

## The Swimbladder Parasite *Anguillicola crassus* in Native Japanese Eels and Exotic American Eels in Taiwan

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**Yu-San Han, Ya-Ting Chang, Horst Taraschewski, Su-Ling Chang, Che-Chun Chen, and Wann-Nian Tzeng (2008)** The swimbladder parasite *Anguillicola crassus* in native Japanese eels and exotic American eels in Taiwan. *Zoological Studies* 47(6): 667-675. To understand differences in infection patterns of the swimbladder parasite *Anguillicola crassus* between habitats and eel species in Taiwan, the prevalence and intensity of the parasite were examined based on specimens collected from wild and cultured Japanese eel *Anguilla japonica* and from exotic cultured American eel *A. rostrata* in the Kaoping River and culture ponds in southwestern Taiwan in 2006-2007. The prevalence of *Aco. crassus* in wild Japanese eels was lower in winter compared with summer/autumn, varying 33%-58%, with a mean intensity of 1.5-4.4. The prevalence and intensity were size-dependent and increased with eel size. In cultured Japanese eels, the prevalence and mean intensity varied greatly at 3%-68% and 1.0-29.0, respectively. In cultured American eels, the prevalence and intensity were very high in ponds without drug treatment. In contrast to wild eels, the mean intensity of larval and adult worms showed a size-dependent decreasing trend in cultured eels. The mean body mass of *Aco. crassus* in American eels was significantly larger than that in Japanese eels. The external morphology, condition factor, and hepatosomatic index showed no significant differences between infected and uninfected groups, indicating a low pathogenic effect of *Aco. crassus* on these 2 eel hosts. Our results showed that both native Japanese eels and naive American eels are highly susceptible to *Aco. crassus*, but it causes little pathogenicity under good pond management. <http://zoolstud.sinica.edu.tw/Journals/47.6/667.pdf>

**Key words:** *Anguillicola crassus*, *Anguilla japonica*, *Anguilla rostrata*, Infection, Aquaculture.

*Anguillicola crassus* (Kuwahara, Niimi and Itagaki 1974) is an endemic swimbladder parasite of the Japanese eel *Anguilla japonica* in East Asia (Kuwahara et al. 1974, Nagasawa et al. 1994). Eels are infected by ingestion of 3rd-stage juveniles (L3 larvae) present in copepods, a crustacean that serves as an intermediate host (Kennedy and Fitch 1990, Ooi et al. 1997), or by preying on small paratenic fish hosts containing L3 larvae (Kirk 2003). Adult male and female nematodes copulate in the lumen of the eel's swimbladder.

Females passively release eggs which leave the swimbladder via the pneumatic duct, pass down the intestine and hatch in the water as a motile 2nd-stage juvenile (L2 larvae), although some hatch in the swimbladder (Kirk et al. 2000). L2 larvae attach to the substratum and undulate to stimulate predation by intermediate hosts and grow to L3 larvae while waiting to enter the definitive eel hosts (Thomas and Ollevier 1993).

In the early 1980s, *Aco. crassus* was accidentally introduced into Europe, possibly through

