin, destination and method of transport. For a particular commodity, where this information is specified, a quantitative assessment would be possible.

Movement of live fish from coastal sites where salinity is greater than 25 ‰ and which comply with measures in Decision 2004/453/EC presents a negligible risk of *G. salaris* transmission. The risk of *G. salaris* transmission from coastal sites of lower salinity will depend primarily on the risk of *G. salaris* infection within the freshwater part of the approved *G. salaris* free zones. However, given the restrictions set out in the legislation, the risk of movement of live fish from coastal part of a free zone cannot be higher than movements from the freshwater part of the approved *G. salaris* free zones. Therefore, it can be concluded that movements of live fish from coastal sites, as permitted in Decision 2004/453/EC, does not increase the risk of *G. salaris* spread to uninfected territories compared with movements from freshwater *G. salaris* free approved zones. However, it should be noted that the total risk of introduction is the product of the risk per unit of commodity and the volume of trade. Thus the total risk will increase if new routes result in increased trade in live fish.

## 15 Acknowledgments

We thank Dr Marion Wooldridge and Dr Tor Atle Mo for their comments on earlier drafts of this paper.

## 16 References

Appleby, C., Mo, T.A., 1997, Population dynamics of *Gyrodactylus salaris* (Monogenea) infecting Atlantic salmon, *Salmo salar*, parr in the River Batnfjordselva, Norway. J Parasitol 83, 23-30.

Bakke, T.A., Harris, P.D., 1998, Diseases and parasites in wild Atlantic salmon (Salmo salar) populations. Canadian Journal of Fisheries & Aquatic Sciences 55, 247-266.

Bakke, T.A., Harris, P.D., Hansen, H., Cable, J., Hansen, L.P., 2004, Susceptibility of Baltic and East Atlantic salmon stocks *Salmo salar* stocks to *Gyrodactylus salaris* (Monogenea). Dis Aquat Org 58, 171-178.

Bakke, T.A., Harris, P.D., Jansen, P.A., 1992a, The susceptibility of *Salvelinus fontinalis* (Mitchill) to *Gyrodactylus salaris* Malmberg (Platyhelminthes; Monogenea) under experimental conditions. J Fish Biol 41, 499-507.

Bakke, T.A., Jansen, P.A., 1991, Experimental transmission of *Gyrodactylus salaris* Malmberg, 1957 (Platyhelminthes, Monogenea) from the Atlantic salmon (*Salmo salar*) to the European eel (*Anguilla anguilla*). Can J Zool 69, 733-737.

Bakke, T.A., Jansen, P.A., Brabrand, A., 1990a, Susceptibility and resistance of brook lamprey, *Lampetra planeri* (Bloch), roach, *Rutilus rutilus* (L.) and perch, *Perca fluviatilis* L. to *Gyrodactylus salaris* Malmberg (Monogenea). Fauna Norvegica, Series A 11, 23-26.

Bakke, T.A., Jansen, P.A., Grande, M., 1992b, The susceptibility of *Salvelinus namaycush* (Walbaum) to *Gyrodactylus salaris* Malmberg (Platyhelminthes; Monogenea) under experimental conditions. Fauna Norvegica, Series A 13, 1-7.

Bakke, T.A., Jansen, P.A., Hansen, L.P., 1990b, Differences in the host resistance of Atlantic salmon, *Salmo salar* L., stocks to the monogenean *Gyrodactylus salaris* Malmberg, 1957. J Fish Biol 37, 577-587.

Bakke, T.A., Jansen, P.A., Harris, P.D., 1996, Differences in Susceptibility of Anadromous and Resident Stocks of Arctic Charr to Infections of *Gyrodactylus salaris* Under Experimental Conditions. J Fish Biol 49, 341-351.

Bakke, T.A., Jansen, P.A., Kennedy, C.R., 1991, The host specificity of *Gyrodactylus salaris* Malmberg (Platyhelminthes, Monogenea): Susceptibility of *Oncorhynchus mykiss* (Walbaum) under experimental conditions. J Fish Biol 39, 45-57.

Bakke, T.A., Sharp, L.A., 1990, Susceptibility and resistance of minnows, *Phoxinus phoxinus* (L.) to *Gyrodactylus salaris* Malmberg, 1957 (Monogenea) under laboratory conditions. Fauna Norvegica, Series A 11, 51-55.

