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Infection of eel *Anguilla anguilla* from the River Elbe estuary with two nematodes, *Anguillicola crassus* and *Pseudoterranova decipiens*

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ABSTRACT· From October 1987 to September 1988, 1778 eels were sampled at monthly intervals in the Elbe estuary, Germany, and examined for parasites in the swimbladder and muscle. Juveniles and adults of the nematode *Anguillicola crassus* were the only parasites found in the swimbladder and L-III stages of the nematode *Pseudoterranova decipiens* were the only parasites found in the muscle. Averaged over all samples, 57.7 % of the eel were infected with *A. crassus* and 3.7 % with *P. decipiens*. Prevalence decreased for *A. crassus* with increasing fish length, but increased for *P. decipiens*. No clear seasonal fluctuations in parasite frequency were detected. Infection with *A. crassus* could not be related to any change in condition factor or liversomatic index. Some *P. decipiens* from the muscle of smelt after experimental oral transfer settled in the body cavity and muscle of eel. The majority of these nematodes, however, penetrated through the stomach wall, muscle and skin and left the eel.

INTRODUCTION

For decades, eel has been the most important species for fisheries in the tidal River Elbe, Germany. Unlike other species, annual landings of eel decreased only moderately in the 1980s compared to records from the end of the last century (Möller 1991). About half of the current annual catch of 110 t is used for stocking purposes. Elbe eels are mostly caught with anchor nets. The best fishing places are the lower reaches of some of the tributary rivers in spring and a short stretch along the northern shore of the estuary, close to the power plant of Brunsbüttel, in autumn (Möller 1989a). Summer eel fishing during former decades was carried out with baited fyke nets. This method is no longer in use since the regular occurrence of oxygen-poor zones every summer enables fishermen to use anchor nets to catch eel concentrating in very high densities in front of the oxygen-poor zone (Möller & Scholz 1991).

Eel fisheries in the Elbe became threatened by the discovery of high levels of mercury and various chlorinated hydrocarbons in the fish (Krüger & Kruse 1982, Kruse et al. 1983). Marketing of Elbe eel for human consumption today is illegal for this reason (Möller 1988). Another threat to local eel fisheries was the introduction of the swimbladder nematode *Anguillicola crassus* in 1982 from eastern Asia to Europe (Paggi et al. 1982), first recorded in Germany from the Weser-Ems region in spring 1982 (Neumann 1985). In 1985, it was recorded for the first time in the River Elbe (Peters & Hartmann 1986). Its conspicuous size and colour may disgust consumers should they cut open the swimbladder when eviscerating the fish. Another conspicuous nematode in Elbe eel is *Pseudoterranova decipiens* which occurs as the L-III stage in the muscle of numerous fish species (Lick 1991). Reaching a length of around 2 to 4 cm (Möller 1989b), it is easily found when filleting the fish, a procedure which, however, is seldom followed when preparing eel in Germany. We have found up to 42 *P. decipiens* in one eel of 69 cm length.

Eel is the only final host for *Anguillicola crassus*, but its larvae have also been found in the swimbladder of other species (Haenen & Banning 1990). Copepods serve as intermediate hosts (De Charleroy et al. 1990). *Pseudoterranova decipiens* matures in the stomach of seals. Benthic crustaceans serve as intermediate hosts (McClelland et al. 1990). It is unclear whether the fish is an obligatory second intermediate host or only a paratenic host which facilitates the transfer to the final host.

