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Research Article

ANGUILLICOLA CRASSUS - AN ALIEN NEMATODE SPECIES FROM THE SWIM BLADDERS OF EEL (*ANGUILLA ANGUILLA*) IN THE POLISH ZONE OF THE SOUTHERN BALTIC AND IN THE WATERS OF NORTHERN POLAND

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Abstract

The dispersal and distribution of the alien nematode *Anguillicola crassus* parasitizing the European eel (*Anguilla anguilla*) in the southern Baltic and in waters of northern Poland is analyzed. The parasite's presence in eel was first recorded in 1988 in the Vistula Lagoon when the prevalence of infection and intensity ranges were 63.3-75% and 1-25 parasites per infected eel, respectively. In 2000-2002, as many as 73.6-76.2% of the eel were affected at an intensity range of 1-53 parasites. In addition to the Vistula Lagoon, *A. crassus* was recorded in the Szczecin Lagoon, the Gulf of Gdańsk, and the Puck Bay as well as in lakes Drużno, Łebsko, Przywłoka, Skąpe, Wielewickie, Miedwie, Ińsko, Łętowskie, Niegocin, Mamry Północne, Strażyn, Raduńskie, and a lake in the village of Gaj as well as in the rivers Rega, Radew, Wieprza, and Dead Vistula. The prevalence of infection was reported to be between 26.4% and 100%. It can be assumed that the colonization of the eel by *A. crassus* and the parasite's dispersal in European waters, including Poland, will increase.

Taxonomy and origin

Parasitic nematodes of the genus *Anguillicola* are represented by the following five species: *Anguillicola globiceps* Yamaguti, 1935 parasitizing *Anguilla japonica* in Japan and China; *Anguillicola australiensis* Johnston et Mawson, 1940 from *Anguilla reinhardtii* in southern Australia; *Anguillicola crassus* Kuwahara, Niimi et Itagaki, 1974 from *Anguilla japonica* in east Asia and from *Anguilla anguilla* in Europe; *Anguillicola novaezelandiae* Moravec et Taraschewski, 1988 from *Anguilla australis* and probably *Anguilla diffenbachii* in New Zealand and Australia and from *Anguilla anguilla* in Italy; and *Anguillicola papernai* Moravec et Taraschewski, 1988 from *Anguilla mossambica* in the Republic of South Africa (Moravec and Taraschewski 1988, Moravec 1994).

Table 1

First published records of the presence of *Anguillicola crassus* in various European countries.

Country	First published report
Austria	Konecny and Wais (1993)
Belgium	Balpaire et al. (1989)
Belarus	Bauer (1998)
Czech Republic	Moravec (1992)
Denmark	Koie (1988)
Estonia	Kangur et al. (1994)
France	Dupont and Petter (1988)
Germany	Neumann (1985)
Greece	Balpaire et al. (1989
Hungary	Szekely et al. (1991)
Ireland	Evans and Matthews (1999)
Latvia	Vismanis et al. (1999)
Italy	Canesti-Trotti (1987)
Macedonia	Cakic et al. 2002
Netherlands	Van Banning et al. (1985)
Norway	Mo and Stein (1994)
Poland	Własow et al. (1991)
Portugal	Cruz et al. (1992)
Russia	Zaostrovceva (1993)
Spain	Belpaire et al. (1989)
Sweden	Hellström et al. (1988)
United Kingdom	Kennedy and Fitch (1990)
Yugoslavia	after Höglung and Thomas (1992)

Anguillicola crassus was accidentally introduced to Europe (northern Germany) in 1982, most probably with imported infested Japanese eel from a culture in Taiwan (Neumann 1985, Koops and Hartmann 1989, Koie 1991). Subsequently, the species spread very rapidly by attacking cultured and wild eel populations. At present, *A. crassus* occurs in almost all European countries (Table 1), in north Africa in Egypt (Koops and Hartmann 1989), Marocco (El

Hilali *et al*. 1996), and Tuniesia (Maamouri *et al*. 1999), in the American eel in the United States (Fries *et al*. 1996, Barse and Secor 1999), and in Taiwan (Ooi *et al*. 1996).

