

REVIEW

Pseudodactylogyrus infections in eel: a review

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ABSTRACT: Infections with monogeneans *Pseudodactylogyrus* spp. cause problems in commercial eel production. A detailed review is presented on the geographic origin and biology of the parasites. Different views regarding the origin are discussed. Various treatments of pseudodactylogyrosis are presented, and their applicability under intensive eel culture conditions is discussed.

INTRODUCTION

In recent years, production of eel *Anguilla anguilla* (L.) in aquaculture has become a rapidly expanding industry in Denmark. Production takes place in recirculation systems at temperatures between 20 and 25°C with a daily water exchange of 5 to 20 %. Under such intensive aquaculture conditions disease problems will inevitably occur. Of these, gill infections with monogeneans *Pseudodactylogyrus* spp. seem to be the predominant problem.

The monogeneans are introduced to the production units with the elvers, which are the basis of commercial eel production. The parasites are able to live and reproduce rapidly under the conditions described. As a number of European countries intend to develop eel production under similar conditions as in Denmark, *Pseudodactylogyrus* infections must also be expected to be one of the main problems there.

This review summarizes and evaluates our present knowledge on origin, distribution, morphology and life cycle of *Pseudodactylogyrus* spp. It also describes the treatment and symptoms of pseudodactylogyrosis based on the available literature and own observations by the reviewers.

ORIGIN AND DISTRIBUTION

In 1929 Kikuchi described *Dactylogyrus bini* on the gills of *Anguilla japonica* originating from Japan. Kikuchi also mentioned another form of the parasite on the gills of the same host with larger hooks (hamuli) on the opisthaptor than were seen in *D. bini*. Yin & Sproston (1948) found the same 2 dactylogyrids on the gills of *A. japonica* from China. They transferred *D. bini* to the genus *Neodactylogyrus* Price 1938. The other form mentioned by Kikuchi (1929) was described as *N. anguillae*.

Gussev (1965) studied these species, found on *Anguilla reinhardtii* from Australia, and erected the genus *Pseudodactylogyrus*. The names of the 2 dactylogyrids are thus *P. bini* (Kikuchi 1929) Gussev 1965, and *P. anguillae* (Yin et Sproston 1948) Gussev 1965. Both these species were recorded on cultured *A. anguilla* in Japan (Ogawa & Egusa 1976, Imada & Muroga 1977). An additional, new species – *P. microrchis* – was reported by Ogawa & Egusa (1976). However, it was later found to be synonymous with *P. anguillae* (Ogawa et al. 1985). *P. bini* and *P. anguillae* were reported on *A. japonica* from Taiwan (Chung et al. (1984) and from China (Chan & Wu 1984).

In Europe *Pseudodactylogyrus bini* and *P. anguillae* were first reported from an eel production plant in the Kalinin region in the western Soviet Union by Golovin (1977), and it was assumed that both species were introduced with *Anguilla japonica* and spread to *A. anguilla*. Molnár (1983, 1984) reported *P. bini* and *P. anguillae* on *A. anguilla* from Hungarian eel farms, and Molnár (1984) stated that pigmented eels caught along the West European coastlines were infected to a great extent by *Pseudodactylogyrus* spp. Molnár (1983) also noted that infections with *Pseudodactylogyrus* spp. had not been reported from elvers originating from West European estuaries and imported to Hungary before 1983.

The presence of *Pseudodactylogyrus anguillae* on *Anguilla anguilla* from rivers in southeastern France was reported by Lambert et al. (1984) and Le Brun et al. (1986). Saroglia et al. (1985) reported *Dactylogyrus* spp. from cultured eels in Italy. However, a more detailed study will probably classify these dactylogyrids as *Pseudodactylogyrus* spp.

Both *Pseudodactylogyrus* and *P. anguillae* were reported from *Anguilla anguilla* in Danish eel farms (Møllergaard & Dalsgaard 1986); *P. anguillae* was the most prevalent. In Denmark, both *P. anguillae* and *P. bini* have been observed on wild *A. anguilla* from a lake in North Zealand, and *P. anguillae* has been found on elvers from the Øresund and on wild eels caught in a stream on the island of Bornholm in the Baltic Sea.