The purpose of this study was to elucidate the seasonal cycle of nematode infections of Elbe eel and to

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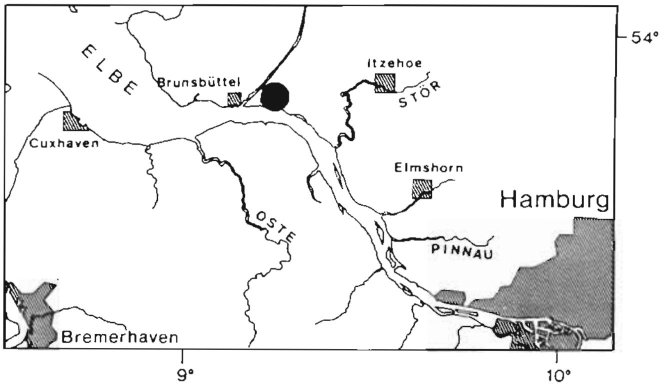

Fig. 1. Location of sampling station at the Brunsbüttel nuclear power plant in the Elbe estuary

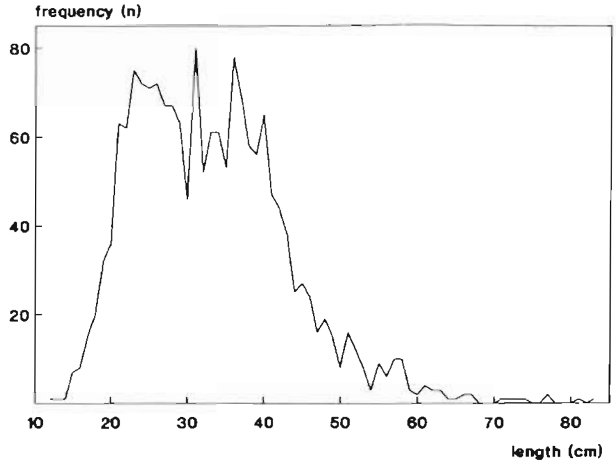

Fig. 2. *Anguilla anguilla*. Length-frequency distribution of eel examined from the Elbe estuary in 1987/88

study their impact on the condition of free-living fish. A fish survey at the intake screens of the power plant at Brunsbüttel (Fig. 1) provided us with sufficient initial material (Möller et al. 1989). Elbe eels consume considerable numbers of smelt *Osmerus eperlanus* (Möller 1984), which is the main host for larval *Pseudoterranova decipiens* in the area (Möller & Klatt 1990). As a repeated transfer of L-III stages from one fish to another is likely (Burt et al. 1990), we expected a very high prevalence of this nematode in eel flesh. As the findings did not confirm these expectations, we performed a series of experiments to study the fate of *P. decipiens* after it enters the eel stomach.

MATERIAL AND METHODS

Between October 1987 and September 1988, 1288 eel were sampled at the intake screens of the power plant at Brunsbüttel on the northern shore of the Elbe estuary. An additional 490 eel were caught by anchor nets 150 m downstream from the cooling water inlet of the power plant in October 1987, and in March, May and July 1988. Except for August when the plant was out of operation and February when only few eel were landed, more than 60 fish were collected per month. The length-frequency distribution of fish and the prevalence of fish parasites from the 2 sources showed no significant differences (Möller et al. 1989). The lengths of the eel examined were 13 to 84 cm, with 88 % falling into the range 13 to 45 cm (Fig. 2).

Immediately after capture, the fish were preserved on dry ice and stored frozen until examination. In the laboratory they were measured to the nearest mm. The weight was recorded to the nearest 0.1 g after removal of the viscera. The condition factor was calculated as K = (gutted weight in g) × 1000/(length in cm)$^{3\ 309}$, where the exponent was taken from the weight-length relationship for eel without nematodes. The liversomatic index was calculated as LSI = (liver weight in g) × 100/(gutted weight in g).

The swimbladder was opened, the parasites were searched for macroscopically and the total number of worms was counted. Thereafter, the fish were filleted and the skin removed. Thick fillets were cut from head to tail. The fillets or slices thereof were placed on a candling table and pressed with an acrylic glass plate. Macroscopically identified parasites were removed and counted. Prevalence data refer to the percentage of infected fish. Mean intensity refers to the average number of parasites per infected fish.