Bakke, T.A., Soleng, A., Harris, P.D., 1999, The susceptibility of Atlantic salmon (*Salmo salar* L.) brown trout (*Salmo trutta* L.) hybrids to *Gyrodactylus salaris* Malmberg and *Gyrodactylus derjavini Mikailov*. Parasitology 119, 467-481.

Bazichuk, N. 2004. Salmon crisis in Norway. In New Scientist.

Buchmann, K., Bresciani, J., 1997, Parasitic infections in pond-reared rainbow trout *Oncorhynchus mykiss* in Denmark. Dis Aquat Org 28, 125-138.

Cunningham, C.O., Collins, C.M., Malmberg, G., Mo, T.A., 2003, Analysis of ribosomal RNA intergenic spacer (IGS) sequences in species and populations of Gyrodactylus (Platyhelminthes: Monogenea) from salmonid fish in Northern Europe. Dis Aquat Org 57, 237-246.

Dalgaard, M., Nielsen, C.V., Buchmann, K., 2003, Comparative susceptibility of two races of *Salmon salar* (Baltic Lule river and Atlantic Conon river strains) to infection with *Gryodactylus salaris*. Dis Aquat Org 53, 173-176.

Doving, K.B., Westerberg, H., Johnsen, P.B., 1985, Role of olfaction inthe behavioural and neuronal responses of Atlantic salmon, *Salmo salar,* to hydrographic stratification. Can J Fish Aquat Sci 42, 1658-1667.

Haenninen, M.L., Ridell, J., Hirvelae-Koski, V., 1995, Phenotypic and molecular characteristics of Aeromonas salmonicida subsp. salmonicida isolated in southern and northern Finland. J Appl Bacteriol 79, 12-21.

Harris, P.D., Jansen, P.A., Bakke, T.A., 1994, The population age structure and reproductive biology of *Gyrodactylus salaris* Malmberg (Monogenea). Parasitology 108, 167-174.

Jansen, P.A., Bakke, T.A., 1991, Temperature-dependent reproduction and survival of *Gyrodactylus salaris* Malmberg, 1957 (Platyhelminthes: Monogenea) on Atlantic salmon (*Salmo salar* L.). Parasitology 102, 105-112.

Jansen, P.A., Bakke, T.A., 1995, Susceptibility of brown trout to *Gyrodactylus salaris* (Monogenea) under experimental conditions. J Fish Biol 46, 415-422.

Johnston, C., Mackenzie, K., Cunningham, C.O., Eiras, J.C., Bruno, D.W., 1996, Occurrence of *G. salaris*, Malmberg 1957, in Portugal. Bull Eur Assoc Fish Pathol 16, 89-91.

Lautraite, A., Blanc, G., Thiery, R., Daniel, P., Vigneulle, M., 1999, Gyrodactylids parasitizing salmonids in Brittany and Western Pyrenees water basins: Epidemiological features of infection and species composition. Bull Fr Peche Piscic 355, 305-325.

Mo, T.A. 1987. Taksonomiske og biologiske undersokeler, virksomheten i 1986 og forslag til virksomhet i 1987 (Oslo, University of Oslo), p. 70.

Mo, T.A., 1992, Seasonal variations in the prevalence and infestation intensity of *Gyrodactylus salaris* Malmberg, 1957 (Monogenea: Gyrodactylidae) on Atlantic salmon parr, *Salmo salar* L., in the River Batnfjordselva, Norway. J Fish Biol 41, 697-707.

Mo, T.A., 1994, Status of *Gyrodactylus salaris* problems and research in Norway, In: Lewis, J.W. (Ed.) Parasitic diseases of fish. Samara Publishing, Tresaith, Dyfed, Wales, pp. 43-48.

Mo, T.A., Norheim, K., Hellesnes, I., 2004, The surveillance and control programme for Gyrodactylus salaris in Atlantic salmon and rainbow trout in Norway. Norst Veterinaer Tidsskrift 3, 157-163.

Nielsen, C.V., Buchmann, K., 2001, Occurrence of *Gyrodactylus* parasites in Danish fish farms. Bull Eur Assoc Fish Pathol 21, 19-25.

