Parasitology International 72 (2019) 101932

Contents lists available at ScienceDirect

Parasitology International

journal homepage: www.elsevier.com/locate/parint

Short communication

A comparison of body condition of the yellowstriped butterfish *Labracoglossa argenteiventris* in relation to parasitism by the cymothoid isopod *Ceratothoa arimae*

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ARTICLE INFO

Keywords:
Cymothoidae
Mouth parasite
Isopoda
Host body condition
Kyphosidae
Izu Island chain

ABSTRACT

Isopods of the genus *Ceratothoa* (Cymothoidae) are one of the largest invertebrates parasitic on a variety of fishes, which include commercially important species. Nevertheless, the parasitic effects on fish body condition have been studied only in a few *Ceratothoa* species, particularly those living in the Mediterranean and Australian waters. Findings from these previous studies suggest the hypothesis that effects of parasitism by *Ceratothoa* species are benign on native host condition in the wild. In this study, to test this hypothesis on another *Ceratothoa*–fish relationship in different region, we examined the effects of *Ceratothoa arimae* on the body condition of the yellowstriped butterfish, *Labracoglossa argenteiventris*, a commercial fish important to local fisheries particularly in the remote islands of Tokyo, Japan. *Ceratothoa arimae* was found in 8 out of 23 fish examined (prevalence: 34.8%). Although infected and uninfected fish were similar in standard length, the body condition index (relative weight) of infected fish was significantly lower than that of uninfected fish. The observed weight of infected fish was an average of 89.2% of the expected weight. These results are inconsistent with the hypothesis and suggest that the potential effects of *Ceratothoa* parasites need to be considered carefully in fishery management plan of host fish.

Ceratothoa Dana, 1852 is a speciose genus in the fish-parasitic isopod family Cymothoidae Leach, 1818, with over 30 species in the world [1]. Most species of the genus parasitize in the buccal cavities of their fish hosts, typically on fish tongues, where they are considered to feed on host blood and tissues [2]. Since they are protandrous hermaphrodites, the females are larger than the males [1] and, in some species, grow to over 30 mm in total length [2,3], often occupying a large portion of fish buccal cavity [4,5].

Despite the fact that isopods of *Ceratothoa* are one of the largest fish parasitic invertebrates and that they parasitize a variety of fishes including commercially important species, the parasitic effects on fish body condition have been studied only in a few *Ceratothoa* species, particularly those living in the Mediterranean and Australian waters [2,4–7]. For example, Carrassón & Cribb [5] found that condition indices of a native host fish did not differ between individuals with and without female *Ceratothoa banksii* (Leach, 1818) (originally reported as *C.* cf. *imbricata*. See also [3]) in Australian waters despite the fact that the isopod occupied most of the buccal cavity of the host (up to 86%). Similarly, previous studies on native *Ceratothoa*–host relationships have frequently reported no or negligible parasitic effects on host conditions in the wild [4,7]. On the other hand, severe effects by *Ceratothoa* isopods have been reported on cultured (and sometimes non-native host) fishes (e.g. [2]). These findings suggest the hypothesis that effects of parasitism by *Ceratothoa* species may be benign on native hosts under natural conditions.

To test this hypothesis in another native *Ceratothoa*–fish system, we examined body condition of the yellowstriped butterfish, *Labracoglossa argenteiventris* Peters, 1866 (Kyphosidae, Perciformes) with and without *Ceratothoa arimae* [8], a northwestern Pacific species. *Ceratothoa arimae* has been reported only from the yellowstriped butterfish, suggesting the high host specificity, and is possibly the largest parasite (up to approximately 25 mm total length) of the fish [8,9]. The yellowstriped butterfish is a zooplanktivorous species that inhabits rocky areas mainly along the Pacific coast of the Japanese Islands, from Kyushu Island to the Boso Peninsula [10]. This fish species has a long history as a fishery product in Japan, especially the remote islands of Tokyo, dating back to

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https://doi.org/10.1016/j.parint.2019.101932
Received 27 December 2018; Received in revised form 20 May 2019; Accepted 20 May 2019
Available online 23 May 2019

at least the 15–16th centuries (Muromachi period) [11]. Nevertheless, effects of parasites on the yellowstriped butterfish condition remain unknown, although the life history and stock assessment of the fish have been examined [12,13]. Therefore, understanding the parasitic effects of *C. arimae* also contributes to sustainable fisheries of the fish.

We purchased twenty-three adult individuals of the yellowstriped butterfish from a fish shop near the Tsukiji fish market, Tokyo, Japan in July 2013. These individuals were caught around Nii-jima Island (23.64 km^2; 34°22′N; 139°15′E), of the northern Izu Island chain on the day. The Izu Island chain is a part of remote islands of Tokyo extending north to south in the Pacific Ocean.