In addition, *Anguillicola novazelandiae*, initially identified as *A. australiensis*, has been recorded locally in Europe. Its presence was first reported in Lake Bracciano in Italy where it was introduced in 1975 with *Anguilla australis* (Paggi *et al*. 1982, Moravec and Taraschewski 1988). The presence of the nematode was confirmed in subsequent studies carried out in 1988-1993 (Moravec *et al*. 1994).

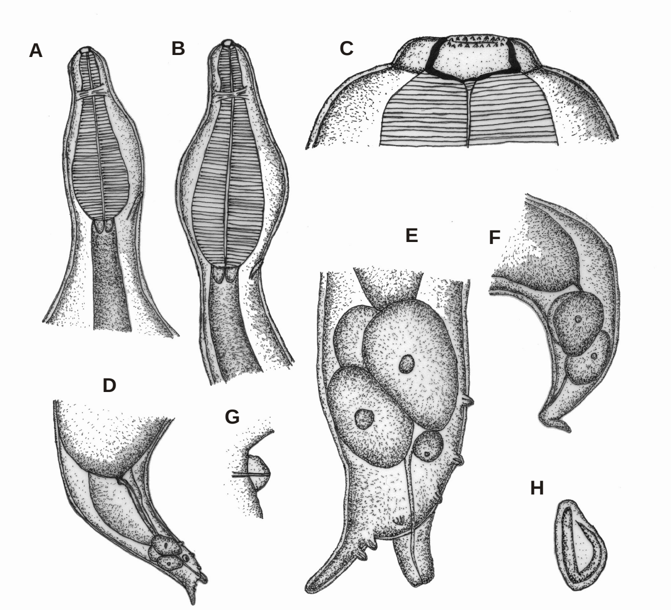

Fig. 1. *Anguillicola crassus* Kuwahara, Niimi et Itagaki, 1974. A, B – head end of male and female, C – buccal capsule of female, D – posterior end of male, E – tail of male, F – caudal end of female, G – vulva, H – larva from uterus. (After Moravec and Taraschewski 1988 and Moravec 1994).

Morphology (after Moravec and Taraschewski 1988 and Moravec 1994), biology, and life cycle

The *Anguillicola crassus* body is fusiform, usually plump, and tapers at both ends. The buccal capsule is well sclerotized, and has one row of 21-28 circumoral teeth. As the nematode feeds on blood, the body has a dark brown coloration (Fig. 1).

Adult females measure 13.08-44.74 mm in length and 1.22-5.0 mm in maximum width. The buccal capsule measures 0.024-0.027 mm in length and 0.054-0.063 mm in width. The esophagus is 0.775-1.09 mm long, with a maximum width of 0.204-0.381 mm. The esophagus length to total body length ratio is 1:15-40. The nerve ring is located 0.258-0.299 mm from the anterior end of the body, and the excretory pore is situated 0.857-1.142 mm away from it. The prominent vulva is conical and located 3.40-7.01 mm from the posterior end of the body. Most of the body is occupied by the uterus filled with eggs containing developing embryos as well as fully developed and molting larvae measuring 0.244-0.258 mm in length and 0.015 mm in width. The conical tail measures 0.136-0.448 mm.

Males measure 5.77-23.12 mm in length and 0.340-1.77 mm in maximum width. The male buccal capsule length and maximum width ranges are 0.021-0.027 and 0.048-0.063 mm, respectively. The esophagus length and maximum width are 0.571-0.843 and 0.135-0.258 mm, respectively. The esophagus length to body length ratio is 1: 9-29. The nerve ring is 0.210-0.286 mm from the anterior end of the body, and the excretory pore is located 0.694-0.924 mm from it. The cloacal duct opens onto a prominent process that is 0.048-0.090 mm long. There are six pairs of caudal papillae - two to three of which are preanal, one adanal, and two to three postanal. The conical tail measures 0.109-0.286 mm.