O.I.E., 2001. Risk analysis in aquatic animal health. In, Paris, 8-10 February 2000.

O.I.E., 2003a, International Aquatic Animal Health Code - fish, molluscs and crustaceans, 6th EditionParis, 165 p.

O.I.E., 2003b, International Manual of Diagnostic Tests for Aquatic Animals, 4th EditionParis, 358 p.

Paisley, L.G., Karlsen, E., Jarp, J., Mo, T.A., 1999, A Monte Carlo simulation model for assessing the risk of introduction of *Gyrodactylus salaris* to the Tana river, Norway. Dis Aquat Org 37, 145-152.

Peeler, E.J., Gardiner, R., Thrush, M.A., 2004, Qualitative risk assessment of routes of transmission of the exotic fish parasite *Gyrodactylus salaris* between river catchments in England and Wales. Preventive Veterinary Medicine 64, 175-189.

Pharo, H.J., 2003. The limits to quantification in import risk analysis. In: 10th International Symposium for Veterinary Epidemiology and Economics, Vina del Mar, Chile.

Poleo, A.B.S., Schjolden, J., Hansens, H., Bakke, T.A., Mo, T.A., 2004, The effect of various metals on *Gyrodactylus salaris* (Platyhelminthes, Monogenea) infections in Atlantic salmon (*Salmo salar*). Parasitology 128, 1-9.

Soleng, A., Bakke, T.A., 1997, Salinity tolerance of *Gyrodactylus salaris* (Platyhelminthes, Monogenea): Laboratory studies. Can J Fish Aquat Sci 54, 1837-1845.

Soleng, A., Bakke, T.A., 1998, The susceptibility of three-spined stickleback (*Gasterosteus aculeatus*), nine-spined stickleback (*Pungitius pungitius*) and flounder (*Platichthys flesus*) to experimental infections with the monogenean *Gyrodactylus salaris*. Folia Parasitol 45, 270-274.

Soleng, A., Bakke, T.A., 2001, The susceptibility of grayling (*Thymallus thymallus*) to experimental infections with the monogenean *Gyrodactylus salaris*. Int J Parasitol 31, 793-797.

Soleng, A., Bakke, T.A., Hansen, L.P., 1998, Potential for dispersal of *Gyrodactylus salaris* (Platyhelminthes, Monogenea) by sea-running stages of the Atlantic salmon (*Salmo salar*): field and laboratory studies. Canadian Journal of Fisheries & Aquatic Sciences 55, 507-514.

Soleng, A., Jansen, P.A., Bakke, T.A., 1999a, Transmission of the monogenean *Gyrodactylus salaris*. Folia Parasitol 46, 179-184.

Soleng, A., Poleo, A.B.S., Alstad, N.E.W., Bakke, T.A., 1999b, Aqueous aluminium eliminates *Gyrodactylus salaris* (Platyhelminthes, Monogenea) infections in Atlantic salmon. Parasitology 119, 19-26.

Trachtman, J.P., 1999, Decisions of the Appellate Body of the World Trade Organisation current survey. Australia - Measures affecting importation of salmon. Eur J Int Law 10, 192-195.

# Appendix 1. The survival of *Gyrodactylus salaris* on different fish species

Brown trout (*Salmo trutta*)
150 trout exposed to 26 infected salmon for 15 days. Mean intensity 7.1 (0-22) (Bakke et al., 1999).

Sea trout (*Salmo trutta*)
150 trout exposed to 26 infected salmon for 6 days. Mean intensity 9.6 (2-21). (Bakke et al., 1999).

Arctic char (*Salvelinus alpinus*)
150 char exposed to 26 infected salmon for 11 days. Mean intensity 55.8 (5-151) (Bakke et al., 1996).

Brook char (*Salvelinus fontinalis*)
150 char exposed to 20 infected salmon for 10 days. Mean intensity 12.7 (6-44) (Bakke et al., 1992a).

Lake trout (*Salvelinus namaycush)*
150 trout exposed to 20 infected salmon for 7 days. Mean intensity 5.7 (3-24) (Bakke et al., 1992b).

