The Crustacean Society

Journal of
Crustacean Biology

Journal of Crustacean Biology, 37(3), 356–358, 2017. doi:10.1093/jcbiol/rux026

Effects of the parasitic isopod *Ichthyoxenus japonensis* Richardson, 1913 (Isopoda, Cymothoidae) on the growth and gonad development of the goldfish *Carassius auratus* Linnaeus, 1758

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(Received 12 February 2017; accepted 27 February 2017)

ABSTRACT

A total of 336 specimens of the goldfish *Carassius auratus* Linnaeus, 1758 were examined in the Baihe River, Henan Province, China, for the presence of the parasitic isopod *Ichthyoxenus japonensis* Richardson, 1913. Only 20 goldfish (5.95%) were infected with single and paired isopods, and seven fish were previously infected. There was no significant difference in mean body condition (as $K = (EW/L^3) \times 100$, where EW is the eviscerated body weight and L is fork length) between infected (mean 1.450) and uninfected fish (mean 1.448; $P = 0.95$). The weight of gonads of the infected fish ($N = 20$) was calculated as zero because the gonads were too small to weigh or to identify the sex. There was also no significant difference in the GSI (gonadosomatic indices) between the infected fish (mean 2.66) and the uninfected individuals (mean 4.80; $P = 0.30$). The results suggest that the reproductive ability of the host was severely reduced by infection of the isopod, but that the gonads of the castrated fish could recover after the loss of the isopods.

Key Words: fish reproduction, gonadosomatic index, parasitic castration

Infections with species of *Ichthyoxenus* Herklots, 1870 usually cause deleterious effects on the hosts (Martin *et al.*, 2014), such as a reduction of the host growth with infection by *Ichthyoxenus fushanensis* Tsai & Dai, 1999 (Tsai & Dai, 1999), malformation of the intestines by *I. amurensis* Gerstfeldt, 1858 (Yamano *et al.*, 2011), and parasitic castration and absence of gonadal development (Huang & Qian, 1980). *Ichthyoxenus japonensis* Richardson, 1913 can be found in many species of freshwater fishes (Ding, 1986; Kuang & Qian, 1991), with the goldfish *Carassius auratus* Linnaeus, 1758 being the preferred host (Huang & Qian, 1980). The adult isopod is commonly found in the body cavity of the host surrounded by a thin-walled membranous sac close to the external surface of the fish, where an orifice develops near the pectoral fin for the escape of the larvae of the isopod. A heterosexual pair of isopods is usually found in the sac, with their posterior ends oriented toward the orifice (Huang & Qian, 1980). The growth and gonadal development of the hosts are usually affected by *I. japonensis*, with high prevalence of infection in lakes, rivers, and reservoirs in China (Huang & Qian, 1980; Ding, 1986).

Carassius auratus is an economically important fish in China, and is abundant due to its high reproductive rate, becoming sexually mature at the age of one year, with a length of about 9 cm (Chen, 1959). Goldfish is very common in the Baihe River, Henan Province. We described the infestation pattern of *I. japonensis* in a population of *C. auratus* in the river in order to test if the parasite has any effect on the growth and gonadal development of the host.

Fish were captured by using trawl nets at the Nanyang section (33°0′10.48″N, 112°35′16.04″E) of the Baihe River in July 2015. Fish were euthanized and fork length measured to the nearest 0.1 cm. The presence of isopods was confirmed by the presence of an orifice on the external surface of the body cavity of the fish.

Table 1. Length frequency of sampled goldfish (*Carassius auratus*) categorized into number of individuals infected by the isopod parasite *Ichthyoxenus japonensis*, uninfected fish, and previously infected fish, and the prevalence of the isopod in each size class of the fish host.

Size class (cm)	≤11	11–13	13–15	15–17	17–19	19–21	>21	Total
Number of uninfected fish	32	40	26	44	50	96	21	309
Number of infected fish	0	5	8	2	3	2	0	20
Number of previously infected fish	0	0	0	0	4	3	0	7
Number of fish in each size-class	32	45	34	46	57	101	21	336
Prevalence (%)	0	11.11	23.53	4.35	5.26	1.98	0	5.95

All isopods were fixed in 80% ethyl alcohol. Fish with an orifice but without isopods were recorded as previously infected. The gonads and eviscerated body weight of each fish were weighed to the nearest 0.1 g. Because the gonads of immature fish (standard length less than 10 cm) and some infected fish were too small to be weighed, the gonad weight was recorded as zero.

