

# Effects of three Caribbean cleaner shrimps on ectoparasitic monogeneans in a semi-natural environment

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**Abstract** Most research on cleaning symbioses on coral reefs has focused on fish clients being cleaned by smaller fishes. While many shrimps and other crustaceans are reported as cleaners, whether they remove parasites from fish hosts and can effectively regulate populations of ectoparasites is unclear. The effects of Pederson shrimp (*Periclimenes pedersoni*), spotted shrimp (*P. yucatanicus*), and banded coral shrimp (*Stenopus hispidus*), on the parasitic monogenean *Neobenedenia melleni* on a host reef fish, blue tang (*Acanthurus coeruleus*), were investigated. The abundance and size of *N. melleni* from fish with and without access to shrimps in a semi-natural macrocosm was quantified. *P. pedersoni* had a strong effect on both the abundance and size of parasites. In contrast, *P. yucatanicus* and *S. hispidus* had no effect on the abundance of parasites but had a small yet statistically significant effect on average size. These data suggest that *P. pedersoni* can play a significant role in the biological regulation of at least some ectoparasites on Caribbean reef fishes, but further suggest that some other shrimps regarded as “cleaners” may have little or no effectiveness at removing parasites and

underscore the need for further verification before this term is applied.

**Keywords** Acanthuridae · Cleaning symbiosis · Ectoparasites · Coral reefs · Anemone

## Introduction

Cleaning symbioses are interspecific associations in which one or more participant “cleaner” organism removes ectoparasites and or tissue from the body of another “client” or “host” organism that often solicits the interaction by adopting stereotypic postures in the presence of the cleaner. Although reported for some terrestrial organisms (Dickman 1992), such interactions are best documented among marine reef organisms, particularly fish clients being cleaned by smaller fishes, most notably Indo-Pacific cleaner wrasses and Caribbean cleaning gobies (Poulin and Grutter 1996; Losey et al. 1999; Côté 2000). Cleaner fishes remove ectoparasites (Losey 1974; Grutter 1999; Arnal and Côté 2000), as well as injured tissue (Foster 1985). However, they also remove and may even prefer host mucus (Arnal et al. 2001; Grutter and Bshary 2003). Thus, whether this activity actually controls ectoparasite loads and results in a net benefit to hosts has been the source of some controversy (Losey 1987; Poulin and Vickery 1995; Côté 2000; Cheney and Côté 2005; Morand 2005).

Approximately 40 species of shrimps and other decapod crustaceans are also regarded as cleaners of reef-associated fishes (Jonasson 1987; VanTassell et al. 1994; Spotte 1998; Côté 2000; Becker and Grutter 2004; Chapuis and Bshary 2009). However, most accounts have been based on observations of “cleaners” crawling on or picking at the external surface of fishes, with many accounts based solely

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on aquarium observations and/or appearing only in the popular aquarium literature. Only a few studies have provided direct evidence that any ostensible cleaner shrimp species effectively removes parasites from fishes (Bunkley-Williams and Williams 1998; Becker and Grutter 2004, 2005; Östlund-Nilsson et al. 2005) and none has examined the longer term effects of cleaner shrimps in regulating parasite populations on fishes, and thus potentially contributing to client fitness.

In the Caribbean and tropical western Atlantic, the Pederson shrimp, *Periclimenes pedersoni* Chase, 1958 and spotted shrimp, *P. yucatanicus* (Ives, 1891) (Palaemonidae), are two of the most common shrimps that are reported as a cleaner (Limbaugh et al. 1961; Wicksten 1995; Spotte 1998; DeLoach and Humann 1999), and are typically found in association with anemones (e.g., Mahnken 1972; Williams and Williams 1982, 2000; Gwaltney and Brooks 1994). *P. pedersoni* has been shown to eat parasitic isopods in captivity (Bunkley-Williams and Williams 1998), making it the only Caribbean species for which removal of parasites from hosts has been documented. However, the range of ectoparasites it consumes and the potential for longer term impacts on ectoparasites is unknown. The banded coral shrimp *Stenopus hispidus* (Olivier, 1911) (Stenopodidae) has also been long reported as a “cleaner shrimp” (e.g., Limbaugh et al. 1961) and is common throughout the Caribbean and tropical western Atlantic (Chockley and St. Mary 2003). However, like *P. yucatanicus*, there are no published data on its removal of parasites from fish hosts.