Females are ovoviviparous and expel eggs containing stage II larvae which, via the pneumatic duct and intestine, exit to the external medium - water. A single female is able to produce up to 150,000 eggs (Thomas and Ollevier 1993). The life span of the free-living larvae depends on salinity and temperature. At 30, 21, and 4ºC the larvae survive for 15, 23, and 42 days, respectively (De Charleroy *et al*. 1987). When swallowed by an intermediate host (mainly a cyclopoid copepod, more seldom an ostracod or an amphipod), the stage II larvae move to the haemocoel where, after 10-12 days at 21 ºC (De Charleroy *et al*. 1990) they molt into a stage III larva, a fish invader. The *A. crassus* life cycle involves paratenic hosts, mainly various small fish which, by feeding on copepods carrying stage III larvae, become infected, but the larvae remain at the same developmental stage. Paratenic hosts are particularly important for large eel that, more often than not, feed on other fish (Fig. 2). Stage III larvae were reported from numerous fish species, *i.e*., carp bream, *Abramis brama*; roach, *Rutilus rutilus*; perch, *Perca fluviatilis*; ruffe, *Gymnocephalus cernuus*; zander, *Sander lucioperca* (*e.g.*, Thomas and Ollevier 1992, Székely 1994, 1995, Rolbiecki 2002, 2003a); ziege, *Pelecus cultratus* (Rolbiecki 2002, 2003a); bleak, *Alburnus alburnus*; asp, *Aspius aspius*; white bream, *Abramis bjoerkna*; gibel carp, *Carassius auratus*; gudgeon, *Gobio* *albipinnatus*; common carp, *Cyprinus carpio*; tench, *Tinca tinca*; pumpkinseed, *Lepomis gibbosus*; pike, *Esox lucius*; European catfish, *Silurus glanis*; river goby, *Neogobius fluviatilis* (*e.g*., Székely 1994, 1995); smelt, *Osmerus eperlanus* (*e.g*., Haenen and van Banning 1990, Rolbiecki 2003b); stickleback, *Gasterosteus aculeatus* (Belpaire *et al*. 1989, Thomas and Ollevier 1992, Rolbiecki 2003c); three-spined stickleback, *Pungitius pungitius* (Rolbiecki 2003c); round goby, *Neogobius melanostomus* (Rolbiecki 2004a); and dab, *Limanda limanda* (Rolbiecki 2004b). The role of paratenic host can also be assumed by amphibians: tadpoles of the frog, *Bombina bombina*, and the newt, *Triturus vulgaris* (Moravec and Skorikova 1998), and even snails, *e.g*., *Galba corvus* (Moravec 1996), or aquatic insects, *e.g*., larvae of the alderfly *Sialis lutaria* (Megaloptera), the dragonflies *Sympetrum sanguineum* and *Coenagrion puella* (Odonata), and the caddisfly *Oligotrichia striati* (Trichoptera) (Moravec and Skorikova 1998).