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importation of infected Japanese eels from Taiwan into Germany in 1980 (Koops and Hartmann 1989). *Aco. crassus* was first detected in 1982 in European eel *A. anguilla* in northern Germany and then rapidly spread in Europe (Kirk 2003). *Aco. crassus* has now spread to eastern states of North America (Fries et al. 1996, Barse et al. 2001) and also to North and East Africa (Sasal et al. 2008). Based on historical records, eel populations, including European, American, and Japanese eels, have declined to approximately 1%-10% of population levels in the 1980s (Dekker et al. 2003). Declines in eel recruitment have probably been caused by a combination of factors including overfishing, pollution, global climatic and oceanic changes, and loss of habitat (Naismith and Knights 1990, Tzeng et al. 1995, Dekker et al. 2003, Tesch 2003). The decline in European eel populations might be partly due to infection by *Aco. crassus* because of its high pathogenicity (Molnár et al. 1993, Würtz and Taraschewski 2000, Kirk 2003, Taraschewski 2006). Studies indicate that *Aco. crassus* does not usually cause serious pathological damage to Japanese eels as it tends to occur at low intensities (Egusa 1992). In Europe when *Aco. crassus* invades a new habitat, it can often rise to 100% prevalence in the eel population. The severity of pathogenicity to European eels and associated high infection levels may reflect a lack of adaptations for resistance acquired after a long host-parasite co-evolutionary period (Würtz and Taraschewski 2000, Kirk 2003). Laboratory infections have revealed a stronger resistance against *Aco. crassus* by Japanese eels than by European eels (Knopf and Mahnke 2004). An enhanced humoral immune response against *A. crassus* in Japanese eels was also found in comparison to European eels (Nielsen 1999). The success of *Aco. crassus* as a colonizer outside Asia may be attributed to its adaptability to a wide range of intermediate and paratenic hosts (Kennedy et al. 1992, Kirk 2003, Moravec et al. 2005) as well as salinities (Kirk et al. 2000).

In Europe, research activities related to *Aco. crassus* are far more intensive than in Asia and America. *Aco. crassus* was first documented in American eel populations in North America in 1995 (Johnson et al. 1995). *Aco. crassus* was found in the middle portion of eastern North America followed by a rapid increase in distribution (Barse and Secor 1999, Barse et al. 2001). The infectivity and pathogenicity of *Aco. crassus* in its American eel host, however, are less well understood. In Taiwan, the Japanese eel is a commercially

important species for aquaculture. Due to a shortage of local Japanese eel elvers for culture, culturists have imported American eel elvers from North America to meet their needs since 1969 (Li 1997). This situation gave us an opportunity to investigate the infection and pathogenicity of *Aco. crassus* in native Japanese eels and exotic American eels in Taiwan as well as the effect of different aquatic environments on the infection patterns of *Aco. crassus*.

## MATERIALS AND METHODS

Wild Japanese eels ( $n = 533$ ) were collected from the Kaoping River estuary in southwestern Taiwan from June 2006 to Feb. 2007. The sampling locations and methods used for eel capture were described in detail by Han and Tzeng (2006). Cultured Japanese eels ( $n = 257$ ) were purchased from 1 pond in Yonglin, 6 ponds in Budai (run by the same farmer), and 1 pond in Syuejia all of southwestern Taiwan in Sept. 2006. Cultured American eels ( $n = 102$ ) were purchased from ponds in Yiwu and Yonglin, southwestern Taiwan in Mar. and Aug. 2007, respectively. Eels were transported to the laboratory and killed by decapitation, followed by a parasitological examination. The length and weight of the eels were measured to the nearest 1.0 mm and 0.1 g, respectively. The condition factor (body weight (g)/total length (mm)<sup>3</sup> × 10<sup>6</sup>) and hepatosomatic index (HSI, liver weight (g)/ body weight (g) × 100) of the eels were calculated as described by Han et al. (2003).

Adult parasites were removed from the swimbladder lumen of the eels by forceps. Their body weight (to the nearest 0.1 mm), sex, and number were recorded. The walls of the swimbladders were checked for larval numbers by squashing them between 2 Perspex plates. The prevalence, mean intensity, and abundance of parasites in eels were calculated as described by Bush et al. (1997).

Differences in mean total length, body weight, and HSI among eel groups were tested by one-way analysis of variance (ANOVA). Dependence of parasite prevalence on the total length of eel stocks was examined by the Chi-squared test of homogeneity using a X<sup>2</sup> contingency table. The condition factor in relation to total length of eels between infected and uninfected groups was first tested for homogeneity of regression slopes, followed by comparison of the adjusted

means using analysis of covariance (ANCOVA) as implanted in the SPSS 10 software. Differences in worm body weights among eel groups were analyzed using the Mann-Whitney *U*-test. Significance was accepted at  $p < 0.05$ .

## RESULTS

### Eel data

Total length, body weight, HSI, and the condition factor of the investigated Japanese and American eels are summarized in table 1. For cultured Japanese and American eels, each batch of samples showed a more-uniform size distribution because of grading procedures or size selection during the course of culturing. Batches of cultured eels with the smallest and largest mean total lengths came from the Budai ponds BD2 and BD5, respectively (Table 1).