Chung et al. (1984) allege that *Pseudodactylogyrus* spp. originated from Europe and was introduced to Japan since 1969. However, this assumption is questionable, since *P. bini* was reported from Japan as early as 1929 by Kikuchi, and *P. bini* and *P. anguillae* were found in China (Yin & Sproston 1948) and in Australia (Gussev 1965). Furthermore, the parasites were first reported in Europe in 1977 (Golovin 1977). Therefore, the original area of distribution of *P. bini* and *P. anguillae* is probably the Pacific Ocean.

It is unknown where and when the *Pseudodactylogyrus* spp. were introduced into Europe. Possibly, the parasites first entered the Soviet Union via import of infected *Anguilla japonica* (Golovin 1977). Another possibility would be an import of *A. australis* from New Zealand to Italy in 1975 (Welcome 1981) as suggested by Molnár (1984). However, Hine (1978) examined a substantial number of *A. australis* and *A. dieffenbachii* from New Zealand without finding any *Pseudodactylogyrus* spp.

The introduction of the parasites into Denmark was most probably associated with import of elvers from France or perhaps the United Kingdom, although the parasites have not yet been reported from the latter. A spread by natural migration of infected eels from western Europe to Denmark cannot be excluded, since

adult *Pseudodactylogyrus bini* and *P. anguillae* can survive salinities of 1 to 2 ‰ for more than 9 d (Imada & Muroga 1979, Chan & Wu 1984).

MORPHOLOGY

Eggs

Egg morphology was studied by Golovin & Shukhgalter (1979) and Chan & Wu (1984); the eggs of both species were found to be oval (Fig. 1) with a 7 to 14 µm long pedicule having a distal extension with an adhesive function. Egg dimensions are shown in Table 1.

Oncomiracidia

Chan & Wu (1984) found oncomiracidia of *Pseudodactylogyrus bini* to possess 2 pairs of eye spots, a spherical pharynx, 14 marginal hooks, 4 ciliated areas and the anlage of the 2 hamuli. Similar structures were found in *P. anguillae* oncomiracidia (Golovin & Shukhgalter 1979, Le Brun et al. 1986). Dimensions of oncomiracidia are listed in Table 1.

Adults

Generally, *Pseudodactylogyrus bini* is longer than *P. anguillae* (Ogawa & Egusa 1976, Chung et al. 1984). Maximum length of *P. anguillae* in fixed condition is 1659 µm; that of *P. bini*, 1960 µm (Chung et al. 1984). Maximum width of *P. anguillae* is 364 µm; that of *P. bini*, 336 µm (Chung et al. 1984); minimum width is 138 µm for *P. anguillae* and 120 µm for *P. bini* (Ogawa & Egusa 1976).

Gussev (1965) stressed, in the description of the genus *Pseudodactylogyrus*, that the haptor and the 2 hamuli were directed ventrally instead of dorsally as is the case in the genus *Dactylogyrus* (see also Fig. 3 & 5). The genus *Dactylogyrus* possesses 2 prostatic reservoirs; Only one was present in *Pseudodactylogyrus*. No additional tendon ligament ('additional hooks') exists in *Pseudodactylogyrus* (Ogawa & Egusa 1976, Ogawa 1986). These structures, found in dactylogyrids, should be considered as vestigial ventral hamuli (Llewellyn 1968).

Size and shape of the hamuli are the characteristics on which a taxonomic separation of the 2 species can be based. The hamuli of *Pseudodactylogyrus bini* are shorter and more stout than those of *P. anguillae* (Fig. 2) (Ogawa & Egusa 1976, Chung et al. 1984, Ogawa et al. 1985). Thus Ogawa et al. indicated in a key to the genus *Pseudodactylogyrus* that the hamuli of *P. bini*

Table 1. *Pseudodactylogyus bini* and *P. anguillae*. Dimensions of eggs and oncomiracidia

Author	<i>P. bini</i>		<i>P. anguillae</i>	
	Eggs	Oncomiracidia	Eggs	Oncomiracidia
Golovin & Shukhgalter (1979)	-*	-	60–80 × 50–60 μm	160 × 50 μm
Chan & Wu (1984)	56–112 × 49–63 μm	161–193 × 42– 70 μm	-	-