This paper reports results of an experimental study to determine whether *P. pedersoni*, *P. yucatanicus*, or *S. hispidus* can regulate populations of the monogenean *Neobenedenia melleni* MacCallum, 1927 (Capsalidae) infecting blue tang, *Acanthurus coeruleus* Bloch and Schneider, 1801 (Acanthuridae) under semi-natural conditions. Monogenean flatworms are among the most common ectoparasites of marine reef fishes (Whittington 1998). Parasite damage affects mucus production and interferes with respiratory function in the gills (Thoney and Hargis 1991), and can contribute to secondary infections (Jithendran et al. 2005). They are also associated with mass die-offs of host fishes in aquaria and aquaculture enclosures (Montero et al. 2004). Cleaner fishes (Cowell et al. 1993; Grutter et al. 2002) and several shrimp species (Becker and Grutter 2004; Östlund-Nilsson et al. 2005) have been reported to remove monogeneans from fish in captivity. *A. coeruleus* was selected as the host species in this study because it is often heavily infected with *N. melleni* in the wild (Sikkel et al. 2009) and is often observed interacting with *P. pedersoni* in the wild (authors’ personal observation).

## Materials and methods

### Preliminary observations

Preliminary feeding trials were conducted on each species prior to its use in macrocosm experiments to determine whether it ate monogeneans. Three to five individuals of each species were placed in separate plastic tubs and offered 5–10 *N. melleni* removed from *A. coeruleus*. All three species were observed eating monogeneans, and all monogeneans disappeared within 24 h.

### Experimental macrocosm and processing of parasites

The experimental trials were conducted between June and October 2007 (*P. pedersoni*), 2008 (*S. hispidus*), and 2009 (*S. hispidus* and *P. yucatanicus*) on St. Thomas, US Virgin Islands (18°20'N, 64°50'W), using a concrete overflow trough that encircled a large ( $3.0 \times 10^5$  l) coral reef display tank, the “Caribbean Reef Encounter” (CRE) at Coral World Ocean Park. The trough measures 0.7 m deep, 0.5 m wide, and approximately 60 m in circumference with sand, rubble, and algae on the bottom, and algae growing on the walls. Invertebrates naturally found living in this kind of substratum on nearby reefs were abundant in the trough. Water for the CRE is drawn directly from the ocean off Coki Point. Exhibit fish have been observed to carry heavy monogenean loads, thus fish in the experimental trough were exposed to high densities of parasitic monogenean eggs and/or larvae flowing into the trough from the exhibit.

For all trials, two equal-sized areas were created opposite one-another using plastic hardware cloth and screen partitions, which allowed for water flow while inhibiting movement of animals between treatments. These two areas were separated by two “buffer” zones to prevent any fish or shrimps from entering the other treatment in the event of an escape. Each section received input from the main tank via two 20-cm diameter pipes. For the first two *P. pedersoni* trials, each section was 7 m in length. For the last *P. pedersoni* trial and all other trials, each of the two sections was expanded to 14 m. This improved water circulation and allowed more freedom of movement for fish and shrimps. Pieces of 16-cm diameter PVC pipe and cement blocks were added to each section for habitat structure and nocturnal shelter sites for fish. *A. coeruleus* used in the experiments were collected at night from sites where fish average fewer than 5 *N. melleni* each (Coki Point and Flat Cay: Sikkel et al. 2009) by divers using aquarium nets and placed into bait buckets. Fish were then held in aerated tanks before being transferred to the experimental macrocosm within 24 h. During experiments, fish fed on algae along the trough walls, supplemented with

romaine lettuce and a small amount of squid. Experiments were monitored every other day by the investigators and opportunistically by Coral World staff.

