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The effect of the cleaner fish *Labroides dimidiatus* on the capsalid monogenean *Benedenia lolo* parasite of the labrid fish *Hemigymnus melapterus*

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The cleaner fish *Labroides dimidiatus* affected the pigmented monogenean parasite *Benedenia lolo* on the fish *Hemigymnus melapterus* (Labridae) held in aquaria. The effect of cleaner fish varied with the size class of fish; only small fish [*a posteriori* size class <11·5 cm standard length (L_S)] exposed to cleaner fish had fewer monogeneans compared with fish not exposed to cleaner fish. The abundance of monogeneans on large fish (*a posteriori* size class >11·5 cm L_S) was not affected by cleaner fish. The size-frequency distributions of monogeneans on both size-classes of *H. melapterus* were affected by cleaner fish. Fish exposed to cleaner fish had fewer large (>3 mm) and more small (<1 mm) monogeneans than fish not exposed to cleaner fish, suggesting cleaner fish selectively removed larger monogeneans. This difference was more pronounced on large fish. In the absence of cleaner fish, small fish had almost as many monogeneans as large fish; they also had more small monogeneans than the large fish, suggesting small fish were more vulnerable to infection by monogeneans than larger fish. This suggests that the cleaner fish *L. dimidiatus* has the potential to control benedeniine monogeneans on captive fish and highlights the importance of taking into account fish size in studies of the effect of cleaner fish on ectoparasites.

Key words: Great Barrier Reef; Capsalidae; *Benedenia*; *Labroides dimidiatus*; cleaning behaviour.

INTRODUCTION

Cleaner fishes have an effect on the size-frequency distribution of parasitic copepods (Gorlick *et al.*, 1987) and abundance of gnathiid isopods on fish in the wild (Grutter, 1999). Although these and the majority of other studies on cleaning behaviour point to crustaceans as the dominant parasites in cleaning interactions, evidence is mounting that other parasites, particularly monogeneans, also may be removed in cleaning interactions (Grutter, 2002).

Marine cleaner organisms are geographically diverse, ranging from tropical to temperate waters (van Tassell *et al.*, 1994; Côté, 2000; Grutter, 2002). Similarly,

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monogeneans are found in most marine habitats (Whittington, 1998) and are common on coral reefs (Grutter, 1994; Whittington, 1998). Despite their prevalence on fishes, little is known of the interactions between cleaner fishes and monogeneans. Indeed, most studies have found only parasitic crustaceans in the diet of cleaner fishes (Grutter, 2002). This, in part, is probably due to the soft bodies of monogeneans being difficult to detect in cleaner fish diet analyses (Grutter, 1997*a*). Yet monogeneans are eaten by cleaner fishes (Grutter, 2002). As predators of monogeneans, cleaner fishes are thus likely to play an important role in the ecology and evolution of monogeneans (Kearn, 1994).

Epizootics of *Benedenia* spp. and other capsalid monogeneans can be a problem in the cultivation of tropical fishes (Paperna *et al.*, 1984; Mueller *et al.*, 1994; Ogawa, 1996; Seng, 1997; Koesharyani *et al.*, 1999) when large populations of worms can proliferate on captive hosts. Chemicals and freshwater baths are often used to control monogeneans but these methods can be expensive (Whittington *et al.*, 2001).

An alternative to chemicals and freshwater baths is the biological control of monogeneans using cleaner organisms (Cowell *et al.*, 1993). They found that *Gobiosoma oceanops* (Jordan) and *Gobiosoma genie* Böhlke & Robins, compared with juvenile *Thalassoma bifasciatum* (Bloch), were superior at removing *Neobenedenia melleni* from seawater cultured Florida red tilapia [a cross between *Oreochromis urolepis hornorum* (Norman) and *Oreochromis mossambicus* Peters].

Benedenia lolo Yamaguti (referred to as *Benedenia* sp. by Grutter, 1998; Deveney & Whittington, 2001) is commonly found on *Hemigymnus melapterus* (Bloch) (Labridae) at Heron Island, Great Barrier Reef (Grutter, 1998) where the host is regularly cleaned by *Labroides dimidiatus* (Valenciennes) (Labridae) (Bansemer *et al.*, 2002). The aim of this study was to test the effect of the cleaner fish *L. dimidiatus* on the abundance and size-frequency distribution of *B. lolo* on *H. melapterus* by exposing fish to cleaners under controlled conditions.