### Infection patterns of *Aco. crassus* in wild and cultured eels

All parasites identified in the eels' swimbladders were *Aco. crassus* according to

the key of Moravec and Taraschewski (1988). The prevalence of *Aco. crassus* in wild Japanese eels ranged 33%-58%, and were lower in winter compared to summer/autumn (Fig. 1). Prevalences of *Aco. crassus* varied 3%-68% in cultured Japanese eels and 24%-69% in cultured American eels (Fig. 1). The abundance and mean intensity of *Aco. crassus* were generally low in wild Japanese eels, but were highly variable in both cultured Japanese and American eels (Table 1).

The relationship between eel size and prevalence indicated that wild Japanese eels smaller than 40 cm had significantly lower prevalences than those larger than 40 cm ( $\chi^2 = 17.39$ ,  $d.f. = 3$ ,  $p < 0.001$ ) (Table 2). The mean intensities of larval and adult worms showed size-dependent increases in wild Japanese eels. Prevalences varied among size classes in cultured Japanese and American eels (Table 2). Mean intensities of larval and adult worms in cultured Japanese and American eels, however, showed size-dependent decreasing and increasing tendencies (Table 2).

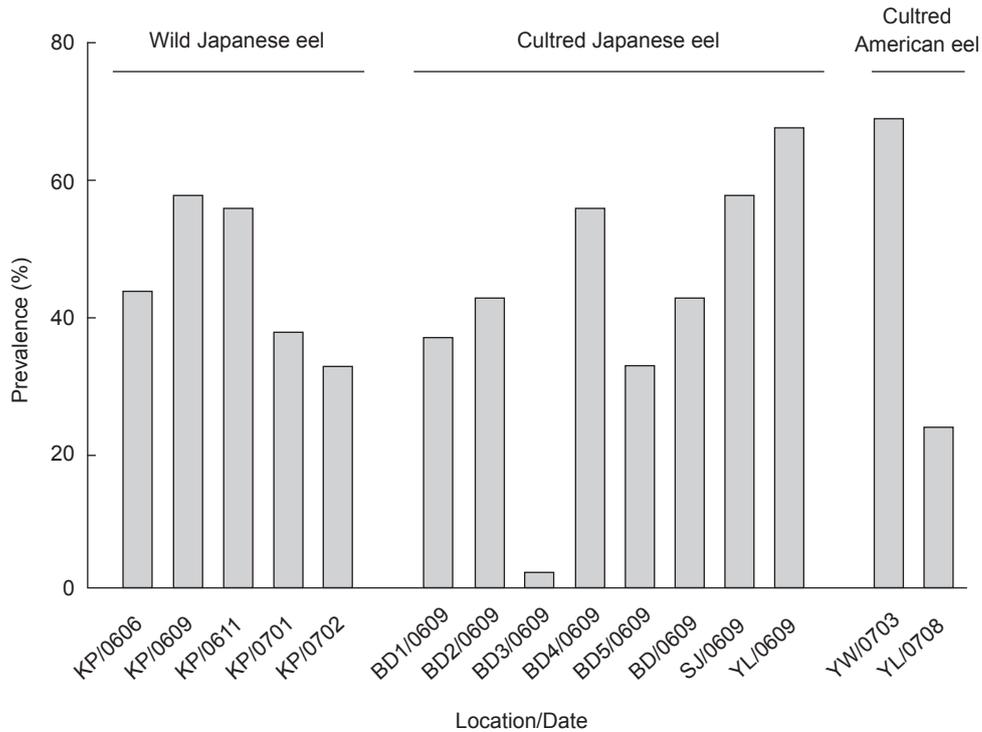
Frequency distributions of adult and larval *Aco. crassus* per eel approached exponential decay in wild and cultured Japanese eels but showed a negative binomial distribution in cultured American eels (Fig. 2). Percentages of seriously