For infection experiments, 22 eel of 20 to 37 cm were taken from a nematode-free aquaculture unit. L-III stages of *Pseudoterranova decipiens* were removed from the muscle of Elbe smelt *Osmerus eperlanus* and stored for up to 6 h in physiological saline. The eel were narcotisized with chinaldine and the nematodes pushed with forceps into the stomach of the fish. One to 16 nematodes per fish, 95 parasites altogether, were transfered to the eels. The eels were kept individually at 15 to 16 °C in water of 16 to 18 ‰ salinity. During the first 5 h after infection, the fish were observed for regurgitation of nematodes. After 30 d, the surviving fish were dissected.

RESULTS

Prevalence and mean intensity

The only parasites found in the swimbladder were juveniles and adults of the nematode *Anguillicola crassus*. The only parasites discovered in the flesh were L-III stages of the nematode *Pseudoterranova decipiens*. No other nematode larvae, plerocercoids or protozoan cysts were recorded.

Table 1. *Anguilla anguilla.* Nematode infection of eel from the Elbe estuary in relation to host length. Average of all data from October 1987 to September 1988

Host length (cm)	No. examined	*Anguillicola crassus*		*Pseudoterranova decipiens*	
		Prevalence (%)	Mean intensity (no. of infected fish)	Prevalence (%)	Mean intensity (no. of infected fish)
13–25	393	62.6	5.4	0.3	1.0
26–35	640	60.6	7.5	0.8	1.0
36–45	533	59.1	8.8	5.3	1.4
46–55	148	39.9	10.6	11.5	3.5
56–84	64	28.1	7.9	21.9	5.1
Stock eel (<36 cm)	1033	61.4	6.7	0.6	1.0
Market eel (>35 cm)	745	52.6	9.0	7.9	2.8
All sizes	1778	57.7	7.6	3.7	2.7

Anguillicola crassus was present in 57.7 % and *Pseudoterranova decipiens* in 3.7 % of all eel examined (Table 1). The mean intensities of infection were 7.5 and 2.7, respectively. The prevalence of *A. crassus* decreased with increasing host length, but increased for *P. decipiens.* Of the stock eel up to 35 cm, 61.4 % had infected swimbladders, while only 52.6 % of the larger market eels were affected. In eel larger than 55 cm the prevalence decreased to 28.1 %. In contrast to the prevalence, the mean intensity of *A. crassus* doubled from the 13 to 25 cm to the 46 to 55 cm group and decreased again in larger fish. Up to 53 nematodes were found in the swimbladder of a 52 cm long eel (Fig. 3).

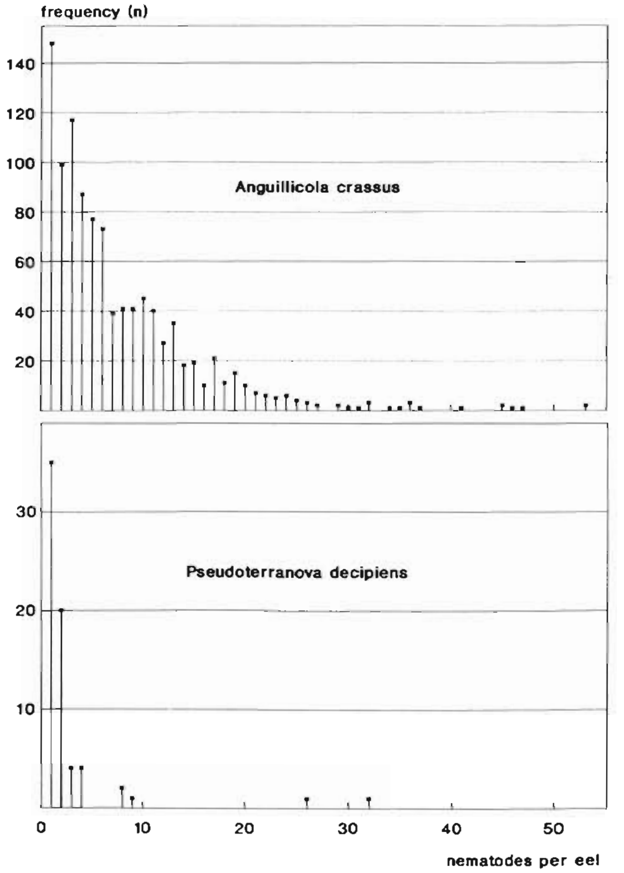

Fig. 3. *Anguilla anguilla.* Frequency distribution of nematodes in 1778 eel from the Elbe estuary in 1987/88. Top: *Anguillicola crassus*, bottom: *Pseudoterranova decipiens*