At the end of each trial, fish were processed as described by Sikkel et al. (2009). Briefly, each fish was individually placed in a bucket with dechlorinated freshwater for approximately 5 min, gently rubbed with a finger to dislodge ectoparasites, measured for fork length and treated with a slime coat replacement (Stresscoat: Aquarium Pharmaceuticals). Fish were used for no more than two trials before being released.

Water from each fish was filtered using a 53- $\mu$ m mesh. All material caught in the mesh was dyed with red food coloring then re-filtered into a Petri dish and contents were examined under a dissecting microscope. Ectoparasites from individual fish were counted and preserved for identification. To examine the effects of cleaners on the size distribution of monogeneans, parasites were photographed with a microscope camera mount or an AVerVision SPC300 and measured using Image-J (U. S. National Institutes of Health, Bethesda, Maryland, USA, <http://rsb.info.nih.gov/ij/>). For fish with high parasite loads (>50), we limited measurement to 30 randomly selected parasites. A total of 736 parasites were photographed and measured from the last *P. pedersoni* trial, 925 and 295 from each of the two *P. yucatanicus* trials, and 821 from the 2008, and 794 from the 2009 *S. hispidus* trials. The second set of measurements for *P. yucatanicus* and *S. hispidus* were made because of the small effect size found in the first set of measurements (see later). For the second *P. yucatanicus* trial, measurements were limited to parasites from a subset of five fish in each treatment.

#### *Periclimenes pedersoni*

Because *P. pedersoni* collected during this study were found in association with *Bartholomea annulata* (LeSeuer, 1817) anemones, anemones attached to rocks were placed on the floor of the treatment trough areas, eight per side. Anemones were collected from several shallow (3–10 m depth) sites off St. Thomas (Saba Rock, Brewers Bay, and Coki Beach) and transported in large buckets with seawater. Fifteen shrimps associated with these and other anemones were also collected and transported in hermetically sealed plastic bags with seawater and introduced to the “shrimp” side of the trough. The anemones and shrimp were acclimatized for 24 h before fish were introduced to treatments. For the first *P. pedersoni* trial, fish ( $n = 12$ ) were matched for size and then randomly assigned to one of two treatments: anemones and shrimp or anemones with no shrimp.

After 17 days, fish were processed as described above, and another trial was started using the same fish, but subject to the opposite treatment (repeated measures): fish

from the “shrimp” side were placed in the “non-shrimp” side and vice versa. Individual fish were identified using size measurements. Size was used rather than marking because tissue damage may influence interactions with cleaners (e.g., Foster 1985). This trial was allowed to run 20 days, however, only three fish from the non-shrimp side survived to the end of the trial. Thus, an additional trial was run using 28 new fish (14 per side). As mentioned earlier, prior to this trial, the experimental areas were expanded, the substratum of each side was vacuumed, and the location of the shrimp and non-shrimp treatments was reversed, and 15 additional shrimp were added. Fish densities and shrimp/fish ratio were therefore similar to the previous (repeated-measures) trials. Twenty-six fish survived until, and were processed on, day 21 of the trial.

#### *Periclimenes yucatanicus*

Because *P. yucatanicus* is similar in size to *P. pedersoni* and also associates with *B. annulata* anemones, both experimental arenas were similarly stocked with anemones, and one side with 22 shrimp, collected from the same sites as *P. pedersoni*. After a 24 h acclimatization period, a repeated-measures experiment was started with 28 fish, which were also matched for size and then randomly distributed between treatments. Fish were processed initially after 14 days, and then returned to the same arenas as before, but subject to the opposite treatment by switching the location of shrimp. They were processed again after 15 days. Four fish died and three escaped following damage to one of the barriers (no shrimp escaped). Thus, 21 fish experienced both treatments. Three doctorfish (*A. chirurgus*) were added to the second shrimp treatment to keep fish densities between treatments similar but these were not included in analyses.