MATERIALS AND METHODS

To obtain a culture of parasites, 14 *H. melapterus* (8 to 20 cm standard length, L_S) were collected (22 to 29 March 1996) by scuba divers at Heron Island using a barrier net and hand-net following Grutter (1994). Fish were placed in a re-sealable plastic bag underwater, then transported to the laboratory in aerated buckets, held for several days in holding tanks and then taken to the University of Queensland. One to two fish were held per aquarium (300 × 300 × 600 mm). A re-circulating seawater system with a sand and shell-grit biological filter was used. The temperature of the water was maintained at *c.* 25° C by controlling the surrounding air temperature. A 12L : 12D photoperiod was maintained using fluorescent lights. After 6 weeks, one fish was bathed in fresh water for 3 min and found to be infected with many of specimens of *B. lolo*. This infection was maintained in the laboratory by placing de-parasitized fish in aquaria that had previously carried, or currently held, infected fish.

Fishes for the experiment to test the effect of cleaner fish on monogeneans were collected between 4 and 9 July 1996. Thirty *H. melapterus* and seven adult *L. dimidiatus* (5·5 to 6·3 L_S) were collected from Heron Island by scuba divers as above. Fishes were transported to the University of Queensland on 11 July. Three *H. melapterus* were allocated randomly to each of 10 aquaria (450 × 450 × 910 mm) that had previously held infected fish. A 10 cm diameter by 20 cm long polyvinylchloride (PVC) pipe provided shelter for fish. To ensure that infections of monogeneans became established in all aquaria, one *H. melapterus* was selected at random from each aquarium and moved to another aquarium every 2 to 3 days, for 24 days. *Labroides dimidiatus* were held separately in aquaria (25 × 25 × 40 cm). The abundance and size of *B. lolo* on *H. melapterus* was estimated prior to their exposure to cleaner fish. Fish were anaesthetized in benzocaine by adding drops from an approximate 10% stock benzocaine solution (0·1 to 0·3 mg ml^{-1} 70% alcohol) until opercular movement almost ceased. Fish were placed on their side in a shallow tray of aerated benzocaine solution and the number, distribution and size of monogeneans mapped onto a diagram of the fish. Fish length was measured and the whole process lasted for *c.* 10 min per fish.

For the experiment, fish were divided into three size classes (<9·5 cm, 9·5 to 12·5 cm, >12·5 cm L_S) and a fish of known length from each size class was allocated randomly to each aquarium. Aquaria were randomly allocated to a treatment (a cleaner fish present or absent). One *L. dimidiatus* was added to each of five of the aquaria. Each treatment had a similar size distribution of fish and allowed identification of each of the three *H. melapterus* per aquarium. A 2 cm diameter by 10 cm long PVC pipe provided a ' sleeping ' shelter for the cleaner fish.

Two *L. dimidiatus* that died on 5 and 11 August were immediately replaced. *Hemigymnus melapterus* and *L. dimidiatus* were fed daily with chopped and mashed, peeled prawns. Uneaten food and wastes were siphoned daily. Both fish species adapted well to captivity. Cleaner fish began cleaning immediately on exposure to client fish.

After 18 days the final abundance of *B. lolo* on each specimen of *H. melapterus* was counted. This duration was chosen as fish did not appear to be suffering from a severe infestation by monogeneans as indicated by lethargy, but showed occasional evidence of moderate parasitism (e.g. ' flashing ' along the bottom of the aquarium). Fish were bathed in fresh water for 3 min and gently rubbed to remove all *B. lolo*. The fresh water was then filtered at 57 μm to collect the monogeneans which were then fixed in 10% formalin. They were counted and measured (total length, including haptor) at × 20 magnification.

The rate at which client fish were cleaned was estimated on 20 August 1996 by recording their behaviour for 15 min per aquarium using a National Panasonic black and white VHS video camera. The order in which they were recorded was random and was done between 0900 and 1200 hours. The frequency and duration of inspections of client fish by cleaner fish were recorded separately for each of the size classes of fish.