Only 0.6 % of the stock eel were infected by *Pseudoterranova decipiens* with only one parasite each. In eel larger than 55 cm, the prevalence increased to 21.9 % with a mean intensity of 5.1. The largest number of *P. decipiens* was 32 in one eel of 53 cm. The flesh colour of heavily infected eel had turned to pale pink instead of white. On average, eel infected with *P. decipiens* were 11 cm longer than nematode-free eel. The average length of eel moderately (1 to 20) infected with *Anguillicola crassus* was less, that of heavily infected eel more, than the average length of unparasitized fish (Fig. 4).

Examining single months, the prevalence of *Anguillicola crassus* in eel of 13 to 45 cm ranged between 50 and 76 %, that of *Pseudoterranova decipiens* between 1 and 5 %. Neither for the prevalence nor for the mean intensity of both parasite species could any characteris-

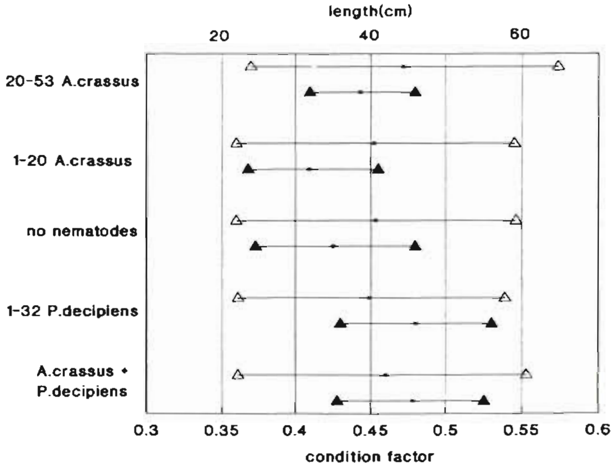

Fig. 4. *Anguilla anguilla.* Comparison of length (△) and condition factor (▲) of parasitized and parasite-free eel from the Elbe estuary 1987/88. Average and standard deviation

Table 2. *Anguilla anguilla*. Monthly fluctuations in infection of eel from the Elbe estuary with nematodes. Length groups 13 to 45 cm only

Month (1987/88)	No. examined	*Anguillicola crassus*		*Pseudoterranova decipiens*	
		Prevalence (%)	Mean intensity (no. of infected fish)	Prevalence (%)	Mean intensity (no. of infected fish)
Oct	206	59.7	7.2	1.0	1.0
Nov	87	57.5	5.8	1.1	1.0
Dec	63	52.4	7.2	4.8	1.7
Jan	83	62.7	9.7	3.6	1.0
Feb	21	52.4	3.9	4.8	2.0
Mar	124	50.0	6.8	0.8	1.0
Apr	81	63.0	7.9	4.9	1.5
May	316	54.1	6.3	2.2	1.0
Jun	100	52.0	7.3	3.0	1.0
Jul	394	75.6	8.1	2.0	1.5
Aug	0	–	–	–	–
Sep	91	50.5	8.0	1.1	2.0
Average		60.6	7.4	2.2	1.3

Table 3. *Anguilla anguilla*. Comparison of condition factor and liversomatic index of eel from the Elbe estuary with and without *Anguillicola crassus* infection. Sum of all data from October 1987 to September 1988