**Table 1.** Sample size, mean total length ( $\pm$  S.D.), body weight, hepatosomatic index (HSI), condition factor (C-factor), and mean intensity of *Anguillicola crassus* in wild (W) and cultured (C) eels. KP, Kaoping; BD, Budai; SJ, Syuejia; YL, Yonglin; YW, Yiwu

Type/Location/Date	n	Total Length(mm)	Body weight(g)	HSI	C-factor	Abundance	Mean intensities		
							Larvae (L)	Adults (A)	L + A
<i>Anguilla japonica</i>									
W/KP/June 2006	9	409.7 $\pm$ 137.6	122.0 $\pm$ 144.9	1.2 $\pm$ 0.2	1.2 $\pm$ 0.2	1.4 $\pm$ 2.2	2.5 $\pm$ 0.0	0.8 $\pm$ 0.7	3.3 $\pm$ 2.0
W/KP/Sept. 2006	31	372.7 $\pm$ 158.1	107.2 $\pm$ 223.3	1.0 $\pm$ 0.3	1.0 $\pm$ 0.2	2.5 $\pm$ 5.8	3.2 $\pm$ 9.2	1.2 $\pm$ 0.5	4.4 $\pm$ 6.8
W/KP/Nov. 2006	68	515.9 $\pm$ 76.9	174.5 $\pm$ 111.9	1.2 $\pm$ 0.3	1.2 $\pm$ 0.2	0.9 $\pm$ 2.0	0.0 $\pm$ 0.0	1.6 $\pm$ 0.8	1.6 $\pm$ 0.8
W/KP/Jan. 2007	139	356.7 $\pm$ 77.7	49.7 $\pm$ 50.4	1.3 $\pm$ 0.1	0.9 $\pm$ 0.2	0.6 $\pm$ 1.7	0.2 $\pm$ 1.6	1.3 $\pm$ 0.7	1.5 $\pm$ 1.7
W/KP/Feb. 2007	286	351.8 $\pm$ 57.3	39.9 $\pm$ 26.1	1.1 $\pm$ 0.3	0.8 $\pm$ 0.2	0.5 $\pm$ 1.6	0.0 $\pm$ 0.0	1.3 $\pm$ 0.7	1.3 $\pm$ 0.7
C/BD1/Sept. 2006	51	291.8 $\pm$ 75.8	37.3 $\pm$ 43.1	1.6 $\pm$ 0.4	1.1 $\pm$ 0.2	1.5 $\pm$ 3.7	2.7 $\pm$ 5.0	1.0 $\pm$ 1.1	3.7 $\pm$ 4.8
C/BD2/Sept. 2006	7	234.6 $\pm$ 35.4	13.9 $\pm$ 9.8	2.2 $\pm$ 0.7	0.9 $\pm$ 0.3	12.4 $\pm$ 28.5	28.0 $\pm$ 49.4	1.0 $\pm$ 0.7	29.0 $\pm$ 40.9
C/BD3/Sept. 2006	36	409.1 $\pm$ 22.8	87.4 $\pm$ 18.6	1.1 $\pm$ 0.2	1.3 $\pm$ 0.1	0.0 $\pm$ 0.1	0.0 $\pm$ 0.0	1.0 $\pm$ 0.0	1.0 $\pm$ 0.0
C/BD4/Sept. 2006	16	539.4 $\pm$ 30.2	230.1 $\pm$ 49.3	1.1 $\pm$ 0.2	1.4 $\pm$ 0.1	9.6 $\pm$ 39.6	7.2 $\pm$ 10.4	9.8 $\pm$ 29.7	17.0 $\pm$ 50.8
C/BD5/Sept. 2006	49	566.8 $\pm$ 26.9	268.7 $\pm$ 41.9	1.3 $\pm$ 0.3	1.5 $\pm$ 0.1	0.4 $\pm$ 1.5	0.0 $\pm$ 0.0	1.4 $\pm$ 0.7	1.4 $\pm$ 0.7
C/BD6/Sept. 2006	40	562.6 $\pm$ 31.8	279.6 $\pm$ 51.9	1.2 $\pm$ 0.2	1.6 $\pm$ 0.2	0.8 $\pm$ 2.4	0.1 $\pm$ 0.0	1.8 $\pm$ 1.2	1.9 $\pm$ 2.4
C/SJ/Sept. 2006	24	407.0 $\pm$ 22.1	83.9 $\pm$ 19.9	1.1 $\pm$ 0.1	1.2 $\pm$ 0.1	1.0 $\pm$ 2.4	0.1 $\pm$ 0.5	1.6 $\pm$ 1.0	1.7 $\pm$ 2.3
C/YL/Sept. 2006	34	367.4 $\pm$ 44.1	52.3 $\pm$ 26.8	1.2 $\pm$ 0.3	1.0 $\pm$ 0.3	3.4 $\pm$ 7.3	3.6 $\pm$ 9.1	1.5 $\pm$ 1.4	5.1 $\pm$ 8.1
<i>Anguilla rostrata</i>									
C/YW/Mar. 2007	64	281.9 $\pm$ 45.1	44.9 $\pm$ 48.2	1.4 $\pm$ 0.4	1.6 $\pm$ 0.3	17.9 $\pm$ 28.9	13.6 $\pm$ 12.6	19.7 $\pm$ 22.1	26.1 $\pm$ 25.5
C/YL/Aug. 2007	38	240.0 $\pm$ 69.3	28.4 $\pm$ 49.3	1.2 $\pm$ 0.2	1.4 $\pm$ 0.3	0.9 $\pm$ 2.7	0.0 $\pm$ 0.0	4.0 $\pm$ 2.1	4.0 $\pm$ 2.1