#### *Stenopus hispidus*

Three trials were run for *S. hispidus*, a single trial in 2008, and repeated-measures trials in 2009. Fish were distributed between trials as in the other experiments ( $n = 35$  in the 2008 experiment, and 28 in 2009). *S. hispidus* used in the experiments were collected from Brewers Bay ( $n = 16$  each) and transported as described previously. Fewer of this species were used because of their larger size compared with *P. pedersoni* and *P. yucatanicus*. As in the other experiments, shrimp were allowed to acclimatize for 24 h before the beginning of each trial. The *S. hispidus* trial in 2008 ran for 15 days, with 33 fish surviving to the end of the trial. In 2009, both trials ran for 14 days. Following the first trial in 2009, all shrimp were removed and placed in the other enclosure (“shrimp” and “non-shrimp” sides were reversed). A total of six fish died during the experiment and thus 22 experienced both treatments. Three *A. chirurgus*

were also used to help equalize densities between treatments but were not included in analyses.

### Statistical analysis

Data were analyzed using SYSTAT 9. Repeated-measures ANOVA using  $\ln(x + 1)$  transformed data was used to compare monogenean loads within fish that were subject to each treatment. In addition, ANCOVA was used for the single (non-repeated-measures) trials for *P. pedersoni* and *S. hispidus*. Treatment (shrimp or no shrimp) was a categorical variable, and body size (fork length) was a covariate. ANOVA was used to compare the effects of shrimp on the size of monogeneans. To control for effects of individual fish on estimates of differences in monogenean size between treatments, fish nested within treatment was included in the model.

