NOBANIS - Invasive Alien Species Fact Sheet

Gyrodactylus salaris

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Species description

Scientific name: *Gyrodactylus salaris* Malmberg, 1956, (Trematoda, Monogenea)
Synonyms: None
Common names: Gyrodactylosis (GB), "Salmon killer" (several countries) "Lachstöter" (DE), laksedræber (DK), Varaallinen lohiloinen (FI), girodaktiloze (LV), "Gyro" (NO), Laxparasiten (SE).

Fig 1. *Gyrodactylus salaris* parasitizing fin of Atlantic salmon, photo by Kurt Buchmann and José Bresciani, Royal Veterinary and Agricultural University, Denmark.

Species identification

Gyrodactylids are ubiquitous monogenean ectoparasites on the skin and gills of teleost fish both in marine and freshwater ecosystems. The most recent species compilation lists some 400 gyrodactylid species. *Gyrodactylus salaris* is a species of this genus found on fins and skin of Atlantic and Baltic salmon in its freshwater phase (Figure 1). The small (0.5 - 1 mm) parasite was described by Malmberg (1957) from salmon parr in a hatchery situated at the river Indalsälven in Sweden. Since then, there have been a growing number of observations of *G. salaris* from several countries both on wild fish and on fish in hatcheries and freshwater fish farms.

Until the mid-1990s, most *Gyrodactylus* species were identified by comparing the morphology of the hard parts in the attachment organ, the opisthaptor. Over recent years, the application of molecular markers in the taxonomy and systematics of *Gyrodactylus* species has increased. A description of *G. salaris* identification routines is given by the World Organisation for Animal Health (OIE, Manual of Diagnostic Tests for Aquatic Animals).

Today, identification of *G. salaris* is predominantly based on sequences of the mitochondrial gene Cytochrome Oxidase 1 (CO1). Based on CO1, Hansen *et al*. (2003) and Meinilä *et al.* (2004) described a number of haplotypes of *G. salaris* in three clades; clade 1 was most abundant and only found on salmon, clade 2 was isolated from the river Göta älv in Sweden and clade 3 was observed on Norwegian salmon in three rivers and on rainbow trout in fish farms in Sweden, Denmark and Finland. Later, additional samples have been analysed and the total cladogram extended (see e.g. Hansen *et al*. 2007).

The systematics of *G. salaris* and its closest relatives is complex. For example, there is no support for the monophyly of either *G. salaris* or its closest relative *G. thymalli* (see e.g. Hansen *et al*. 2007). Furthermore, strains of non-pathogenic *G. salaris* have been described (see "Ecology", below) for which it has not been possible to describe systematic diagnostic markers. The degree of pathogenicity can therefore not readily be deduced from a molecular identification of the species.

Native range

The native area of *G. salaris* is the Karelian part of Russia and the Baltic parts of Finland and Sweden. Genetic studies of the host, Atlantic salmon, suggest a large-scale, geographic grouping which has relevance to understanding the host/parasite relationship. Baltic salmon constitute one of the three major groups of the species, the others being the west and east Atlantic groups (Ståhl 1987) or races (Cross *et al.* 1998). Nowadays, Baltic salmon as a whole forms one effectively isolated evolutionary unit of Atlantic salmon and differs clearly from Atlantic salmon of the rivers draining into the Atlantic Ocean and Barents Sea (Ståhl 1987, Koljonen 1989, Kazakov and Titov 1993, Nilsson *et al.* 2001).

Southern Baltic salmon from an inlet river to the Onega lake (Russia) (Shulman *et al.* 2000, 2005) and from the river Neva (Bakke *et al.* 1990) which is the outlet river from the Ladoga lake, showed a response against *G. salaris* while northern Baltic salmon showed an intermediate susceptibility against *G. salaris* (Dalgaard *et al* 2003, 2004, Bakke *et al.* 2004, Lindenstrøm *et al.* 2006).

Based on these observations there are reasons to believe that the Lake Onega is confirmed to belong to the native range of *G. salaris*. Even though the relation between the host and the parasite in the rest of the Baltic is somewhat different from the situation in the Lake Onega, *G. salaris* has been in the Baltic for so long that the whole Baltic area should probably be considered as the native range of *G. salaris* (Meinilä *et al.* 2004).