STATISTICAL ANALYSIS

Four *H. melapterus* which were ill and were removed on days 10, 11 and 15 (from aquaria without a cleaner fish) and day 11 (from an aquarium with a cleaner fish) were omitted from the analysis. An outlier (a fish with no parasites in an aquarium with a cleaner fish) was also omitted. A transformed plot of the abundance of monogeneans and *H. melapterus* L_S showed that the relationship with size was not linear throughout the size range (Fig. 1) as predicted from a previous study (Grutter, 1998) which showed that the abundance of *B. lolo* increases exponentially with size. Instead, fish <11·5 cm showed evidence of different slopes and intercepts compared with fish >11·5 cm (Fig. 1). Fish were therefore separated into these two size classes for statistical analysis. An analysis of covariance (ANCOVA) was used to test for an effect of treatment on the abundance of monogeneans and whether this varied between fish size class with *H. melapterus* L_S as a covariable. This provided separate regressions for each ' *a posteriori* ' size class. The abundance of monogeneans and fish L_S were $\log_{10}$ transformed to satisfy the assumptions of homogeneity of variance and linearity for the analysis. Differences in the size-frequency distribution of monogeneans between treatments for large and small fish were tested using a Kolmogorov–Smirnov test. This test was also used to test whether the proportion of monogeneans on the posterior, dark green part of the body of *H. melapterus* and elsewhere on the fish differed for small (<1 mm) and large (≥1 mm) monogeneans. Kruskal–Wallis rank sum tests were used to test whether the frequency and duration of inspection differed among size classes of fish and whether the abundance of monogeneans varied among aquaria. The three original size classes (rather than the *a posteriori* classes) were used as they were balanced across aquaria.

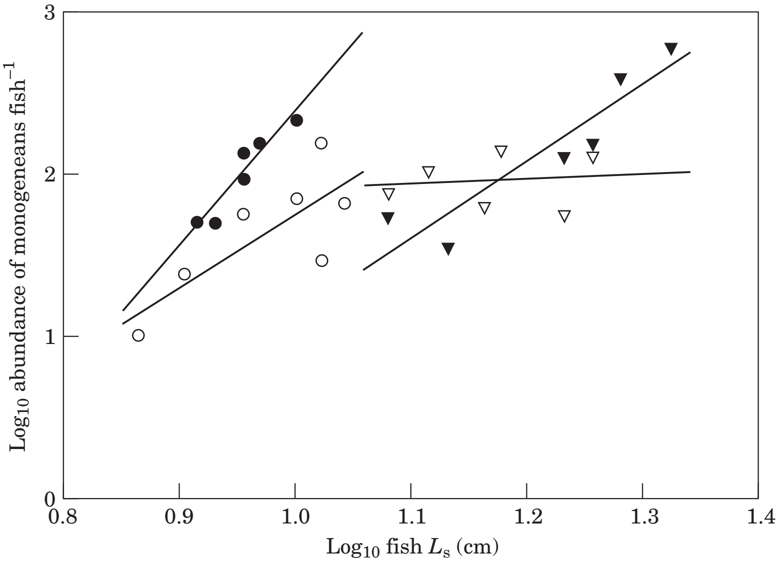

FIG. 1. Log$_{10}$ abundance of the monogenean *Benedenia lolo* per *Hemigymnus melapterus* plotted against log$_{10}$ fish standard length for fish exposed to the cleaner fish *Labroides dimidiatus* (○, ▽) or no cleaner fish (●, ▼). The data were separated *a posteriori* into small fish (<11·5 cm) (○, ●) and large fish (>11·5 cm) (▽, ▼). Regression lines are provided for each fish 'size class' and 'treatment (presence or absence of cleaner fish)' combination: small monogeneans exposed to no cleaners, $y = -5{\cdot}902(1{\cdot}340) + 8{\cdot}287(1{\cdot}400)x$; small monogeneans exposed to cleaners, $y = -2{\cdot}690(1{\cdot}560) + 4{\cdot}474(1{\cdot}600)x$; large monogeneans exposed to no cleaners, $y = -3{\cdot}620(1{\cdot}190) + 4{\cdot}754(0{\cdot}980)x$; large monogeneans exposed to cleaners, $y = 1{\cdot}611(1{\cdot}440) + 0{\cdot}291(1{\cdot}230)x$. S.E. given in parentheses.