## Results

### Effects of shrimp on monogenean loads

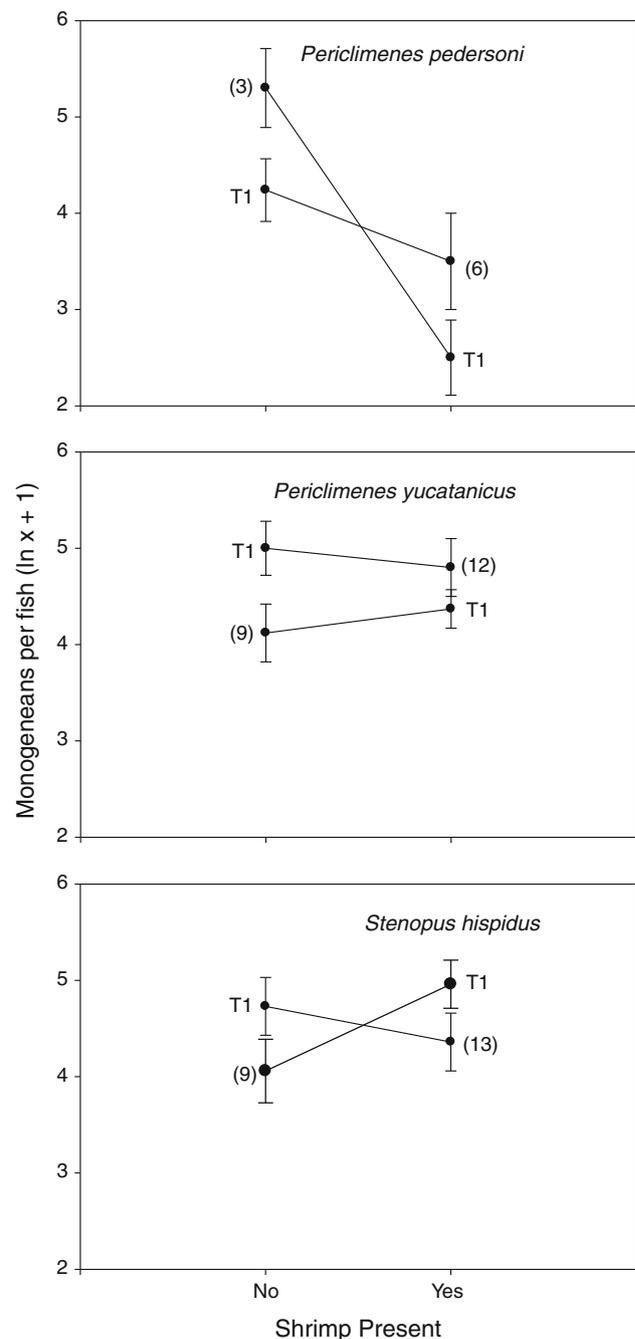
#### *Periclimenes pedersoni*

The number of monogeneans on fish in each group during a given trial was strongly dependent on the treatment they experienced (treatment  $\times$  trial  $F_{1,7} = 22.41$ ,  $P = 0.002$ ): All three fish that had access to *P. pedersoni* in the first trial but did not in the second experienced an increase in parasite load between trials (average = 15 times that of the first trial). Similarly, five of six fish that did not have access to shrimp during the first trial but did in the second experienced a decrease between trials (average =  $\frac{1}{2}$  of the trial 1 loads; Fig. 1). Overall monogenean loads in the trough increased between trials (trial effect:  $F_{1,7} = 8.10$ ,  $P = 0.025$ ) and the two groups (i.e., shrimp then no shrimp vs. no shrimp then shrimp) did not differ in overall monogenean loads combined over the two trials ( $P = 0.996$ ).

The result of the single, independent, trial for *P. pedersoni* was consistent with the repeated measures trials. There was a significant effect of both body size ( $F_{1,23} = 11.72$ ,  $P = 0.002$ ) and treatment ( $F_{1,23} = 25.16$ ,  $P < 0.001$ ) that explained 63.2% of the variation in monogenean loads. Monogenean loads among fish without access to shrimp were as high as 155 (mean = 79.25, median = 79), compared with 61 (mean = 18.5, median = 23), and thus averaged 4.4 times higher compared with those that did have access to shrimp (Fig. 2).

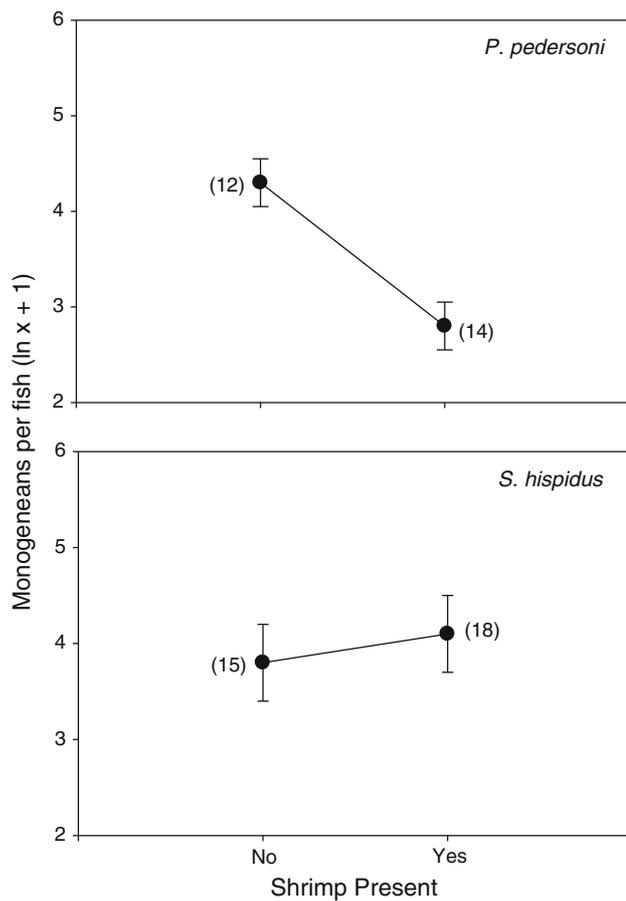
#### *Periclimenes yucatanicus*

As with *P. pedersoni*, the two groups of fish averaged similar numbers of monogeneans combined between trials



**Fig. 1** Results of within-fish (repeated measures) comparisons showing the number (mean  $\pm$  SE,  $\ln(x + 1)$  transformed) of *Neobenedenia melleni* on individual *Acanthurus coeruleus* in experimental macrocosms when fish did and did not have access to shrimp. T1 indicates the treatment fish in each of the two groups received during the first of the two trials. Only data from fish experiencing both treatments were used, and the number of such fish in each group is shown in parentheses next to their trial 2 values. S shrimp present; NS no shrimp present