Alien distribution

History of introduction and geographical spread

Observations from the different countries indicate that *G. salaris* does not occur naturally in the Atlantic distribution area of the Atlantic salmon populations (see Table 1). It has been introduced in later years to rivers in Norway (1970's, Johnsen and Jensen 1986), to rivers on the Swedish west coast (1980's, Alenäs *et al.* 1998), and to a Russian river draining into the White Sea (1980's, Ieshko *et al.* 1995). Until 2007, *G. salaris* had not been found in Poland. Rokicka *et al.* (2007) reported finding the parasite on rainbow trout in seven farms. The *G. salaris* was the same type as described earlier in Denmark (Lindenstrøm *et al*. 2003).

Pathways of introduction

G. salaris is spread in the alien range mainly by anthropogenic movement of infected fish between hatcheries/fish farms, between hatcheries/fish farms and rivers and by migration of infected fish in rivers and in brackish water in fiords.

In May 1972, *G. salaris* was recorded on *O. mykiss* in a Danish rainbow trout farm (in Køge) (Malmberg and Malmberg 1993). Later, Buchmann and Bresciani (1997) found *G. salaris* on rainbow trout and indicated the presence of an infection reservoir in spawners in Danish freshwater fish farms. *G. salaris* is present in most counties in Jutland on rainbow trout. This could seem quite problematic because a large stocking programme using salmon susceptible to the Norwegian type of *G. salaris* is in progress in Denmark. However, the Danish strain of the parasite shows very low pathogenicity to Scottish salmon and Danish salmon and high predilection for rainbow trout.

In Russia, the epidemic in the river Keret was caused by *G. salaris* transferred from Lake Onega (Kuusela *et al*. 2009). In the river Pisto, Kuitozero Lake, Karelia, *G. salaris* was first observed in 2001. The parasite belongs to the rainbow trout specific clade and was most probably introduced from upstream fish farms on the Finnish side of the border.

In the first investigation carried out at the Swedish west coast in the year 1989, the parasite was found in a salmon hatchery in Laholm at the river Lagan and the same year on wild parr in the river Säveån (a tributary to the river Göta älv) (Malmberg and Malmberg 1991, Karlsson *et al.* 2003b). Since the first finding in 1989, the parasite has spread gradually (Malmberg and Malmberg 1991). It was found in the river Ätran in 1991 (Alenäs 1998). According to Alenäs *et al.* (1998) *G. salaris* might have been introduced to the river Ätran possibly about 1986. In 1997, more comprehensive investigations including almost all salmon rivers on the Swedish west coast from Skåne to the Norwegian border were conducted, and *G. salaris* was found in 8 rivers. The river Stensån was probably infected later than 1994 since two earlier investigations showed no *G. salaris* (Malmberg 1998). Degerman *et al*. (2012) reported that by 2011, *G. salaris* had been found in 19 of 28 wild salmon rivers on the Swedish west coast. In April 2013, *G. salaris* was for the first time found on adult landlocked salmon in the mouth of River Klarälven, Vänern (K. Olstad, unpublished data). Altough these parasites had the same haplotype (see below) as found on sea-migrating salmon in Göta älv, further studies are required to conclude regarding the introduction of *G. salaris* into Lake Vänern

Hansen *et al.* (2003) elucidated the mitochondrial haplotypes of *G.salaris* in several rivers on the Swedish west coast. Interestingly, they observed different origins. In the rivers Ätran and Surtan, the mtDNA type was identical to the Norwegian “salmon killer” suggesting introduction from Bothnian Bay by fish transport. In the rivers Suseån and Stensån, the parasite was specific and most closely related to the haplotype from Gauja, Latvia. This, as well as the fact that the salmon population in some of the rivers on the Swedish west coast carry a collection of Baltic mitochondrial haplotypes without any Atlantic mixture (Nilsson *et al.* 2001) led Meinilä *et al.* (2004) to suggest that part of the Swedish west coast parasite population is native.

Regional investigations of salmon parr (about 50,000) from a large number of rivers in Norway show that *G. salaris* is not native in the country. In 139 of the rivers more than 90 salmon parr have been investigated without finding the parasite. If the parasite had occurred with a prevalence of 5 % or more in one of these rivers, there is a 99 % probability that it would have been discovered (Johnsen *et al.* 1999a).