After removing *C. arimae*, all fish were measured to the nearest 0.1 mm standard length and weighed to the nearest 0.1 g wet weight. Fish sex was not measured because the yellowstriped butterfish does not exhibit obvious sexual dimorphism in morphology and because we sampled the fish during its non-reproductive season [10]. For *C. arimae*, number of individuals per a host, total length (to the nearest 0.1 mm), wet weight (to the nearest 0.1 g) and sex were measured.

To evaluate the effects of *C. arimae* infection on the host body condition, we applied the concept of relative weight [14] to the present study. First, a linear logarithmic weight—length equation was developed using uninfected fish:

$$\mathrm{Log}\ y = 0.8766\ \mathrm{Log}\ x + 0.1998$$

where x and y are fish length and weight, respectively ($R^2 = 0.44$, $p = 0.007$; Fig. 1A). Then, the relative weight, Wr, was calculated for all fish according to the following equation:

$$W_r = (W/W_e)$$

where W is the actual fish weight and W_e is the expected weight at a given body length (calculated from the weight—length equation). A value of $0 < W_r < 1$ means lower body weight than expected for fish length (i.e. poor body condition).

The relationships between host length and both female and male isopod lengths were examined using Pearson's correlation coefficient. To examine the effects of cymothoid infection on the host, fish standard length and relative weight were analyzed using a Student's *t*-test with parasite presence as the main factor. Fish standard length and isopod total length were log-transformed prior to the analyses to improve normality. All statistical analyses were performed in R 3.1.2 [15].

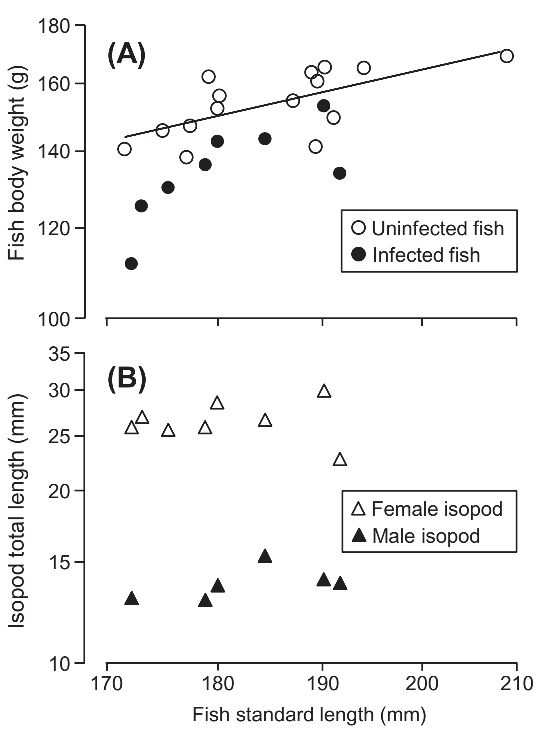

Fig. 1. (A) Relationship between the yellowstriped butterfish *Labracoglossa argenteiventris* standard length and body weight; the linear regression (line) was performed using only uninfected fish. (B) Relationship between the yellowstriped butterfish standard length and *Ceratothoa arimae* male and female total length. Both axes are logarithmic.

Among the 23 yellowstriped butterfish individuals, 8 were parasitized by *C. arimae* (parasite prevalence: 34.8%). Most of infected fish carried a female–male pair of isopods (6 fish) and only 2 fish had a single female isopod in the buccal cavity.

Standard length of fish and total lengths of female and male isopods were 183.6 ± 9.0, 26.4 ± 2.1, and 13.7 ± 0.9 mm (mean ± SD), respectively. Female and male isopod lengths showed no correlation with fish length (female, $r = -0.052$, $p = 0.90$; male, $r = 0.519$, $p = 0.29$; Fig. 1B). The difference in fish standard length between infected and uninfected individuals was not statistically significant (*t*-test, $t = -1.19$, $p = 0.25$). However, fish relative weight was significantly lower in infected individuals than in uninfected individuals (*t*-test, $t = -4.54$, $p < 0.001$; Fig. 1A). The observed weight of infected fish was an average of 89.2% of the expected weight (observed and expected weights, 134.5 ± 12.7 and 150.6 ± 5.4 g, respectively; mean ± SD).