	Level of parasitation		
	No *Anguillicola*	1–20 *Anguillicola*	> 20 *Anguillicola*
No. examined	745	953	63
Length (cm)			
Range	14–84	13–78	20–59
Average	35.1	31.9	38.9
Standard deviation	10.88	8.86	7.13
Condition factor			
Range	0.131–0.871	0.160–0.803	0.239–0.846
Average	0.453	0.452	0.472
Standard deviation	0.093	0.092	0.102
Liversomatic index			
Range	0.726–7.317	0.752–4.993	1.524–4.902
Average	2.245	2.367	2.342
Standard deviation	0.693	0.660	0.602

tic seasonal fluctuations be demonstrated (Table 2). Eel larger than 45 cm, mostly occurring in autumn, were excluded from this seasonal comparison because of their relatively low prevalence of *A. crassus* (Table 1).

Effects on host condition

Based on all 727 eel without any nematodes, the weight-length relationship was determined as $W = 10^{-3.3523} \times L^{3.3090}$, $r^2 = 0.952$. The condition factor was calculated as $K = W \times 1000/L^{3.309}$.

In Table 3 the condition factor and the liversomatic index of parasite-free, moderately parasitized and heavily parasitized eel are compared. Results give no indication of any of these parameters being influenced by *Anguillicola crassus* infections. Heavily infected eel even show a slightly, but statistically not significant, higher condition factor than parasite-free eel.

The seasonal fluctuations of condition factor of both *Anguillicola*-infected and *Anguillicola*-free eel followed the same patterns. Lowest values were recorded from March to May, while maxima were found in September (Fig. 5).

Infection experiments

Four of the 22 eels died within 24 h after experimental infection with *Pseudoterranova decipiens* larvae. The other fish survived until the end of the experiment of Day 30 (Table 4). The dead eels had been given 2, 4,

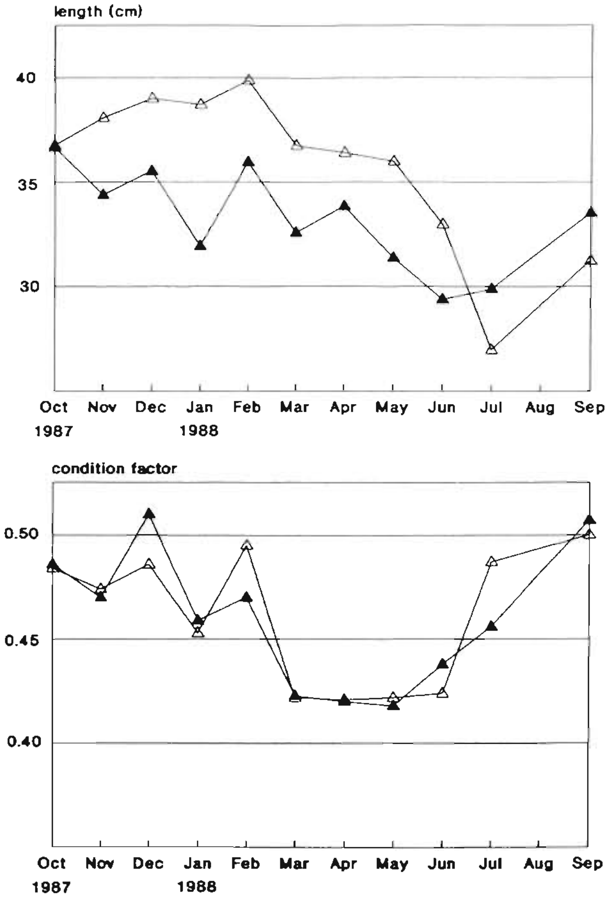

Fig. 5. *Anguilla anguilla.* Seasonal fluctuation of condition factor (bottom) and average length (top) of *Anguillicola*-infected (▲) and *Anguillicola*-free (△) eel from the Elbe estuary in 1987/88

8, and 16 nematodes, respectively. As soon as 1 h after infection, these 4 eels showed abnormal slow swimming movements and increased opercula activity. Three of them changed to a conspicuous light colouration. Only one of the 30 nematodes given to these 4 eel was regurgitated. Five were found free in the stomach, 19 were found penetrating the stomach wall, 4 between the viscera, and one in the muscle of the belly flap.