RESULTS

At the beginning of the experiment, individual *H. melapterus* had one to 30 *B. lolo*, except for three fish that had none. The distribution of parasites on the fish also varied with the size of monogeneans (Kolmogorov–Smirnov statistic=0·31, $P<0{\cdot}0001$). Small monogeneans (<1 mm) were found on the posterior, dark green, part of the body (75%) with the remainder on the eye (3%), white anterior part of the body and head (4%), pectoral fins (3%), and dorsal fin (17%). This distribution differed for larger monogeneans (≥1 mm) which were found mostly on the posterior, dark green, part of the body (97%) with very few elsewhere (1% on the white anterior part of the body and 2% on the dorsal fins). In attempts to estimate the monogenean abundance before the experiment, examination of the benzocaine solution after the counts revealed that between 10 to 30% of monogeneans had dropped off fish. This loss appeared to occur mainly on the side of the fish resting on the tray during counts. As some monogeneans may also have fallen off after the counts, due to benzocaine treatment, the initial assessments were deemed unreliable for use in statistical analyses. The counts, however, provide an approximate estimate of the range in abundance and spatial distribution of monogeneans on fish at the beginning of the experiment.

The ANCOVA showed that the effect of treatment (presence or absence of *L. dimidiatus*) on the abundance of *B. lolo* varied between size classes [' Treatment (sizeclass) '] (Table I). This was due to the abundance of *B. lolo* being higher and

Table I. Analysis of covariance (ANCOVA) to test whether there was an effect of treatment (presence or absence of the cleaner fish *Labroides dimidiatus*) on the abundance of monogenean parasites, *Benedenia lolo*, and whether this varied between fish size classes with fish *Hemigymnus melapterus* standard length as a covariable. This provided separate regressions for each size class. The abundance of monogeneans and the standard length of fish were $\log_{10}$ transformed to satisfy the assumptions of homogeneity of variance and linearity for the analysis

Source	d.f.	SS	*F*	*P*
Size class	1	0·181	4·73	0·043
Treatment × $\log_{10}L_S$	1	0·350	9·16	0·007
Treament (size class)	2	0·618	8·09	0·003
$\text{Log}_{10}L_S$ (size class)	2	1·692	22·13	<0·0001

the slope being steeper on fish not exposed to cleaner fish compared with fish exposed to cleaner fish, but only for ‘ small ’ fish (<11·5 cm L_S) (Fig. 1). In contrast, on ‘ large ’ fish (>11·5 cm L_S), the abundance of *B. lolo* and the slope did not vary between treatments. The term ‘ Treatment × $\log_{10}L_S$ ’ was significant indicating the slope varied between treatments. The term ‘ $\text{Log}_{10}L_S$(size class) ’ was also significant (Table I) indicating that fish L_S was a significant covariable for only the size class <11·5 cm L_S (Fig. 1). The effect of aquarium was not significant (P=0·161).

Variation in the size frequency distribution of *B. lolo* within a treatment was examined separately for each treatment. The size-frequency distributions of worms for small and large fish exposed to cleaner fish were not significantly different (P=0·063) whereas for small and large *H. melapterus* not exposed to cleaner fish, they were (Kolmogorov–Smirnof statistic=0·23, P<0·0001) due to more large monogeneans on large fish (Fig. 2).

The effect of treatment (presence or absence of cleaner fish) was examined separately within each size class. The size-frequency distribution of monogeneans on small fish (<11·5 cm L_S) differed significantly between treatments (Kolmogorov–Smirnof statistic=0·11, P=0·006), mainly due to more small (<1 mm) monogeneans on fish exposed to cleaner fish compared with fish not exposed to cleaner fish (Fig. 2). A similar pattern was observed for large fish (>11·5 cm L_S) with a more pronounced difference between the treatments (Kolmogorov–Smirnof statistic=0·22, P<0·0001), mainly due to more large (≥3 mm) monogeneans on fish not exposed to cleaner fish.