Prevalence (percentage of fish infected) was calculated for the sample as defined by Bush *et al.* (1997). To analyze changes of the number of infected, previously infected, and uninfected fish in relation to fish length (L in cm), fish were arbitrarily grouped into seven size classes ($L \leq 11$; $L = 11–13$; $L = 13–15$; $L = 15–17$; $L = 17–19$; $L = 19–21$; and $L > 21$ cm), and the prevalence for each size-class calculated. Host body condition was measured as $K = (EW/L^3) \times 100$, where EW is the eviscerated body weight (g) and L fork length (cm). Gonadosomatic index (GSI) was calculated as $GSI = A \times 100/EW$, where A is gonad weight. The significance of the difference in body condition between infected and uninfected fish was tested using a t-test. Because the minimum length of infected fish was 11.5 cm and that of immature fish was less than 9 cm, individuals less than and equal to 11 cm was excluded in the analysis of the gonadosomatic index. The recovery of gonads after the isopods had left previously infected hosts and the significance of differences in GSI and gonad weight were tested using a t-test between previously infected and uninfected fish.

A total of 336 goldfish, fork length ranging from 6.7 to 25.0 cm (16.7 ± 3.9), were examined for the presence of *I. japonensis* (Table 1). Only 20 fish (prevalence = 5.95%) were found to be infected with paired *I. japonensis* (in 17 fish) and single females (in three fish), and seven fish had evidence of previous infection without isopods. There was no infection in fish less than 11 cm and larger than 21 cm. Prevalence (23.53%) peaked in the intermediate-size group (13–15 cm). All instances of previous infections were found in large fish (17–21 cm) (Table 1).

All the parasitized fish showed no evidence of gonad development, and their gonad weight was recorded as zero. The average gonad weight of previously infected fish (1.93 ± 1.87 g) was lower than uninfected fish (4.27 ± 5.67 g), but the difference was not significant (t-test, $t = -1.093$, $df = 282$, $P = 0.28$). There was no significant difference in the GSI between the previously infected fish (2.66 ± 2.62) and the uninfected individuals (4.80 ± 5.40) ($t = -1.044$, $df = 282$, $P = 0.30$). There was no significant difference in mean body condition between infected (1.450 ± 0.216) and uninfected fish (1.448 ± 0.159) ($t = 0.69$, $df = 327$, $P = 0.95$).

Macro-parasites such as isopods usually consume tissue, having detrimental effects on the growth of their fish hosts (Adlard & Lester, 1994; Bunkley-Williams & Williams, 1998). Some parasitic isopods, however, do not exert a significant influence on the weight-size ratio or condition factor of their fish hosts (Romestand & Trilles, 1979; Parker & Booth, 2013). There was no significant difference in body condition between goldfish with and without *I. japonensis*. This apparent absence of effects on the host body condition might be the result of an increased food intake to compensate for the extra nutritional requirements caused by the parasitic infection (Giles, 1987; Lozano, 1991). The cardinal fish *Cheilodipterus quinquelineatus* Cuvier, 1828 infected by the isopod *Anilocra apogonae* Bruce, 1987, for example, lost more weight than non-parasitized fish when fed on a low-food diet, but gained a similar amount of weight when the fish received large rations of food. This result suggests that the energy balance affected by the isopod can be compensated for with high food intake (Ostlund-Nilsson *et al.*, 2005).

Infection with *I. japonensis* nevertheless caused a suppression of the gonad development in their host. A reduction in the reproductive ability of a host is a common phenomenon among fishes infected by isopods (Adlard & Lester, 1994; Fogelman *et al.*, 2009). Goldfish usually reproduce in spring and summer. The hatchlings mature by the end of the year (Chen, 1959). Despite sampling in July after the breeding season, gonads of all the uninfected goldfish could be detached and weighed. Gonads of infected fish, however, were hardly visible. The mechanism of parasitic castration of the host remains poorly known, but hormonal interference (Beck, 1980; Lima *et al.*, 2007) and nutritional drain caused by the parasite (Anderson, 1977; Walker, 1977; Conner & Bauer, 2010) have been proposed as explanations. Another cymothoid isopod, *Riggia paranensis* Szidat, 1948, which burrows into the flesh of its fish host, *Cyphocharax gilbert* Quoy & Gaimard, 1824, also causes parasitic castration (Azevedo *et al.*, 2006). This parasite perhaps affects the host's endocrine system and alters the sex-specific plasma proteins (Azevedo *et al.*, 2002; Gomes *et al.*, 2005; Azevedo *et al.*, 2006; Lima *et al.*, 2007). The inhibition of gonad development of the infected host by isopod parasites is not permanent or unrecoverable (Beck, 1980). Despite gonad weight of previously infected fish being lower than that of uninfected fish, their gonads recover, and the fish regain some reproductive ability after the death or detachment of the parasitic isopods.

ACKNOWLEDGEMENTS

This work was supported by the Earmarked Fund for China Agriculture Research System (CARS-46-08), the National Natural Science Foundation of China (31272695, 31572658) and the major scientific and technological innovation project of Hubei Province (2015ABA045).

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