* No information available

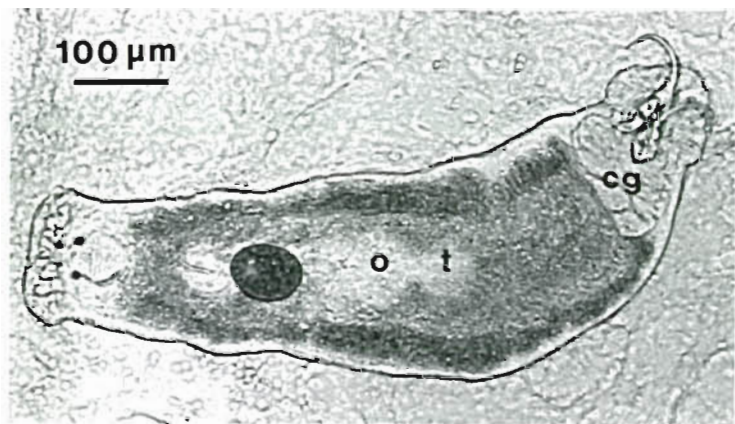


Fig. 1. *Pseudodactylogyus anguillae*. Flattened live parasite containing an egg. o: ovary; t: testis; cg: cement glands

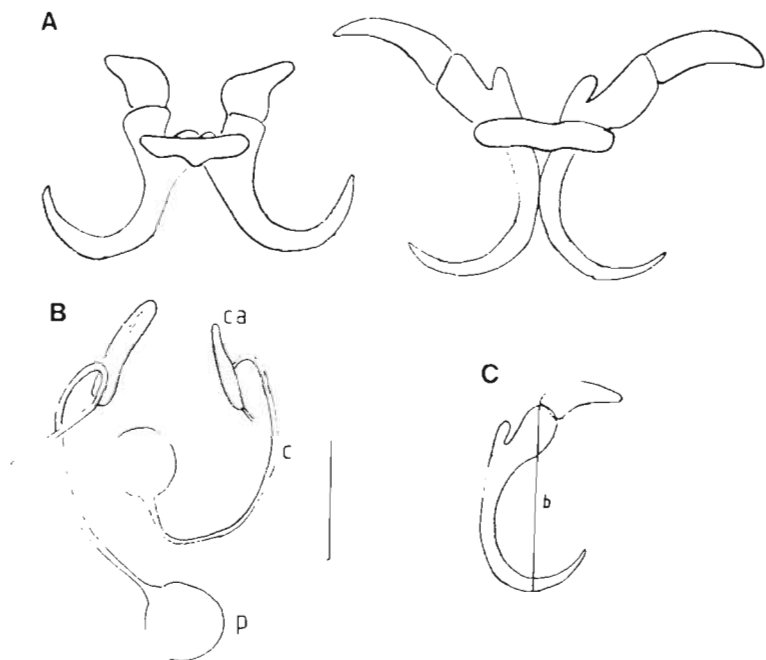


Fig. 2. *Pseudodactylogyus*. (A) Hamuli of *P. bini* (left) and *P. anguillae* (right); bar = 50 μm. (B) Copulatory organs of *P. bini* (left) and *P. anguillae* (right); c: cirrus; ca: accessory cirrus; p: prostatic reservoir; bar = 50 μm (C) Hamulus showing distance 'b' used for species differentiation

were up to 70 μm (measured as 'b' in Fig. 2c). They were at least 80 μm long in *P. anguillae*. Similarly, the length of the bar connecting the hamuli was generally longer in *P. anguillae* than in *P. bini* although a certain overlap existed (Gussev 1965, Ogawa & Egusa 1976, Molnár 1983, Chung et al. 1984). Specimens of *P.*

anguillae and *P. bini* are illustrated in Fig. 3 to 5. According to Chung et al. (1984) the ovary of *Pseudodactylogyrus bini* was always smaller than the testis while the ovary-testis ratio in *P. anguillae* was variable. Ogawa et al. (1985) indicated that the cement gland in the posterior body of *P. bini* was long, but short in *P. anguillae*. For further specifications on different structures and organs see Gussev (1965), Ogawa & Egusa (1976), Molnár (1983), Chan & Wu (1984), Chung et al. (1984), Ogawa et al. (1985) and Le Brun et al. (1986). However, species differentiation should be based on sclerotized structures because different treatments during preparation of the parasites can affect the size of unsclerotized structures.