Cleaning rates showed that the time spent by cleaner fish inspecting client fish per 30 min period varied with the size of client fish (Kruskal–Wallis rank sum test χ^2=6·826, d.f.=2, P=0·033) with cleaner fish spending 60 to 154 times more time on large client fish (>12·5 cm L_S) than on medium (9·5 to 12·5 cm L_S) or small sized fish (<9·5 cm L_S) which were inspected for a median (10th, 90th quantile) (time, s) of 384·4 (117·9, 387·4), 6·4 (0, 123·9), and 2·5 (0, 9·8), respectively (note that size classes were the original three size classes used per aquarium). Although the frequency of client fish inspection by cleaner fish did not vary significantly among size classes of client fish (P=0·064), there was a

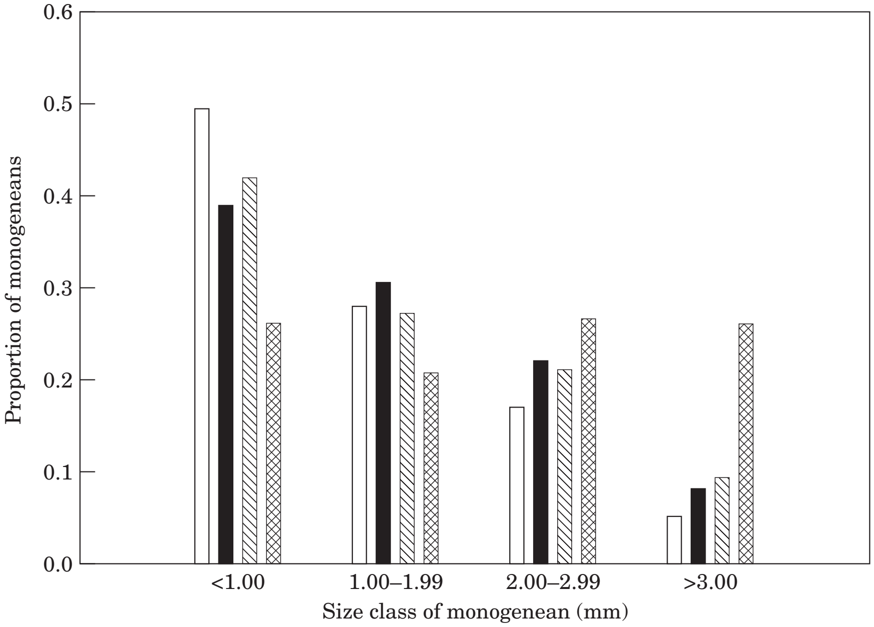

FIG. 2. The proportion of monogeneans per monogenean size class for small and large *Hemigymnus melapterus* exposed or not exposed to the cleaner fish *Labroides dimidiatus.* □, small fish exposed to cleaner fish, ■, small fish not exposed to cleaner fish, ▧, large fish exposed to cleaner fish, and ▩, large fish not exposed to cleaner fish. See Fig. 1 for fish sizes.

trend for cleaner fish to inspect large fish more frequently (median, 10th, 90th quantile, s) (19·5, 18, 34) compared with medium sized fish (1, 0, 25) and small fish (0·5, 0, 2).

DISCUSSION

Labroides dimidiatus affected the abundance and size-frequency distribution of the monogenean parasite *B. lolo* on its host *H. melapterus* held in aquaria. This adds to the growing body of information demonstrating that cleaner fish species affect the abundance (Grutter, 1999) and size-frequency distribution of parasites on wild (Gorlick *et al.*, 1987) and captive fishes (Sayer *et al.*, 1995). The present study also supports that of Cowell *et al.* (1993) but differs in that a system was used that exists in the wild.

Fish not exposed to cleaner fish had more monogeneans than *H. melapterus* in the wild and this was more pronounced for small fish. The mean abundance of *B. lolo* on small fish was *c.* 100 times higher than that found on wild fish (Grutter, 1998) whereas on large fish it was *c.* 15 times higher. Such high densities are common in captive fishes (Thoney & Hargis, 1991).

The relationship between monogenean abundance and length of fish in this study differed between length classes of fish and from that observed in the wild. Although the abundance of *B. lolo* on the small *H. melapterus* increased exponentially with fish length as it does in the wild (Grutter, 1998), a pattern supported by several studies on other monogeneans (Frankland, 1954; Paperna *et al.*, 1984; Buchmann, 1989), small fish overall had almost as many *B. lolo* as large fish. The lack of a correlation between the abundance of monogeneans and host size is not unknown and has been reported for the capsalid *Neobenedenia*, on kyphosids (Gaida & Frost, 1991) and *Anoplodiscus cirruspiralis* (Anoplodiscidae) on caged snappers *Pagrus auratus* (Bloch & Schneider) (West & Roubal, 1998).