( $P = 0.949$ ), although the overall monogenean loads decreased between the first and second trials ( $F_{1,19} = 7.55$ ,  $P = 0.013$ ). Unlike *P. pedersoni*, the number of monogeneans



**Fig. 2** Results of between-fish comparisons showing the number of *N. melleni* (mean  $\pm$  SE,  $\ln(x + 1)$  transformed) on fish with and without access to shrimp in experimental macrocosms after 15–21 days. Numbers in parentheses represent the number of fish processed in each replicate trial for each treatment

on fish in each group during a given trial was not dependent on the treatment they experienced (treatment  $\times$  trial  $F_{1,19} = 0.941$ ,  $P = 0.344$ ; Fig. 1).

#### *Stenopus hispidus*

Again, both groups of fish averaged similar numbers of monogeneans combined between trials ( $P = 0.376$ ), and there was a decrease in overall monogenean loads between the first and second trial ( $F_{1,20} = 4.28$ ,  $P = 0.052$ ). As with *P. yucatanicus*, the number of monogeneans on fish in each group during a given trial was not dependent on the treatment they experienced (treatment  $\times$  trial  $F_{1,20} = 0.023$ ,  $P = 0.88$ ; Fig. 1).

The result of the single *S. hispidus* trial was consistent with repeated measures trials. Unlike the *P. pedersoni* trial, there was no significant effect of body size on monogenean loads ( $F_{1,30} = 1.32$ ,  $P = 0.261$ ), and the fish with access to shrimp tended to have more monogeneans than those

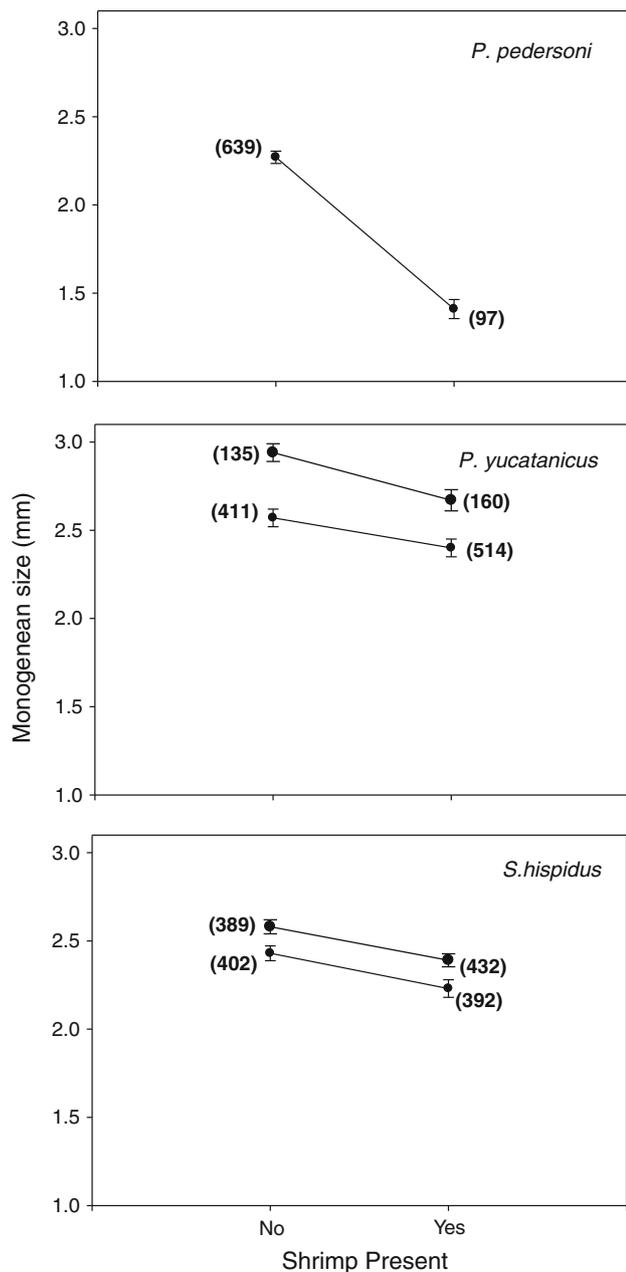
without, although the difference was not significant ( $F_{1,30} = 0.329$ ,  $P = 0.571$ ; Fig. 2).