Among the 18 surviving eel, no regurgitation was observed within the 5 h observation period after infection. However, 3 h after infection, the first nematodes were already observed under the skin. These locations became swollen and the eels continuously turned around their own axis and tried to bite into the infected sites. Four hours after infection, the first nematodes occurred in the eyes of the eel (Fig. 6). After 5 d, the first fish with a hole in the belly flap, surrounded by ulcerative tissue, were found.

Thirty days after experimental infection the fish were dissected. Thirteen eel were free from *Pseudoterranova decipiens*. In 7 of them, which had been infected with 1 to 5 nematodes each, no external wounds were observed. In another 6 fish, having been infected with 1 to 8 nematodes, ulcerations were found at various parts of the belly flaps. In 4 fish, a hole was clearly visible in the centre of the ulceration. In 2 fish the ulcerations were in a healing stage.

In 5 eel, 1 or 2 nematodes were recovered at the end of the experiment. These fish had been infected with 1 to 8 worms. Three worms were found in hypaxial muscles, 4 were found encapsulated between the viscera.

During the experiment the condition factor of the fish, which had not been fed, decreased by between 6 and 29 % of the starting value. The degree of decrease was not related to the number of nematodes transfered (Table 4).

DISCUSSION

After its accidental introduction into Europe, *Anguillicola crassus* rapidly spread among the European eel population, and now covers the area from the northern central Baltic to England, France and Italy. In the Elbe estuary, more than half of the population is affected. In northern Germany the parasite's distribution was facilitated by stocking eel from the Elbe to numerous other open and closed waters. This practice was continued even after it had become evident that this would lead to an even faster and more complete dissemination of the parasite. Similar observations were made earlier in Belgium (Belpaire et al. 1989).

The effect of the parasite on its host has been evaluated in different ways. We could not detect any loss in weight of infected eel and we thus assume that the effect on the flesh quality is small. Similar results have been presented by Dekker & Willigen (1988) from Dutch eel populations. It has to be mentioned, however, that the condition factor of wild eel shows a much greater variation than that of most other fish species and that light or moderate differences between different groups are thus difficult to detect. In contrast to our field studies, Boon et al. (1990a) recorded a reduction of body weight due to artificial infection of eel with *Anguillicola crassus*. More serious effects occur with respect to the swimbladder which may exhibit acute inflammatory reactions, fibriosis and other pathological conditions (Banning & Haenen 1990, Boon et al. 1990b). A significant reduction in swimming ability of infected eel as recorded by Sprengel & Lüchtenberg (1991) could even affect reproduction on a population level as these fish might not reach their spawning grounds.

The decrease in prevalence of *Anguillicola crassus* infections in very large eel reflects the fact that these fish predate mainly on carnivorous smelt, while smaller eel feed mainly on smaller fish which themselves may contain larger numbers of infected copepods in their

Table 4. *Anguilla anguilla*. Results of experimental transfer of *Pseudoterranova decipiens* larvae into eel stomachs. Condition factor = (weight in g) × 1000/(length in cm)^3

Host length (mm)	Condition factor at start	No. of nematodes transferred	Decrement of condition factor (%)	No. of nematodes found in: Body cavity	Muscle
		Dead after 1 d			
222	0.161	2			
255	0.153	4			
235	0.168	8			
237	0.176	16			
		Dissected after 30 d			
218	0.156	1	12.1	0	0
246	0.160	1	9.8	0	0
257	0.161	1	19.4	0	1
232	0.170	2	19.6	0	0
252	0.160	2	6.1	0	0
315	0.169	2	20.0	1	0
322	0.173	2	19.3	0	0
332	0.159	2	14.7	0	0
345	0.189	2	23.3	0	0
366	0.225	2	18.8	0	0
241	0.183	4	7.7	0	0
254	0.170	4	11.6	0	1
347	0.217	4	22.9	0	0
318	0.181	5	28.7	0	0
335	0.197	7	22.7	2	0
203	0.156	8	13.0	0	0
216	0.167	8	13.7	0	0
334	0.180	8	16.5	1	1