Four anthropogenic introductions of *G. salaris* into Norway along with infected salmonids from hatcheries around the Baltic Sea have been suggested (Johnsen *et al.* 1999a). *G. salaris* was found for the first time in Norway at Sunndalsøra hatchery in July 1975 (Tanum 1983, Malmberg 1989). In August the same year, *G. salaris* was found on salmon parr in the river Lakselva, northern Norway (Johnsen 1978). Later the parasite was discovered in a number of Norwegian rivers (Heggberget and Johnsen 1982, Johnsen and Jensen 1986, 1991, 1992) and the number of rivers where *G. salaris* has been found is now 48 of which 40 can be traced to three sources: stocking of fish from infected hatcheries, infected hatcheries situated by the rivers or brackish water spread from infected rivers.

The colonization of rivers after parasite introduction has been rapid (1 - 3 years). For example in the large salmon river Vefsna the parasite was found in the lower parts in 1978. In 1980 it had spread throughout the entire watercourse. Data from other infected Norwegian rivers such as the Lakselva, Beiarelva, Ranaelva, Steinkjervassdraget, Rauma and Lærdalselva present a similar picture of a very rapid colonization (1 - 3 years) (Johnsen and Jensen 1988).

There are numerous examples of dispersal of *G. salaris* between rivers in fiord regions in Norway. The rivers within these regions are situated so close to each other that the occurrence of *G. salaris* in the neighbouring rivers may be explained as the result of spreading with fish through brackish water in the fiord area (Johnsen and Jensen 1986). This kind of spread has, however, been slower. For example infection of four new rivers in Romsdalsfiord took 13 years.

Alien status in region

Country	Not found	Not established	Rare	local	Common	Very common	Not known
Austria	X						
Czech Republic	X						
Denmark					X		
Estonia				Native			
European part of Russia				Native			
Finland				Native			
Faroe Islands	X						
Germany	X						
Greenland	X						
Iceland	X						
Latvia				Native			
Lithuania				Native			
Norway			X				
Poland			X				
Sweden				Native			

Table 1. The frequency and establishment of *Gyrodactylis salaris*, please refer also to the information provided for this species at www.nobanis.org/search.asp. Legend for this table: **Not found** –The species is not found in the country; **Not established** - The species has not formed self-reproducing populations (but is found as a casual or incidental species); **Rare** - Few sites where it is found in the country; **Local** - Locally abundant, many individuals in some areas of the country; **Common** - Many sites in the country; **Very common** - Many sites and many individuals; **Not known** – No information was available; **Native** – when a species is native in a country this is indicated in the table under the relevant frequency category.

Ecology

Habitat description

In general, the epidemiological outcome of a parasite-host relationship depends on relevant intrinsic qualities of the host and the parasite, as well as qualities of the environment in which the parasite-host relationship takes place. Both pathogenic and non-pathogenic strains of *G. salaris* have been described. Furthermore, among a range of salmonid hosts, susceptibility towards the parasite varies from very high to very low. Finally, a number of environmental factors are known to potentially have effect on the epidemiology of *G. salaris* on its different hosts.

Other than Atlantic and Baltic salmon, *G. salaris* can survive and reproduce on rainbow trout (*Oncorhynchus mykiss*), Arctic charr (*Salvelinus alpinus*), North American brook trout (*Salvelinus fontinalis*), grayling (*Thymallus thymallus*), North American lake trout (*Salvelinus namaycush*) and brown trout (*Salmo trutta*) (in declining order of susceptibility, see e.g. Bakke *et al.* 2002, 2007). Rainbow trout and Arctic charr have been found capable of sustaining *G. salaris* infection over time (in fish farms and in wild populations, respectively). Introduction of the parasite to habitats / localities in which one or more of these species are found is thus a potential range extension. The remaining species can act as transport hosts within their respective maximum capacity for sustaining an infection.

In Denmark, a special variant (Gx) of *G. salaris* was reported from rainbow trout farms. However, infection experiments revealed that this particular morphotype exhibits low virulence towards Atlantic salmon (Lindenstrøm *et al.* 2003, Jørgensen *at al*. 2007). This variant does not readily reproduce and transmit between salmon (Lindenstrøm *et al.* 2000) which is found highly susceptible to *G. salaris* (Bakke and MacKenzie 1993, Nielsen and Buchmann 2001). Another strain of *G. salaris* of the non-virulent type has also been found parasitizing Arctic charr (*Salvelinus alpinus*) in an inland lake in Southern Norway (Robertsen *et al*. 2007). In a laboratory test on the infectivity of this *G. salaris* type on a range of hosts, salmon was the last susceptible (Olstad *et al*. 2007).