infected samples with the number of larvae > 7 in wild Japanese eels, cultured Japanese eels, and American eels were 0.4%, 2.8%, and 23.5%, and samples with a no. of adults of > 7 were 0.0%,

0.3%, and 24.5%, respectively (Fig. 2). Mean body mass values of *Aco. crassus*, regardless of being male or female, were significantly larger in American eels than in Japanese eels, and no



**Fig. 1.** Prevalence of *Anguillicola crassus* in wild ( $n = 533$ ) and cultured ( $n = 257$ ) Japanese eels and cultured ( $n = 102$ ) American eels. KP, Kaoping; BD, Budai; SJ, Syuejia; YL, Yonglin; YW, Yiwu. Sampling date: yy/mm.

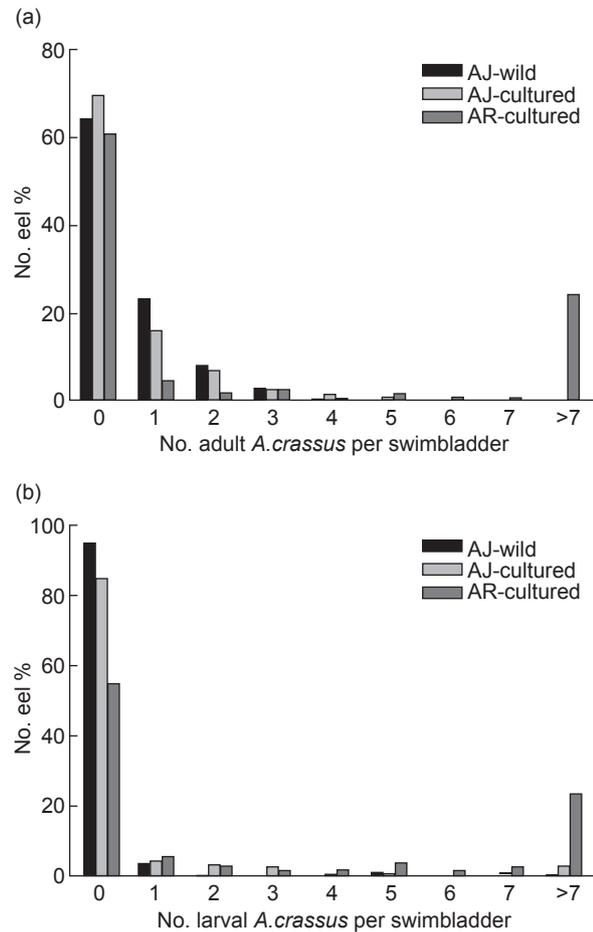
**Table 2.** Relationship between size and infection in wild and cultured eels. TL, total length (mm);  $n$ , sample size; P, prevalence (%)