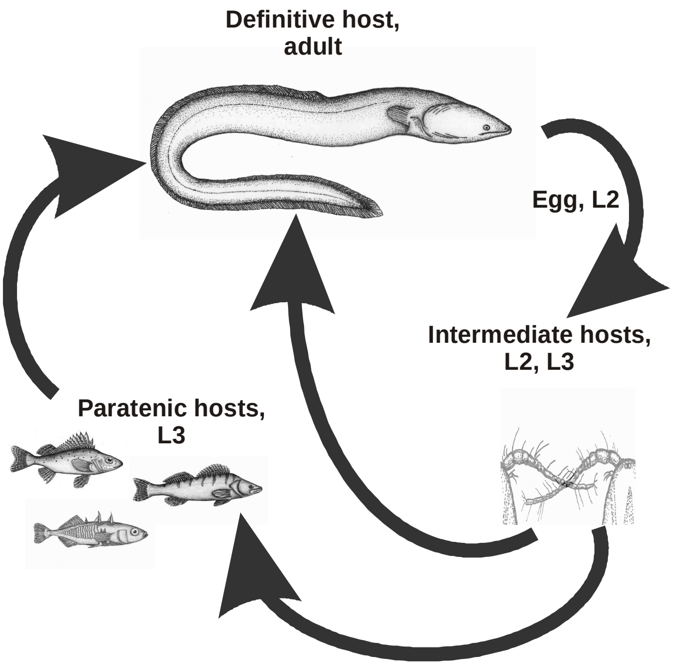

Fig. 2. Life cycle of *Anguillicola crassus*

The role of paratenic hosts in various water bodies can differ depending on the food preferences of the eel. For example, the main *A. crassus* paratenic host in Lake Balaton is bleak (Székely 1994) as it accounts for as much as 93.5% of the eel food (Paulovits and Bíró 1987). Thus, eel become infected either via intermediate or paratenic hosts, the latter increasing the possibility of the parasite life cycle being completed. Stage III larvae move from the definitive host's intestinal lumen through the intestinal walls and the body cavity to the swim bladder where, two to three weeks later, they molt to become stage IV larvae. These larvae feed on the host's blood, molt once again, mature, and begin to reproduce. Under laboratory conditions, at 20˚C, the life cycle is completed in 2 months (De Charleroy *et al*. 1990).

Pathogenicity, clinical symptoms, and anatomopathological changes produced

Anguillicola crassus has proved more dangerous to the European than to the Japanese eel (type host). In Japan, 10-40% of the eel are infected by the nematode. Although it lives in the swim bladder and feeds on blood, the nematode does not harm the host in any substantial manner. As reported by Egusa (1979), the Japanese eel has been evolutionarily immunized to any damage the parasite could induce. On the other hand, the nematode's prevalence in the European eel may be as high as 100%, the infection intensity reaching several tens of nematodes per infected fish, which cannot leave the host's condition unaffected.

Anguillicola crassus causes anguillicolosis. The nematodes feeding within the eel produce acute and chronic inflammations as well as edemas and fibrosis of the swim bladder walls which become opaque and thickened (*e.g.*, Van Banning and Haenen 1990, Molnár *et al*. 1993). Occasionally, the adjacent organs may become fibrotic as well (Van Banning and Haenen 1990). The feeding nematodes mechanically damage the swim bladder epithelium. The epithelial cells become hyperaemic, hypertrophic, hyperplasic, and dysplasic, which frequently results in collapse of the swim bladder (Würtz and Taraschewski 2000). When the swim bladder holds a high number of the nematodes, the fish abdomen is swollen (Kirk *et al*. 2000). Frequently, the eel swim bladder contains a thick, black liquid that resembles blood - a remnant of dead nematodes (*e.g.*, Rolbiecki *et al*. 2000). As the larvae migrate in the swim bladder wall, they damage it and cause hemorrhages. The walls of the intestine and swim bladder often have tumors containing dead larvae and their remains (Molnár 1994). *A. crassus* impairs swim bladder gas secretion. The gas content in a healthy eel's swim bladder is 70% oxygen, about 25% carbon dioxide, with argon and nitrogen as the remaining gases. In fish infested by as few as 10 adult nematodes, the volume of oxygen in the swim bladder is reduced by as much as 60% (Würtz and Taraschewski 2000). In addition, the swimming speed of such fish is reduced by 18% (Kirk 2003), making them easy prey for large predators

Table 2

The occurrence of *Anguillicola crassus* in the eel in the Polish zone of the southern Baltic and northern Poland.