LIFE CYCLE

Egg release rate

Egg release rate of adult *Pseudodactylogyrus anguillae* is temperature dependent. At 10 °C an average of 1.2 eggs were released per specimen per day; at 20 °C 9.6 (range 4.9. to 19.0); and at 28 °C, 7.7 (range 3.0 to 9.8) (Imada & Muroga 1978). Comparable information for *P. bini* is not available.

Hatching time

Hatching time for the eggs also depends on temperature (Table 2). Eggs did not develop at low temperatures; however, they were not damaged. Chan & Wu (1984) observed that *Pseudodactylogyrus bini* eggs, kept at 5 °C for 10 d without development, continued to develop and hatched (75.5%) after transfer to room temperature (19 to 26 °C). Minor divergences between authors (Table 2) may be attributed to differences in experimental conditions. Thus eel mucus was found to be necessary for hatching of *P. bini* eggs (Chan & Wu 1984), and hatching time was increased at pH values below 4 and above 9.5 (Golovin & Shukhgalter 1979).

Oncomiracidia

According to Chan & Wu (1984) the oncomiracidium of *Pseudodactylogyrus bini* displayed very fast swimming movements, both in straight and curved lines for 30 min at 19 to 26 °C. Then the oncomiracidium attempted to attach itself on the glass, for 3 to 4 h., while stretching and contracting. The oncomiracidia died after 5 to 6 h. The life span of *P. anguillae* oncomiracidia was found to be 3 to 5 h at 20 to 22 °C

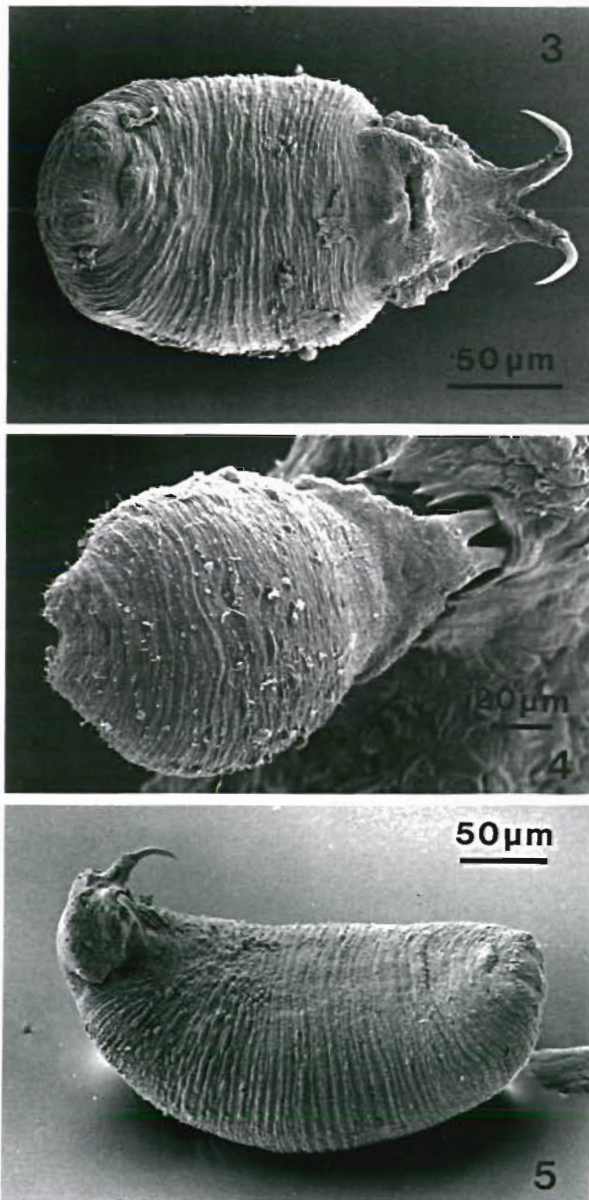


Fig. 3 to 5. *Pseudodactylogyrus*. SEM micrographs. All specimens were fixed for 2 to 3 h in 2.5% glutaraldehyde buffered with cacodylate (pH 7.4), washed in buffer; and postfixed for 1 to 2 h in cacodylate-buffered osmium tetroxide, dehydrated in ethanol and benzene. Mounted specimens were coated with gold and examined in a Joel 840 scanning electron microscope. Fig. 3. Ventral view of *P. anguillae*. Fig. 4. Dorsal view of a young *P. anguillae*; hamuli are deeply inserted in the eel's gill tissue. Fig. 5. Ventrolateral view of *P. bini*