	TL < 300	300 ≤ TL < 400	400 ≤ TL < 500	TL ≥ 500
<i>Wild Anguilla japonica</i>				
$n$	100	277	96	60
P (%)	30.3	33.7	52.1	51.7
Larval mean intensity	0.03 ± 0.18	0.34 ± 1.99	0.40 ± 1.21	1.56 ± 4.41
Adult mean intensity	1.23 ± 0.56	1.22 ± 0.67	1.50 ± 0.91	1.56 ± 1.09
<i>Cultured Anguilla japonica</i>				
$n$	49	44	61	103
P (%)	44.9	50.0	25.0	40.8
Larval mean intensity	6.18 ± 16.38	2.73 ± 7.96	1.92 ± 3.62	1.63 ± 5.42
Adult mean intensity	1.05 ± 1.25	1.27 ± 1.16	1.77 ± 1.69	3.37 ± 12.30
<i>Cultured Anguilla rostrata</i>				
$n$	75	25	-	-
P (%)	42.7	76.0	-	-
Larval mean intensity	14.40 ± 12.65	9.68 ± 12.38	-	-
Adult mean intensity	10.60 ± 22.59	18.16 ± 17.14	-	-

significant differences were found between wild and cultured Japanese eels (Fig. 3).

**Comparison of morphometric characteristics between infected and uninfected eels**

Infected eels showed a normal external morphology and activity with no observable disorders. The total length, body weight, and HSI showed no significant differences between infected and uninfected eel groups among wild and cultured Japanese eels or in American eels. Condition factors showed significant size-dependent increases (Fig. 4). The regression slopes and adjusted means (ANCOVA, wild Japanese eels:  $p = 0.302$ ; cultured Japanese eels:  $p = 0.782$ ; and cultured American eels:  $p = 0.102$ ) showed no significant differences between infected and uninfected eel groups (Fig. 4).

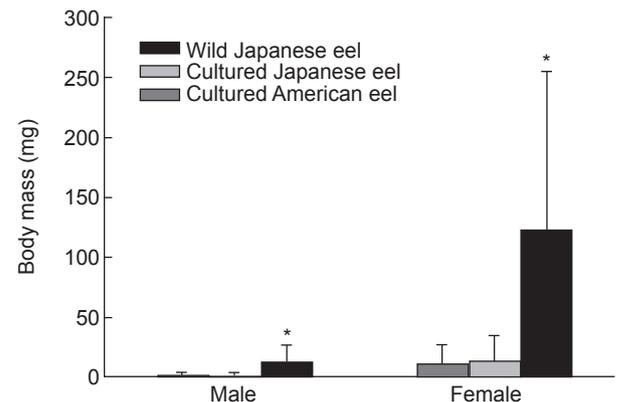


**Fig. 2.** Frequency distribution of adult (a) and larval (b) *Anguillicola crassus* in wild and cultured Japanese eels (AJ) and cultured American eels (AR).