Grayling (*Thymallus thymallus*)
150 fish were exposed to 20 infected salmon for 1 week. After one week mean intensity was 12.7 (3-25). In two trials (pooled fish and individually held fish) there was an increasing intensity up to day 22 and day 7 respectively, then a decline. Max observed duration of infection was 50 days (Soleng and Bakke, 2001).

European eel (*Anguilla anguilla*)
Maximum duration of *G. salaris* on eels was 8 days (Bakke and Jansen, 1991).

Brook lamprey (*Lampetra planeri*)
10 lamprey cohabited with 10 heavily infected salmon for 2 days. 100% prev after 2 days, 11.5$^{o}$C, mean intensity 28.9, range 14-53, population crashed to 0 within 4 days, no parasite reproduction, (Bakke et al., 1990a)

Perch (*Perca fluviatilis*)
10 perch cohabited with 20 heavily infected salmon for 5 days. 100% prev. after 5 days, 11.5$^{o}$C, mean intensity 7.6, range 3-11 population crashed to 0 within 2 days, no parasite reproduction, (Bakke et al., 1990a)

Minnows (*Phoxinus phoxinus*)
*G. salaris* persisted on minnows for only 2-4 days (Bakke and Sharp, 1990)

Roach (*Rutilus rutilus*)
10 roach cohabited with 20 heavily infected salmon for 5 days. 100% prev. after 5 days, 11.5$^{o}$C, mean intensity 2.9, range 1-5 population crashed to 0 within 2 days. No parasite reproduction, (Bakke et al., 1990a)

Three-spined stickleback (*Gasterosteus aculeatus*), nine-spined stickleback (*Pungitius pungitius*)
The infections were eliminated after 6 days on nine-spined stickleback, and 8 days on three-spined stickleback (Soleng and Bakke, 1998)

Flounder (*Platichthys flesus*)
The infections were eliminated after a maximum of 3 days on flounder (Soleng and Bakke, 1998).

## Appendix 2. Survival of *Gyrodactylus salaris* at different salinities at 1.4°C

Table A2a. Survival of *G. salaris* at different salinities (data from (Soleng and Bakke, 1997)

| **Salinity (‰)** | **Survival time at 1.4°C (h = hours, d=days)** | | |
|---|---|---|---|
| | **mean** | **mean + 2 SE** | **maximum** |
| 0 | | population growth | |
| 5 | | population growth | |
| 7.5[1] | 38 d | 44.4 d | 56 d |
| 10 | 229.1 h | 236.7 h | 240.0 h |
| 15 | 64.0 h | 69.6 h | 78.0 h |
| 20 | 36.5 h | 38.5 h | 42.0 h |
| 33 | 0.3 h | 0.3 h | 0.3 h |

[1]at 6°C, data for 1.4°C not available

Figure A2a. Survival of *G. salaris* at salinities from 5 to 33 ‰ and at 6°C (data from (Soleng and Bakke, 1997)