Table 2. *Pseudodactylogyus bini* and *P. anguillae*. Period from oviposition to hatching of eggs at different temperatures

Temperature (°C)	<i>P. bini</i>		<i>P. anguillae</i>		
	Chan & Wu (1984)	Golovin & Shukhgalter (1979)	Imada & Muroga (1978)	Golovin & Shukhgalter (1979)	Le Brun et al. (1986)
5	n h	-*	-	-	-
6-9	-	-	-	n h	-
10	-	-	n h	-	-
14-16	-	-	-	6-8 d	-
20	-	-	5-8 d	-	-
19-26	6-7 d	-	-	-	-
22-23	-	3 d	3 d	3 d	4-6 d
28-30	4-5 d	2-2.5 d	2-5 d	2.5-3 d	-

* No information available; n h = no hatching

(Golovin & Shukhgalter 1979). Following attachment to the host, the oncomiracidia of *P. anguillae* developed to mature parasites in 6 to 7 d at 28 °C (Imada & Muroga 1978) or in 7 to 9 days at 25 to 28 °C (Golovin & Shukhgalter 1979). Comparable data are not available for *P. bini*.

SYMPTOMS

Anguilla anguilla is highly susceptible to *Pseudodactylogyus* infections (Egusa 1979). In moderately to heavily infected eels the skin of the mandibular and gill regions is hyperaemic. Extensive hyperaemia occurred on the gills. The parasites were widely distributed over the gill filaments, but aggregations of parasites were often seen on the filaments towards the bend of the gill arch. This was observed both in *A. japonica* (Chan & Wu 1984) and *A. anguilla* (own observation).

Infection results in increased mucus secretion and destruction of gill structures (Chan & Wu 1984). The hamuli can perforate the gill tissue (Fig. 4) and reach the gill cartilage. Severe haemorrhages and extensive

hyperplasia of the gill epithelium were seen, and in some cases the haptor was embedded in the gill tissue (Chan & Wu 1984).

TREATMENT

Potassium permanganate

Chan & Wu (1984) recorded that a bath treatment of *Anguilla japonica* with 20 ppm potassium permanganate for 20 min at 22 °C reduced the intensity of infection (no. of parasites per eel) of *Pseudodactylogyus* by 50.6%. The eels were not affected by the treatment.

Sodium chloride

Long-term treatment with sodium chloride was found to reduce the intensity of infection (Table 3). Five-minute treatments with 4% sodium chloride reduced the intensity of infection, but caused mucus sloughing (Chan & Wu 1984).

Table 3. *Pseudodactylogyus* spp. Influence of treatment with various concentrations of sodium chloride on mean intensity of infection (no. of parasites per eel) in *Anguilla anguilla* and *A. japonica*

Author	Host species	Parasite species	Temp. (°C)	Exposure time	Concentration of sodium chloride:							
					1%		1.5%		2%		4%	
					Before	After	Before	After	Before	After	Before	After
Imada & Muroga (1979)	<i>A. anguilla</i>	<i>P. anguillae</i>	25.5-28	9 d	39	< 20	39	< 20	39	< 20	39	< 20
Chan & Wu (1984)	<i>A. japonica</i>	<i>Pseudodactylogyus</i> spp.	19	10 d	-*	-	-	-	55.8	22	-	-
			22	9 d	76.9	23.9	-	-	-	-	-	-
			22	5 min	-	-	-	-	-	-	76.9	18.3

* No information available

Ammonia

Golovin & Shukhgalter (1979) recorded a reduction of parasitization impact after treatment with 0.2% ammonia for 1 min. According to Chan & Wu (1984), treatment with 0.05% ammonia for 8 min at 24 °C (pH 6 to 7) reduced the infection intensity by 41%, but the eels showed increased respiratory activity and the mucus was sloughed during the treatment. Paralysis and mortality was observed among eels when treated with 0.1% ammonia (pH 6 to 7) for 5 min.