Site specificity of *G. salaris* on 853 Atlantic salmon parr infected with 1 - 10 625 parasites was studied in the river Lakselva in northern Norway. At low intensities (< 100), the dorsal fin was the principal site of attachment, followed by the pectoral and anal fins. However, the distribution of parasites on the fish, and their crowding, varied with infection intensity. When the intensity increased to more than 100, more parasites were located on the caudal fin, and when it exceeded 1000, the body of the fish was also heavily infected (Jensen and Johnsen 1992).

Monegeneans of the genus *Gyrodactylus* are widespread ectoparasites of both freshwater and marine fishes. *G. salaris* lives and reproduces in freshwater, but is able to tolerate brackish water for shorter or longer periods depending on salinity. Soleng and Bakke (1997) who conducted experiments on the salinity tolerance of *G. salaris*, found that in 7,5 ‰ salinity the population of *G. salaris* declined and became extinct after a maximum of 56 days, without any significant differences between 6,0 ºC and 12,0 ºC. At higher salinities the survival time decreased.

G. salaris is postulated to be a cold-water adapted parasite (Malmberg 1973, 1988). In laboratory experiments, Jansen and Bakke (1991) found that within the temperature range 6 - 13 ºC, the number of offspring produced by a single parasite was maximal and higher than reported for other *Gyrodactylus* species.

Reproduction and life cycle
Most Gyrodactylids are viviparous, with embryos in utero already containing a further developing embryo. The cytological details by which this occurs are unclear, but there is evidence that at least the first-born daughter develop without cross- or self-fertilization. On a later stage in the life-cycle, the worms develop male sexual organs, allowing for cross-fertilization. Gyrodactylids have no specific transmission stage; the viviparous worms give birth to fully grown adults, which during the birth process attach to the same host as the parent and only subsequently may transfer to a new host (a thorough description of G. salaris reproductive biology is given in Harris *et al.* 1994).

Dispersal and spread
Based on experiences from several rivers, Johnsen and Jensen (1988) suggested that *G. salaris* has very rapid powers of dispersal in a new host population.

Bakke *et al*. (1992) proposed four routes by which *G. salaris* could transfer to new hosts within a river: (i) via contact with live hosts, (ii) via dead hosts, (iii) by detached parasites drifting in the water column, and (iv) by parasites attached to the substrate. The relative importance of the four different transmission routes has not been quantified, although he most common is traditionally assumed to be through contact between living hosts.In spite of very low densities of salmon parr, the prevalence and intensity were still very high in both 0+, 1+ and in the few 2+ Atlantic salmon found in the river Lakselva. This is in contrast to classic parasite theory which would predict that parasite infection levels should have fallen because of low density of hosts and the drop in transmission rates (Johnsen and Jensen 1992).

Between rivers spreading may take place with fish migrating in brackish water as pointed out regarding the rivers in the Romsdalsfjord (Johnsen and Jensen 1991). During low salinity conditions such spread may take place over long distances.

Stocking of fish from infected hatcheries has, however, been the most important factor causing spread of *G. salaris* in Norway. The parasite was also probably introduced to the river Keret on the White Sea coast of Russia together with stocked fish (Johnsen *et al.* 1999b). Also, in the Swedish west coast rivers there seems to be a connection between occurrence of *G. salaris* and stockings of fish (Ingemar Alenäs pers. comm.).

Although never documented, *G. salaris* can in theory also be spread between localities with any equipment that has been in contact with water or fish. According to Olstad *et al*. (2006), the parasite detached from a host can survive for up to 60 hours, provided low temperatures (60, 45, and 27 hours at 3, 12, and 18 ºC, respectively). Accordingly, the OIE, Manual of Diagnostic Tests for Aquatic Animals, Gyrodactylosis states: "*The general recommended husbandry practices for avoiding the spread of infective agents between units in freshwater fish farms apply to* G. salaris. *Equipment (e.g. fish nets) used in one unit should not be used in another without adequate disinfection*."