Reservoir	Sampling date	No. of fish examined	Prevalence [%]	Mean intensity [ind.]	Range of intensity [ind.]
Vistula Lagoon					
[Grawiński 1994]	1988	-	75[1]	12[1]	-
[Rolbiecki et al. 1996]	1988-1990	117	63.3	-	1-25
[Własow et al. 1997]	1996	10	100	8.3	1-24
	1997	14	92.9	6.9	1-17
	1997	18	94.4	10.3	1-30
	1997	12	91.7	4.3	1-11
	1997	1[2]	100	2,0	2
[Rokicki et al. 2002]	2000	288	73.6	7.0	1-53
[Bystydzieńska et al. 2003]	2001-2002	488	76.2	7.0	-
Jezioro Druzno					
[Rolbiecki and Rokicki 1997, unpubl.]	1997	16	37.5	7.3	5-16
Jezioro Raduńskie					
[Rolbiecki 2004, unpubl.]	2004	2	100	12	6-18
Dead Vistula					
[Rolbiecki 1996, unpubl]	1996	8	37.5	5.0	3-8
[Rolbiecki 2004, unpubl]	2004	12	58.3	6.0	2-12
Łebsko Lake					
[Morozińska 2004]	2001-2003	60	78	6.2	1-26
Jeziora Przywłoka, Skąpe, Wielewickie					
[Grawiński 1994]	1989	-	about 80	-	-
Lake Miedwie					
[Sobecka and Piasecki 2002]	1997-99	20	100	-	3-44
Lake Ińsko					
[Orecka-Grabda et all. 1994]	1993	84	88.7	-	1-15
[Rząd 1998]	1993-1996	136[3]	88.7	-	1-15
Szczecin Lagoon					
[Rząd 1998]	1993-1996	136[3]	65.0	-	1-35
[Garbacik-Wesołowska and Szkudlarek 1994]	1993	106	26.4	-	0-12
	1994	19	68.4	-	0-11
	1994	16	37.5	-	0-36
[Sobecka 1995]	1993	106	24.5	-	-
	1994	-	68.4		1-29
Pomeranian Bay					
[Garbacik-Wesołowska and Szkudlarek 1994]	1994	10	30.0	-	0-10
Pomeranian rivers:					
Rega	1999-2003	198	59.1	1.7	1-11
Radew	2000-2001	64	65.6	2.1	1-12
Wieprza	1999-2001	60	41.7	1.3	1-8
[Pilecka-Rapacz and Sobecka 2004]					
Lake Łętowskie					
[Garbacik-Wesołowska and Szkudlarek 1994]	1994	29	69.0	-	0-22
[Sobecka 1995]	1994	29	69.0	-	-30[4]
Lake Niegocin					
[Własow et al. 1991]	1989	15	27.7	-	1-2
Lake Mamry Północne					
[Własow et al. 1991]	1990	15	27.7	-	2-33
Lake Strażyn					
[Własow et al. 1994]	1993	55[5]	78.3	-	1-204 600
Lake in the town Gaj					
[Własow et al. 1994]	1993	55[5]	25.0	-	1-102
Gulf of Gdańsk					
[Rolbiecki et al. 2000]	1997-1998	372	41.9	3.0	-
Gulf of Puck					
[Bystydzieńska et al. 2003]	2001-2002	133	74.4	8.3	-

[1]: the author published the maximum prevalence and intensity values only

[2]: a single eel regurgitated by a black cormorant in Kąty Rybackie

[3]: the number of fish examined was a pooled sample from the Szczecin Lagoon and Lake Ińsko

[4]: the author published the maximum intensity values only

[5]: the number of fish examined was a pooled sample from lakes Strażyn and Gaj

-: no value reported

(Barse and Secor 1999). Moreover, Koie (1988) contends that anguillicolosis impairs the ability of eel to undertake spawning migrations to the western Atlantic. Tesch (1995) adds that a properly functioning swim bladder is indispensable in long-distance oceanic migrations as, among other functions, it helps fish maintain the appropriate depth during the day (500 m) and at night (250 m).

As reported by Lefebvre *et al*. (2002), danger from swim bladder damage increases as eel grow; this is most probably related to the accumulation of pathological changes.

In the presence of additional stressors (*e.g.*, bacterial infection, oxygen deficiency in the water, high fish density, transport), the afflicted fish affected may die. Mortality of this kind was reported in Lake Balaton in Hungary in 1991 (Molnár *et al*. 1991) and in the Czech Republic in 1994 and 1995 (Baruš 1994, 1995).

Dispersal and distribution of *Anguillicola crassus* in the eel in the Southern Baltic and adjacent waters