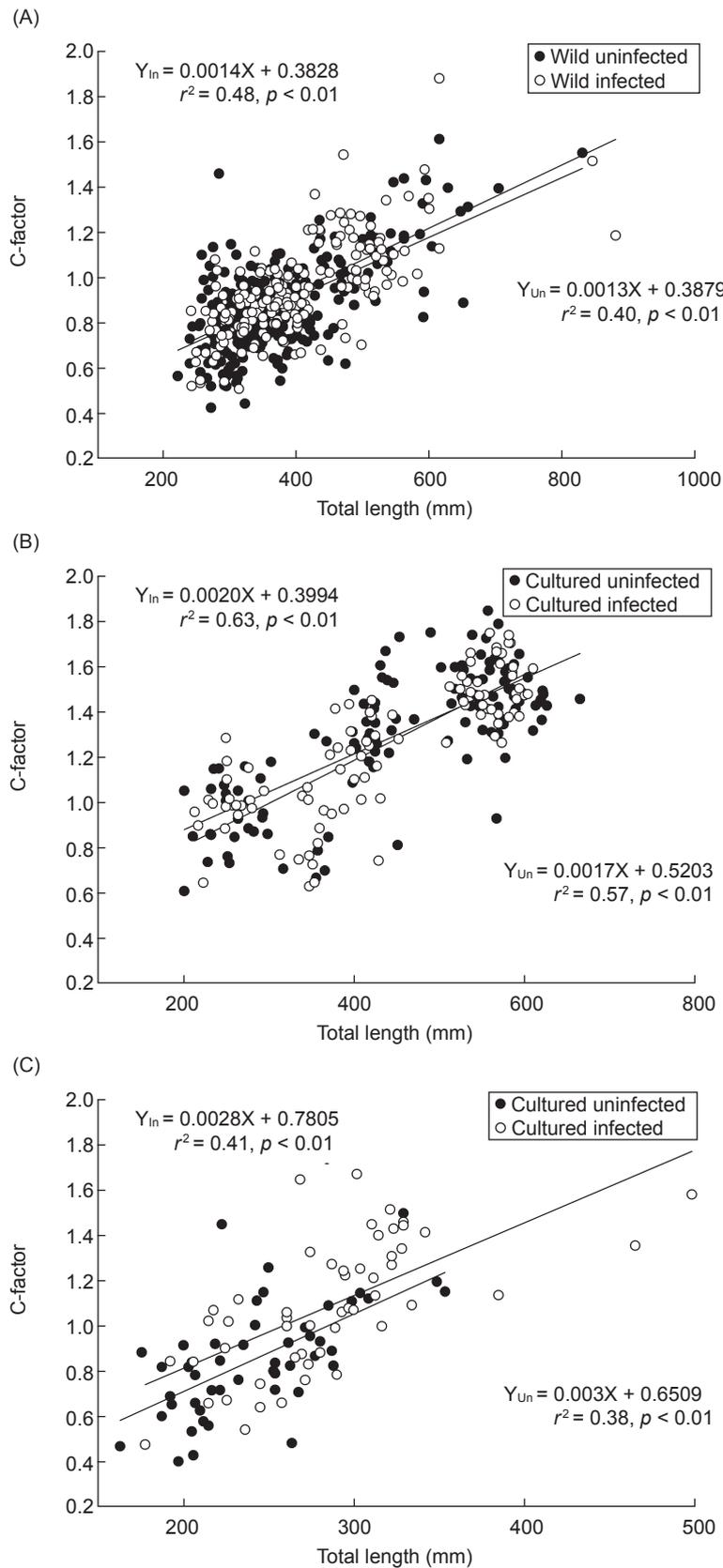
**DISCUSSION**

In a previous study in 2000-2003 (Münderle et al. 2006), the prevalence of *Aco. crassus* in eels from the Kaoping River ranged 51%-62% in spring and autumn but dropped to 21% in winter. In this study, the prevalence of *Aco. crassus* in the same location showed similar trends, with higher prevalences in summer/autumn than in winter. Seasonal changes in prevalences of *Aco. crassus* were also observed in cultured Japanese eels in Japan (Egusa et al. 1969) and Korea (Kim et al. 1989), which might reflect the lower abundances of intermediate and/or paratenic fish hosts in the cold season, or reduced feeding activity of the eel hosts. On the other hand, the prevalence and mean intensity of both larval and adult-stage worms showed size-dependent increases in wild Japanese eels. This suggests that the eel accumulates parasites during its lifetime. However, the intensity of larval stage worms showed size-dependent decreases in both cultured Japanese and American eels. The reason might be that the host regulates repeated infections by *Aco. crassus* to some extent (Knopf and Lucius 2008), especially when the infection intensity is already high, such as in cultured eels.