Formaldehyde

Formaldehyde treatment was used by Imada & Muroga (1979) and Chan & Wu (1984). It reduced the parasite burden markedly, although the parasites were never totally eliminated (Table 4).

In Denmark, formaldehyde is the only substance

used for treatment of pseudodactylogyrosis. Before introduction into the eel farm, elvers are treated for 30 min in 300 ppm formaldehyde; this, however, rarely eliminates all parasites. In the production unit infected eels are treated with formaldehyde (60 ppm 4 times at intervals of 2 or 3 d; at infection levels of 75 to 150 parasites per eel).

Trichlorfon (Metrifonate)

Trichlorfon treatment eliminated all parasites from eels under experimental conditions when used over several consecutive days (0.27 to 1.0 ppm) or in the form of repeated treatments at 2 to 3 d intervals (Table 5) (Imada & Muroga 1979, Chan & Wu 1984). However, these observations could not be confirmed in Danish experiments. Treatment with 1 ppm trichlorfon for 24 h (30 °C) did not affect the parasites. Exposure up to 5 ppm trichlorfon for 4 d did not reduce the parasite

Table 4. *Pseudodactylogyrus* spp. Influence of treatment with various concentrations of formaldehyde on intensity of infection in eels

Author	Host species	Parasite species	Temp. (°C)	Exposure time	Concentration ppm	Intensity of infection	
						Before	After
Imada & Muroga (1979)	<i>A. anguilla</i>	<i>P. anguillae</i>	25.5-28	1 × 24 h	30	79	45
				2 × 24 h	30	79	82
				1 × 24 h	100	79	25
				2 × 24 h (11 d)	100	79	2
Chan & Wu (1984)	<i>A. japonica</i>	<i>Pseudodactylogyrus</i> spp.	22	2 × 24 h (4 d)	100	76.9	38.0

Table 5. *Pseudodactylogyrus* spp. Influence of treatment with various concentrations of trichlorfon (metrifonate) on intensity of infection in eels

Author	Host species	Parasite species	Temp. (°C)	Exposure time	Concentration of trichlorfon:					
					0.27 ppm		0.45-0.5 ppm		0.9-1.0 ppm	
					Before	After	Before	After	Before	After
Imada & Muroga (1979)	<i>A. anguilla</i>	<i>P. anguillae</i>	25.5-28	1 × 24 h	-*	-	79	9	79	5
				2 × 24 h (1 d interval)	-	-	193	4	-	-
				2 × 24 h (3 d interval)	-	-	193	0	-	-
				7 d	-	-	39	0	39	0
Chan & Wu (1984)	<i>A. japonica</i>	<i>Pseudodactylogyrus</i> spp.	19 24	2 × 24 h (2 d interval)	-	-	-	-	55.8	0
				9 d	-	-	55.8	0	-	-
				9 d	204	0	-	-	-	-

* No information available

burden, but the eels developed spasms. This drug concentration seems to be near the tolerance limit of the eels. The reasons for such contradictory results are not clear; it cannot be excluded that the parasite population in Europe is resistant to this substance. Goven et al. (1980), for example, reported *Gyrodactylus elegans* to be resistant to the drug.

CONCLUSIONS

Pseudodactylogyrus anguillae and *P. bini* are examples of parasites that were introduced into new habitats by transporting fish between different parts of the world for aquaculture purposes. These monogeneans spread to most European countries and are now causing severe problems in eel farms.

Experiments conducted in the far east showed that trichlorfon can eradicate *Pseudodactylogyrus* parasitizing eels. However, results obtained in Denmark cannot confirm these observations.

Treatments with potassium permanganate, sodium chloride, ammonia and formaldehyde could only reduce the intensity of infection by these monogeneans; total parasite elimination was never seen.

Intensified research is needed in order to develop new and better control methods for this helminthosis. Effective control measures are essential for optimizing operation conditions in the growing industry of eel production in recirculation systems in Europe.

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