#### Effects of shrimp on size of monogeneans

For both *Periclimenes* species, there was a significant effect of fish nested within treatment on the size of monogeneans (all  $P < 0.001$ ), but there was also a significant treatment effect ( $F_{1,717} = 29.25$ ,  $P < 0.001$ ; and  $F_{1,1187} = 28.27$ ; Fig. 3). For *P. pedersoni*, the effect was strong, with the size of monogeneans on fish without access to shrimp averaging nearly twice as large as those on fish with access. For *P. yucatanicus*, the effect was small, and while monogeneans averaged larger during the second trial ( $F_{1,1187} = 28.22$ ,  $P < 0.001$ ), it was consistent between trials (interaction  $P = 0.07$ ): monogeneans from fish without access to shrimp averaged 7 and 9% larger in the first and second trial, respectively. For *S. hispidus*, there was no significant effect of fish nested within treatment ( $P = 0.12$ ) and the term was dropped from the model. As with *P. yucatanicus*, both treatment ( $F_{1,1515} = 8.73$ ,  $P = 0.003$ ) and year ( $F_{1,1515} = 16.01$ ,  $P < 0.001$ ) effects were significant, but there was no interaction between the two ( $P = 0.85$ ), and treatment effect size was similarly small: 7% larger for fish without shrimp in 2009, and 6% larger in 2008 (Fig. 3). The small effect of treatment for *P. yucatanicus* and *S. hispidus* appeared to be the result of relatively low numbers of monogeneans in the largest size class (4–5 mm) among fish with access to shrimp.

#### Discussion

In the first study to document removal of ecto-parasites by a cleaner shrimp, Bunkley-Williams and Williams (1998) presented fish that had newly attached juveniles of the parasitic cymothoid isopod *Anilocra haemuli* to potential cleaners (four fishes and four shrimps) for a 24-h period. Only *P. pedersoni* removed these parasites. Becker and Grutter (2004, 2005) subsequently found that two tropical Pacific species (*P. holthuisi* and *Urocaridella sp*) removed monogeneans from fish in aquaria. In the present study, *P. pedersoni* significantly reduced both the number and size of monogenean ectoparasites on host fish. Unlike previous studies on cleaner shrimps, shrimp and fish in this study were placed in large enclosures under semi-natural conditions with a constant supply of parasite larvae, and for extended periods of time. Shrimp had access to natural habitat (rock and/or dead coral rubble with anemones) as well as to alternative sources of food, and there was sufficient space to allow shrimp and fish to avoid each other. During routine inspections, at least some fish were always observed visiting shrimp, and the effect on parasite



**Fig. 3** Size of *Neobenedenia melleni* (mean  $\pm$  SE) on *A. coeruleus* in experimental macrocosms that did or did not have access to shrimp. Data are from the last trial of 2007 for *Periclimenes pedersoni*, each of the two 2009 trials for *P. yucatanicus*, and the last trials for 2008 and 2009 for *S. hispidus*. Numbers in parentheses represent the number of *N. melleni* measured

abundance and size was strong. Thus, in addition to providing one of few experimental studies showing that a “cleaner shrimp” actually removes parasites from fish, these data further establish *P. pedersoni* as a highly effective Caribbean cleaner shrimp.

One limitation of this study is that it used a single host species and a single parasite species. However, the host species, *A. coeruleus*, not only has the highest loads of

*N. melleni* among Caribbean surgeonfishes (Sikkel et al. 2009), but has the highest loads among any of the common reef fishes at our Virgin Islands study sites, and appears to be the primary host of this parasite. Thus, as a minimum, *P. pedersoni* has the potential to effectively regulate populations of *Neobenedenia* on Caribbean coral reef fishes. Because of its close association with anemones, anemone distribution and abundance can influence the distribution and abundance of *P. pedersoni* (Silbiger and Childress 2008), and fish may even use anemone location to find cleaner shrimps (Limbaugh et al. 1961; Mahnken 1972; Kulbicki and Arnal 1999). The findings reported here therefore suggest that the distribution and abundance of anemones may have indirect effects on fish parasite loads through their effect on the distribution of shrimps. This link would be a profitable area for further study.