Impact

Affected habitats and indigenous organisms
Gyrodactylid monogeneans are widespread parasites of freshwater and marine fishes. The disease resulting from *Gyrodactylus*-infections, gyrodactylosis, has been reported to be responsible for losses in a wide variety of captive fish species (Cone and Odense 1984). Little is known about the disease Gyrodactylosis and the cause of death in infected individuals. Secondary infections in wounds from attachment and feeding is assumed to be important. For example are infections with the

pseudofungus *Saprolegnia* sp. occasionally associated with *G. salaris*-induced mortality in salmon parr. Another assumed cause of death is osmoregulatory problems (Pettersen *et al*. 2012). Whatever the pathogenic mechanisms involved in gyrodactylosis may be, host mortality is probably some function of parasite burden (Anderson and Gordon 1982, Scott and Anderson 1984). There are few reports of overt disease in natural host populations. This is also the case with *G. salaris*, which within its native range cause little or no harm to its host, the Baltic salmon.

In Norway, *G. salaris* has caused epidemics that have devastated stocks of Atlantic salmon in many rivers (Johnsen 1978, Heggberget and Johnsen, 1982, Johnsen and Jensen 1986, 1988, 1991, 1992). The density of salmon parr in infected rivers has been reduced on an average of 86 % and the catch of salmon in infected rivers are reduced on an average of 87 % (Johnsen *et al.* 1999a).

The *Gyrodactylus* infection in the river Keret on the White Sea Coast has an epidemic character and the density of salmon parr was reduced dramatically and was very low in the period 1992-1998 compared to the years 1990 and 1991 (Johnsen *et al.* 1999b).

In Sweden, the effect of *G. salaris* on salmon populations on the west coast has been debated. Survival of salmon parr in the river Högvadsån, which is a part of the river Ätran, was studied by Alenäs *et al.* (1998). Survival decreased steadily, and the average density of salmon parr was reduced with about 90 %. However, other factors such as low numbers of spawners and low summer discharges in the river did probably have a major negative influence on parr production in the 1990's (Karlsson *et al* 2003a). Degerman *et al*. (2012) also described a general decrease in the west coast populations since the late 1980s. With a lack of difference in this trend between rivers with and without the parasite, they concluded that *G. salaris* did not have any significant negative impact on the salmon populations along the Swedish west coast. Infection experiments were carried out in 2002 with *G. salaris* originating from infected west coast salmon and from rainbow trout. The results showed that the stocks differed in sensitivity to the parasite. Furthermore there were indications that local conditions could influence the sensitivity to parasites, as fish tested in Oslo seemed to have a higher sensitivity to the parasite than those tested at a Swedish field station along the river Enningdalsälven (Karlsson *et al.* 2003a).

The Danish salmon stocks are as susceptible to the Norwegian form of *G. salaris* as the Scottish salmon (Dalgaard *et al.* 2004). This work raises concern for the old Danish salmon strains if the Norwegian or Swedish form of *G. salaris* should be introduced. The Danish form does not seem to represent a problem.

An indirect effect of *G. salaris* may be the negative effect upon the freshwater pearl mussel *Margaritifera margaritifera* caused by reductions in salmon parr populations. This may cause reductions in the population of the freshwater pearl mussel because the larvae (glochidiae) of the pearl mussel are dependent on Atlantic salmon parr in a certain stage of their life. Studies have revealed that freshwater pearl mussel larvae in many water courses have an obligatory period either in the gills of salmon or trout (Larsen *et al.* 2002).

Genetic effects

In Norway extremely high proportions of hybrids between Atlantic salmon and brown trout have recently been detected in rivers Vefsna and Driva. The salmon populations in both rivers have been infected by *G. salaris* since the 1970's. Reasons for the remarkable hybridization rates are probably the dramatically reduced wild salmon stocks and a high frequency of non-native (farmed) salmon. Increased hybridization may cause vulnerable populations to become even less viable and may increase the likelihood of rare events such as backcrosses to one or other parental species and introgression of genes from one species to another. Triploid backcrosses have been identified in both rivers (Johnsen *et al.* 2005).

Human health effects
No direct human health effects are known.