Most of the data on the occurrence of *A. crassus* in the eel in Poland come from northern Poland and the Baltic Sea. In this region, the presence of *A. crassus* has been reported from the Vistula and Szczecin Lagoons, the Gulf of Gdańsk, the Puck and Pomeranian Bays, and from the lakes Drużno, Łebsko, Przywłoka, Skąpe, Wielewickie, Miedwie, Ińsko, Łętowskie, Niegocin, Mamry Północne, Strażyn, Raduńskie, a lake in the village of Gaj, and in the rivers Rega, Radew, Wieprza, and Dead Vistula (Table 2). Most nematode studies were conducted in the Vistula and Szczecin lagoons. The first record of the parasite dates to 1988 when it was identified in the Vistula Lagoon (Grawiński 1988, Rolbiecki *et al*. 1996) in 75% (Grawiński 1994) and 63.3% of the eel examined (the latter value was calculated based on the prevalence in the fish caught in 1988-1990) (Rolbiecki *et al*. 1996). It is worth adding that Grawiński (1994) did not mention the number of fish examined, and the prevalence of infection he reported, which was calculated from a small number of fish examined, could have been overestimated. Additionally, Grawiński (1994) only reported the maximum prevalence and intensity. Subsequent studies on Vistula Lagoon eel indicated that there was an increase in the extent of infection. In 2000, the prevalence and mean intensity were 73.6% and 7.0 parasites, respectively; in 2001-2002, the prevalence was observed to increase to 76.2%, while the mean intensity remained at an unchanged level (Bystydzieńska *et al*. 2003). It should be mentioned here that the Vistula Lagoon eel were examined for parasites in 1996-1997 as well, but the study involved as few as 1–18 fish specimens (Własow *et al*. 1997). In the Szczecin Lagoon, *A. crassus* was first identified in 1993 (Garbacik-Wesołowska and Szkudlarek 1994, Sobecka 1995, Rząd 1998). The prevalence and maximum intensity reported by Garbacik-Wesołowska and Szkudlarek (1994) were 26.4% and 12 parasites, respectively; the authors did not mention the value at the lowest intensity. Sobecka (1995) reported an infestation prevalence of 24.5%, but did not report the intensity level, while Rząd (1998) reported prevalence and intensity of 65% and 1-35 parasites, respectively. The differences in infection could have resulted from the fact that Rząd (1998) reported prevalence of infection pooled over the 1993-1996 period, while Garbacik-Wesołowska and Szkudlarek (1994) and Sobecka (1995) referred only to 1993 values. Additionally, Rząd (1998) did not state the number of fish examined. Garbacik-Wesołowska and Szkudlarek (1994) reported two eel samples, examined in 1994 (with prevalences of 37.5% and 68.4%), consisting of as few as 16 and 19 specimens. In the same year, Sobecka (1995) reported higher prevalence (68.4%), but did not mention the number of fish examined.

There were usually only single samples from the remaining areas. The proportion of infected fish ranged from 30% in the Pomeranian Bay (Garbacik-Wesołowska and Szkudlarek 1994), 41.9% in the Gulf of Gdańsk (Rolbiecki *et al*. 2000), to 74.4% in the Puck Bay (Bystydzieńska *et al*. 2003). Among the eel caught in lakes, the prevalence of infection varied from 25% in the lake in the village of Gaj (Grawiński 1994) to, for example, 88.7% in Lake Ińsko (Orecka-Grabda *et al*. 1994, Rząd 1998) and even to 100% (based on as few as 20 fish examined) in Lake Miedwie (Sobecka and Piasecki 2002). The prevalence in rivers ranged from 41.7% in the Wieprza to 65.6% in the Radew (Pilecka-Rapacz and Sobecka 2004).

The differences in the infection level in various water bodies could have resulted from a number of factors. These can be biotic including the presence of intermediate hosts (mainly copepods), paratenic hosts, or the opportunity the fish have to migrate from one reservoir to another. They can also be abiotic and include factors such as salinity or temperature, or they can be anthropogenic. The presence of a high number of species that are potential intermediate and paratenic hosts increases the chance of the definitive host, the eel, to become infected. Migrations of both paratenic hosts and eel are an important factor enhancing dispersal of the parasite both on a local and global scale. Water temperature is an important factor accelerating the parasite’s development. On the other hand, salinity may be a factor limiting the distribution of *A. crassus*. The parasite is commonly regarded as a freshwater species, but, as reported by numerous authors (including those referred to in this paper), it is highly tolerant to salinity changes. Human activities, particularly uncontrolled stocking, may play a role as well. Each batch of stocking material should be examined for the presence of parasites, including *A. crassus*, and the infected fish should be eliminated. The water infected fish were transported in should not be poured into clean reservoirs, as it may contain stage II larvae.

In summary, the distribution range of *A. crassus* in northern Poland and the Baltic is increasing as is the extent of infection. Perhaps the process will level off with time as a result of a stabilizing effect exerted by constraints imposed by interspecific interactions and habitat saturation.

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