Given the strong effect of *P. pedersoni* on abundance and size of *Neobenedenia* parasites, the similarity in size and habitat of *P. yucatanicus* and its reputation as a cleaner, the lack of any significant effect of *P. yucatanicus* on *Neobenedenia* abundance and the small effect on size distribution seems surprising. Unlike *P. pedersoni* trials, fish were not observed interacting with shrimps during routine daytime inspections or during occasional night inspections. However, the small size of the shrimp and their coloration made them difficult to see at night, even with a light. One possible explanation for the difference is that while *P. yucatanicus* will feed opportunistically on larger *Neobenedenia* it may be incapable of removing smaller monogeneans or may prefer other parasites, benthic invertebrates or even host mucus. Feeding primarily on alternative sources and removing small numbers of the largest monogeneans could increase the overall number of available attachment sites for smaller parasites and thus the number of parasites. Alternatively and/or in addition, *P. yucatanicus* may simply prefer and/or be preferred by other fish hosts. The first alternative, combined with the similarity in habitat and appearance to *P. pedersoni* may even allow *P. yucatanicus* to function as a cleaner mimic (Limbaugh et al. 1961; Mahnken 1972). The fact that it is less common than *P. pedersoni* at least at sites that are dominated by *B. annulata* anemones (Gwaltney and Brooks 1994; Silbiger and Childress 2008), and that *P. pedersoni* seems so effective at cleaning and avoiding predation (Stanton 1977; Mihalik and Brooks 1995) would facilitate such a mimicry. Although mimicry has been well documented in cleaning fish symbioses (e.g., Wickler 1966; Côté and Cheney 2007) it has not been described for cleaner shrimps.

Apparent cleaning interactions between *A. coeruleus* and *S. hispidus* were also not observed in the experimental macrocosm during inspections. However, during occasional night inspections, *S. hispidus* were found

sharing shelter holes with resting fish. It is possible that these shrimp are tolerated by resting fishes and that shrimp treat fishes as they would any other substratum or preferentially clean resting fish as described for *Lysmata californica* Stimpson, 1866 (Jonasson 1987). This would enable them to remove potential food items, including parasites, from the body surface of the fish. Because of their larger size, *S. hispidus* may only be tolerated by larger fish and may only be capable of removing the largest monogeneans. This could explain the approximately 0.2 mm difference in the average size of monogeneans on *A. coeruleus* that did not have access to shrimp. Smaller *S. hispidus* may be more effective at removing smaller monogeneans.

Field observations for this species are consistent with macrocosm observations. While apparent cleaning interactions involving fishes and other shrimps are commonly observed at field sites used in this and previous studies (Sikkel et al. 2004, 2009), observations involving *S. hispidus* are rare. On occasions where apparent cleaning by *S. hispidus* in the field has been reported by others, the shrimp and fish are co-occupying a crevice or cave, often at night (Limbaugh et al. 1961; Jonasson 1987). However, during 48 h of focal animal observations conducted during this study of 12 pairs of *S. hispidus* in Lameshur Bay, St. John that included 1 h each of dawn, dusk, mid day, and night, no apparent cleaning was observed. This is also consistent with field reports of other investigators who have studied the ecology of this species extensively at other localities in the Caribbean (C. St. Mary personal communication). The finding that *P. pedersoni* is a more effective biological regulator of monogenean fish ectoparasites than *P. yucatanicus* and *S. hispidus*, in spite of the fact that the latter have been reported to be a more “efficient” cleaner in aquarium observations (Jonasson 1987) further underscores the need for verification of the extent of fish ectoparasite removal by decapod crustaceans before the term “cleaner” is applied.

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