Economic and societal effects (positive/negative)
In Norway the catch of salmon in infected rivers is reduced on an average of 87 %. Total yearly loss in the river fishery caused by *G. salaris* is estimated to about 45 tons. Without any measures the *G. salaris* attacks would have reduced the Norwegian salmon fishery by a minimum of 15 % (Johnsen *et al.* 1999b). The economic value of the Norwegian salmon fishery in rivers is estimated to about 125 million Euros. Very simplified, the loss due to *G. salaris* may be calculated to an amount in the region of 20 million Euros.

Social effects occur specially in the area of large salmon rivers with *G. salaris* due to loss of income and lost recreational fishery opportunities as the salmon population is reduced to a very low level.

Management approaches

Prevention methods
Management approaches differs between different countries. In the native area of *G. salaris* (Karelian part of Russia and the Baltic part of Finland and Sweden) no special management approaches have been taken since the parasite is not considered to be a problem.

In Denmark there is concern for the old Danish salmon strains if the Norwegian or Swedish form of *G. salaris* will be introduced. Import restrictions should therefore be discussed in order to prevent the pathogenic form to enter Denmark.

G. salaris is a notifiable disease in Norway and surveillance of the parasite has been performed since the late 1970s. The main goal of the Norwegian freshwater fish authorities is to eradicate the parasite from all infected rivers and fish farms.

In Sweden management of *G. salaris* was for a long period dominated by the situation in the Baltic, where only few cases of negative impact of the parasite have been described (Malmberg and Malmberg 1991, Rintamäki and Valtonen 1996). In the last few years this situation has changed to some extent and infection with *G. salaris* became a notified disease in Sweden in 2002. There are also since a number of years regulations concerning release of fish in non-infected wild salmon rivers at the west coast. In order to prevent further spreading of the parasite it is important to increase the awareness among fishermen and fish farmers that makes accidental transfer of the parasite unlikely (Karlsson *et al*. 2003b, Degerman *et al*. 2012)

In general it is very important not to import salmonid fish from the native area of *G. salaris* (the Baltic Sea area) to the distribution area of the East Atlantic salmon. U.K., Ireland and rivers Tana (Finnish Teno) and Neiden (Finnish Näätämö) watersheds in Finland has been given status of approved zone, free from the parasite, by the European commission in year 2004. This means that imports of live fish for aquaculture purposes in these areas not can be done without fulfilling strict conditions.

Eradication, control and monitoring efforts
In Norway, measures in hatcheries and fish farms have proved to be effective in exterminating *G. salaris*. Measures like construction of migration barriers and rotenone treatment have proven effective in infected rivers. By early 2013, 33 of the 48 rivers with infection had been treated with rotenone. Among these, 20 have been declared free of the parasite. The remaining 13 were treated within the last 5 years and has not to date been officially declared free. In later years treatments with acid aluminium to kill the parasite, but not the host, have proven to be successful in laboratory experiments (Poleo *et al.* 2004). A combination of acid aluminium and rotenone was tested in River Lærdalselva in 2011 and 2012 in an attempt to get rid of the parasite without killing the hosts. It is yet too early to state whether these treatments were successful.

In the infected river Keret of Russia which drains to the White Sea, building of a barrier close to the outlet have been suggested and discussed. So far no measures have been taken.

Information and awareness
The Directorate for Nature Management in Norway has produced posters to spread out along rivers and several folders to distribute among fishermen and others. In these publications information about *G. salaris* has been given.

The authorities in Finland have also produced information material to prevent spread of the parasite across the border from Finland to Norway and over the Baltic- Atlantic (Barents) watershed. The Swedish Board of Fisheries has produced posters and pamphlets now being spread on the Swedish west coast and areas neighbouring Finland and Norway.

Knowledge and research
Since the 1980s numerous studies have been conducted on a wide variety of problems concerning *G. salaris* in Denmark, Finland, Russia, Sweden and Norway. Many of the publications from this work are referred to in this Fact Sheet and a comprehensive list of references is given. In addition to cited references from the present text, the list also includes a number of related references to suggested further reading. A thorough scientific review on the biology of *G. salaris* was provided by Bakke *et al*. (2007).

Recommendations or comments from experts and local communities
None.

References and other resources

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Links

Aquatic Animal Pathogen and Quarantine Information System - AAPQIS
OIE, Manual of Diagnostic Tests for Aquatic Animals

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