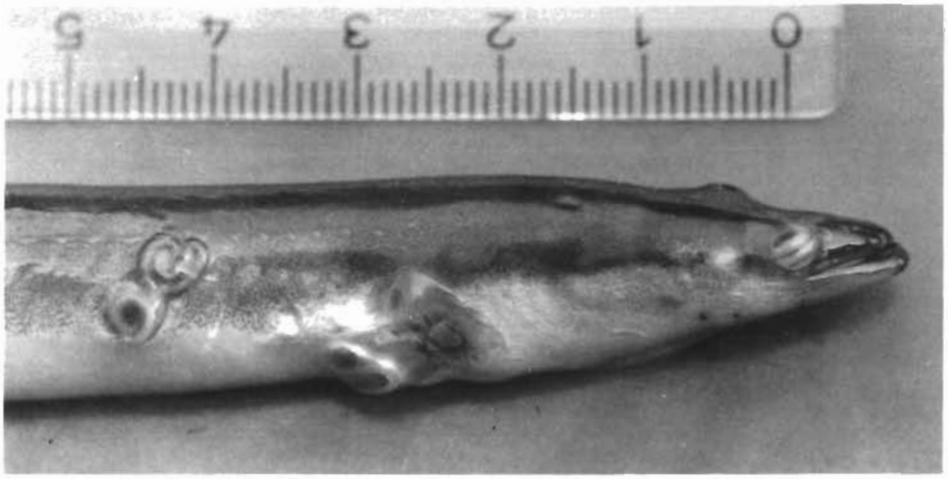

Fig. 6. *Anguilla anguilla*. Twenty-four hours after experimental transmission into the stomach, all 8 *Pseudoterranova decipiens* are visible below the skin and in the right eye of this eel (scale in cm)

gastro-intestinal tract. This could also explain why large eel suffer preferentially from infection with *Pseudoterranova decipiens*. The main source of infection is smelt in which the prevalence of infection increases with increasing age (Kerstan 1991). The lack of clear seasonal fluctuations in the frequency of both parasite species in eel suggests that early larval stages are available all year round and/or that they remain for a relatively long period of time in this host, unlike other helminth species which mature in the gastro-intestinal tract of fish (Möller & Anders 1986).

While *Anguillicola crassus* forms no threat to the consumer if the eel is properly eviscerated, finding the relatively large *Pseudoterranova decipiens* in the flesh is repugnant. Changes in flesh colour suggest changes in the composition of the muscle, but more detailed information is lacking.

Since eel prey mainly on smelt, which in the Elbe estuary is the main host of *Pseudoterranova decipiens* (Möller & Klatt 1990), a much higher prevalence of this parasite in eel had been expected. The results from the infection experiments explain why this assumption was wrong: of 65 parasites experimentally transmitted to eel, only 7 were found in the fish after 30 d. Some 89 % of the nematodes had left the new host, obviously by penetrating the stomach wall, muscle and skin. It is unknown whether eel is not a suitable host for this species or whether eels used for the experiment were of too small size. It is also unknown whether it was the nematodes' activity which caused the death of 4 of the 22 experimental fish.

Wild eel populations may temporarily suffer from infections with the bacterium *Vibrio anguillarum* (Aaser 1925, Mattheis 1960). Skin ulceration is one of the disease signs which is most easily detected. Such lesions are typically crater-like and surrounded by ring-like white swollen tissue. In contrast, ulcerations induced by penetration of *Pseudoterranova decipiens* larvae typically occur in the belly area and during early stages show a clearly visible hole in the center of the ulcerated tissue. There is, however, no reason to doubt that the nematode-induced lesions may be infected secondarily by bacteria such as *V. anguillarum*.

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