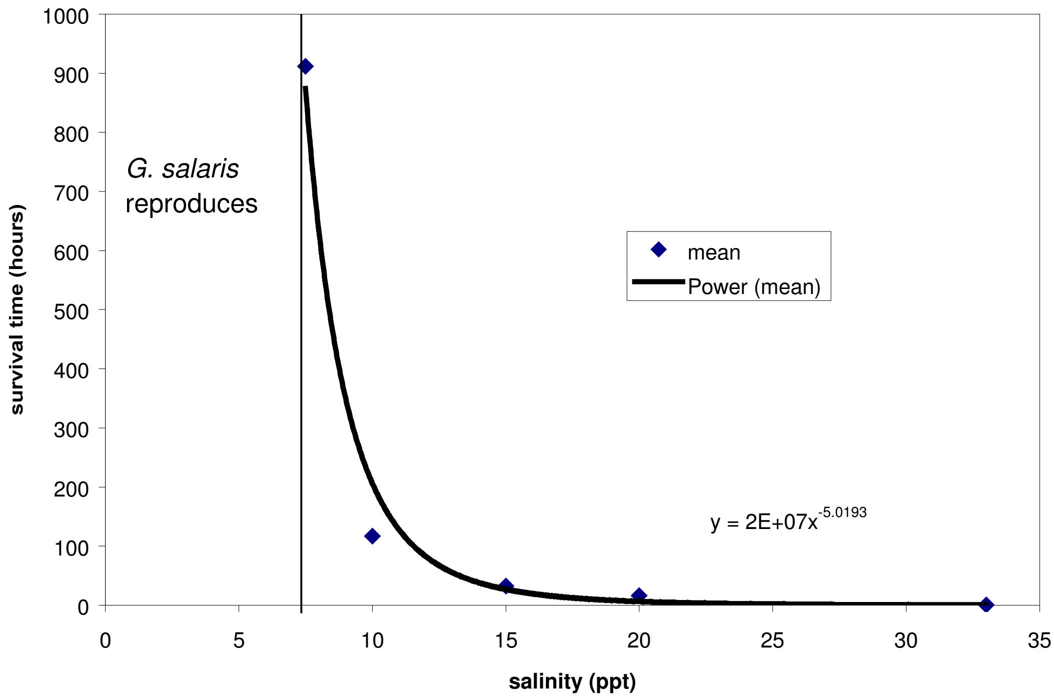
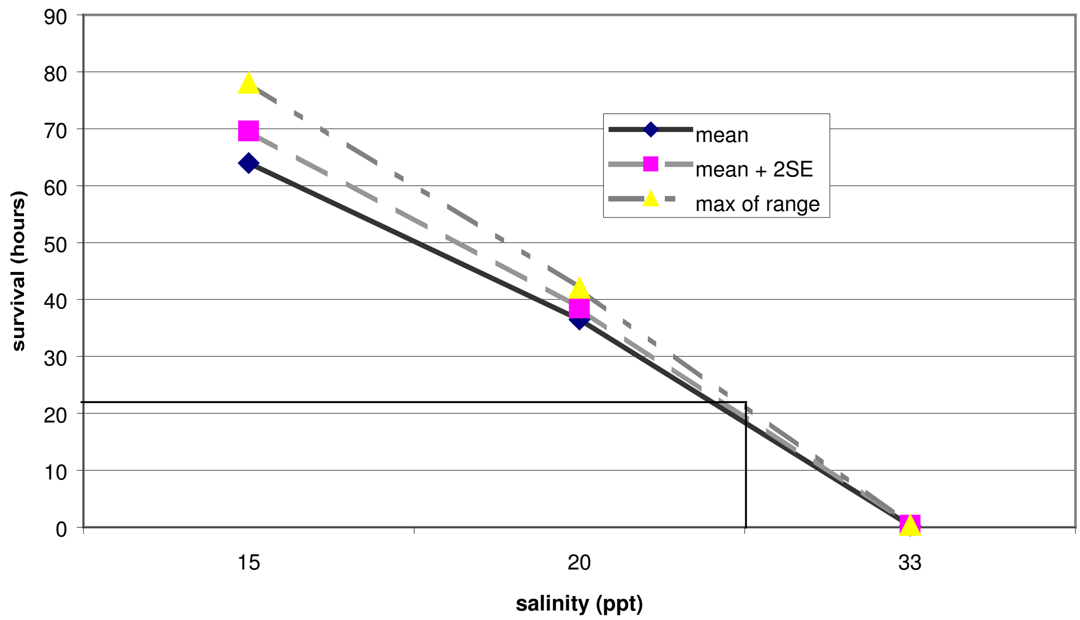



Figure A2b. Survival of *G. salaris* at salinities from 15 – 33 ‰ and at 1.4°C (data from (Soleng and Bakke, 1997)



## Appendix 3. Salinity at different depths

Table A3a Salinities and temperatures at different depths in the Drammensfjord, Norway (taken from Soleng et al, 1998)

| depth (metres) | mean temperature (°C) | mean salinity (‰) |
|---|---|---|
| 0 | 10.2 | 2.6 |
| 1 | 10.0 | 3.0 |
| 2 | 9.9 | 3.6 |
| 3 | 9.9 | 4.9 |
| 4 | 10.0 | 9.2 |
| 5 | 10.1 | 12.7 |
| 6 | 10.3 | 17.6 |
| 7 | 10.3 | 18.5 |
| 8 | 10.3 | 19.7 |