Under aquaculture conditions, the mean intensity of *Aco. crassus* infection was at least 2-fold higher than that in the wild. The higher intensity of infection in cultured eels is probably related to the higher density of eels and greater chances of contact with the parasite in controlled environments like ponds. Due to the absence or



**Fig. 3.** Comparison of the mean body mass of male and female *Anguillicola crassus* among wild and cultured Japanese eels and cultured American eels. \* $p < 0.05$ , compared to wild Japanese eels.



**Fig. 4.** Regression of total length on the condition factor (C-factor) between uninfected and infected groups of wild (A) and cultured (B) Japanese eels and cultured (C) American eels.

low availability of paratenic fish hosts in eel ponds, the dispersal of *Aco. crassus* totally depends on copepods and ostracods in the rearing water, which are swallowed with the feed by accident. Although intermediate hosts are abundant in culture ponds, the availability of *Aco. crassus*, however, seemed to differ among ponds. The reuse of pond water and customary size selection activities of eels every 1-2 mo during the culture course might result in diverse prevalences among ponds.

The frequency distribution of adult and larval worms exhibited an exponential decay in wild and cultured Japanese eels, which differed from the negative binominal distribution in cultured American eels. This reflects a high susceptibility to *Aco. crassus* by American eels. Interestingly, some batches of cultured Japanese eels possessed a similar prevalence (YL), mean larval intensity (BD2), and mean adult intensity (BD4) compared to cultured American eels (YW). This suggests that infection by *Aco. crassus* can also be very high in cultured Japanese eels under high infection pressures. On the other hand, infection of cultured American eels greatly differed between the 2 sampled ponds. This may be attributed to the regular use of the insecticide, Trichlorfon (Dipterex), in the pond with a low prevalence. Trichlorfon killed the intermediate hosts of *Aco. crassus*, thus efficiently interrupting its infection route. All other batches of cultured eels were collected from ponds without a history of drug application. In addition, *Aco. crassus* adults collected from American eels were considerably larger than worms dissected from Japanese eels, similar to the condition found in the European eels (Knopf and Mahnke 2004, Munderle 2005). This indicates that both naive American and European eels have poor defenses against *Aco. crassus* infection compared to native Japanese eels.

Since the swimbladder is important for buoyancy control, oxygen exchange, absorption, secretion, and acid-base homeostasis (Würtz et al. 1996, Tesch 2003), impairment of the swimbladder's function may result in aberrant migratory behavior in association with reduced swimming performance (Sprengel and Lüchtenberg 1991). Infected eels may also be more vulnerable to predation (Barse and Secor 1999) and capture by commercial trawlers (Sprengel and Lüchtenberg 1991). In the present study, except for a slight thickening and dispersed blood vessels of the swimbladder in heavily infected eels, we observed no other clinical signs in infected

Japanese or American eels. The condition factor, which represents the nutrition status, showed no significant differences between infected and uninfected groups. The HSI, an index that may reflect the presence of infection due to liver swelling in fish (Rahimian 1998), also showed no significant differences between infected and uninfected eels. This is supported by a study of European eels (Möller et al. 1991). Although economic losses of cultured European (Egusa 1969) and American eels (Ooi et al. 1996) after *Aco. crassus* infections have been reported, the parasite obviously did not seem to be a serious problem for cultured eels in the present study. Good pond management might prevent the possible pathogenesis in culture ponds.

Declines in eel resources seem to be a global trend, which occurred long before the invasion by *Aco. crassus* into Europe and North America (Johnson et al. 1995, Dekker et al. 2003, Taraschewski 2006). The possible effect of the *Aco. crassus* invasion on the long-term resources of European and American eels thus requires further study. In conclusion, we found diverse infection patterns of *Aco. crassus* among native wild and cultured Japanese eels and exotic American eels. The normal growth and insignificant pathogenesis in infected eels provide some information on eel culture. Many countries in South and Southeast Asia, Oceania, and Africa (South Africa, Mozambique, Madagascar, and Reunion) are presently establishing eel farms with local or imported eels (Taraschewski 2006). These projects should pay more attention first to preventing the invasion and spread of *Aco. crassus* and second to good pond management to alleviate any possible pathogenesis.

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