The present study revealed that *C. arimae* infection significantly lowered the body condition of the yellowstriped butterfish: the infected fish's body weight was approximately 90% of the expected body weight. This results contrast with the previous studies in the Mediterranean and Australian waters, which studies suggested that *Ceratothoa* isopods are benign parasites for their native hosts in the wild [4,5,7]. The good health of the host is beneficial for parasites. This is particularly true for cymothoid isopods because they lose their swimming ability after attaching to the definitive host and cannot infect a new host individual [1]. They therefore need to optimize host exploitation to maximize fitness while minimizing impacts on host mortality. In buccal-attaching species like *C. arimae*, furthermore, their growth (and also fecundity) is spatially constrained by the buccal cavity volume of the host (i.e. host growth) [4,5]. In such a situation, natural selection would favor individuals that take a strategy in which they exploit in moderation and grow in harmony with their host growth. In fact, a clear positive correlation between parasite and host body length has been reported in many cymothoid species (e.g. [4,5]), although it was unclear in the present study due to the narrow range in fish size.

As cymothoids and hosts grow older, however, the situation may change because longevity of cymothoids is considered to be shorter than that of their hosts (e.g. [7]). That is, it may be more adaptive for the older parasite to invest in reproduction by increasing host exploitation than to exploit in moderation for future growth. According to Watari [12], the yellowstriped butterfish lives up to approximately 8 years along a characteristic growth curve; the fish grows rapidly to over 150 mm fork length until 2 years of age, but the growth rate decreases considerably after 3 years of age (ca. 5 mm per year, [12]). Given this growth curve, all the individuals we examined were estimated to be 2 years of age or older, at which the growth rate had already been slowed. Therefore, the obvious effects of infection we found might be due to increased host exploitation by well-matured *C. arimae* individuals with a limited life expectancy. Future research should focus on ontogenetic changes in the effects of the infection by collecting a series of ages of the yellowstriped butterfish.

Difference in host specialization among *Ceratothoa* species may be an additional factor influencing host–parasite interactions. *Ceratothoa arimae* parasitizes only the yellowstriped butterfish while the other *Ceratothoa* species previously studied are known from > 5 fish species each [3,16]. A broader host range may increase transmission success, but it also reduces performance of parasites in each host species due to increased costs of dealing with different immune systems and life histories of multiple hosts [17]. Consequently, effects of parasites with broad host range on body conditions of each host species might lower and often become undetectable coupled with energy compensation by host itself [18]. On the other hand, parasites with a single host can maximize their performance by dealing with the host immune system and optimizing a host-exploitation strategy to the host life history.

Some studies reported that harmful effects of cymothoids were seen even in native host fishes when there were other environmental stressors from anthropogenic activities, such as water pollution and overfishing [6,19]. For example, Sala-Bozano et al. [6] found negative effects of *Ceratothoa italica* on growth and hepatosomatic index of the striped sea bream, *Lithognathus mormyrus* (Linnaeus, 1758) in an area of intense fishing pressure, but not in an area close to a marine protected area in the Mediterranean Sea. In the present study area, however, the effects of anthropogenic activities might be low because of the remote island far from urban areas (> 100 km). In fact, coastal areas around the Izu Island chain have good water quality; the chemical oxygen demand (COD) at marine beaches of the islands was approximately 0.5–1.5 mg/L [20]. In addition, even if low-quality habitats were distributed patchily around the islands, the effects of such patches on the present results might be limited because the yellowstriped butterfish is a schooling fish migrating along rocky coast. Severe fishing pressure was also unlikely despite the fact that the yellowstriped butterfish is one of the fisheries products in the northern Izu Island. Capture of small butterfish (≤ 100 mm total length) is prohibited by the fisheries management regulation of Tokyo to protect the fish stock. Watari [13] estimated the yellowstriped butterfish stock during 1994–2003 in the northern Izu Island chain using a tuned virtual population analysis. Indices of biological resource management suggested that the recent fishing pressure on the fish was not severe [13]. In addition, the number of installed nets targeting the yellowstriped butterfish has decreased in the last few decades [13] probably due to depopulation of fisherman in the islands.

In coastal and island countries, fisheries have targeted various wild fish species, some of which are known as hosts of Cymothoidae including *Ceratothoa*. For example, *Ceratothoa* species are known to parasitize at least 10 fish species that have been targeted in fishery in Japanese coastal waters [21]. Nevertheless, effects of *Ceratothoa* species on their host conditions are little known, particularly in fishes important for local fishery. Our results indicate that parasitism of *Ceratothoa* isopods is not always benign for native hosts and can have negative effects on the host body condition even in the wild. Therefore, for sustainable fishery management of host fishes, the potential effects of *Ceratothoa* parasites will need to be considered carefully.

Acknowledgments

The authors are grateful to H. Mishima and S. Fujii for providing valuable information on parasitic isopods in Izu Islands. We would like to thank two anonymous reviewers for helpful comments. This work was partly supported by the Mikimoto Fund for Marine Ecology and by the Showa Seitoku Memorial Foundation.

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