Higher parasite densities on small fish may be one explanation for why these monogeneans were more affected by cleaner fish compared with large fish. Although small fish had similar numbers of monogeneans to large fish, the surface area of fish was smaller (Grutter, 1995) and thus the density of monogeneans higher. Frequency-dependent selection of prey by fish where predators feed disproportionately on prey whose relative abundance is high is well known (Hughes, 1997). Thus cleaner fish may selectively remove *B. lolo* more often on small fish because their population density was higher than on large fish.

Small fish appeared more susceptible to infection. Of *H. melapterus* not exposed to cleaner fish, small fish had almost as many monogeneans as large fish and more very small monogeneans (<1 mm). This suggests small fish were more vulnerable to infection by oncomiracidia.

Size-related variation in the susceptibility of fishes to parasites may be due to variation in the immune system. Fishes exhibit immunity against parasites, including monogeneans (Woo, 1992; Buchmann, 1999; Jones, 2001) and this immunity may be acquired (Lester & Adams, 1974*a*, *b*; Scott, 1985; Bondad-Reantaso *et al.*, 1995). Thus, the high number of *B. lolo* on small *H. melapterus* may be due to their immune system not being as competent as that of larger fish. Size-related differences in infection levels due to immunity changes have been reported in host-parasite interactions (Noble *et al.*, 1989) including monogeneans (Hess, 1930; Scott, 1985) and other fish parasite groups (Rigby & Dufour, 1996). Acquired immunity could be reflected as age-related immunity with fewer parasites being found on larger, and therefore, older fishes.

Alternatively, it is possible that differences in the behaviour of *H. melapterus* between the size classes may have affected the abundance of monogeneans on fish. Hierarchies among fishes can cause stress (Adams *et al.*, 2000) and affect levels of parasitaemia (Barrow, 1955). Laboratory observations of *H. melapterus* suggest that there is a hierarchy among fish based on size (A. S. Grutter, pers. obs.). Although fish in the same tanks did not attack each other aggressively, it is likely that hierarchies existed.

Bondad-Reantaso *et al.* (1995) found that re-infected fish had smaller monogeneans suggesting their growth was suppressed. Hess (1930) observed a similar pattern with larger *Dactylogyrus* sp. on recently infected fish, particularly young fish. These suggest that if larger fish have acquired immunity, then they may have smaller parasites. In contrast, in the present study, it was found that among fish not exposed to cleaner fish, large fish had more large monogeneans than small fish. Thus acquired immunity may not explain the variation in monogenean size observed between small and large fish.

A possible explanation for the presence of fewer large monogeneans and more small monogeneans on *H. melapterus* exposed to cleaner fish, compared with fish not exposed to cleaner fish, is that cleaners may have selectively removed larger monogeneans. This agrees with other studies that show that *L. dimidiatus* selectively feed on larger species of ectoparasites (Grutter, 1997*a*) and larger individuals within a family (Gnathiidae) (Grutter, 1997*b*).

The effect of cleaner fish on the size frequency distribution of monogeneans was more pronounced on large fish than on small fish. Large fish, although they had proportionally more large monogeneans, also had a lower monogenean density than did small fish. In contrast, small fish had many small monogeneans but their size-frequency distribution was not as affected by cleaner fish. Such patterns can occur when low-ranking prey (i.e. small monogeneans) become very abundant and are then encountered more frequently than the next higher in rank, resulting in learning differentially increasing the profitability of low-ranking prey (Hughes, 1997).

There was some evidence that the habitat of monogeneans varied with their size. Small (<1 mm) monogeneans, which probably settled recently on the fish, were not as site-specific as larger monogeneans (>1 mm) which were mostly found on the posterior, dark green part of *H. melapterus*. It is not surprising that small monogeneans were found in areas where adult monogeneans are not normally found (white anterior part of the body, pelvic and dorsal fins, and eyes) because many oncomiracidia do not invade the host at the precise site of its future habitat. Instead, they migrate from the site of initial contact to the definitive habitat (Whittington & Ernst, 2002). Larvae of *Benedenia lutjani*, for example, invade most of the body surface of its host *Lutjanus carponotatus* (Richardson) (Whittington & Ernst, 2002). Reduced site-specificity is common in epizootics (Paperna *et al.*, 1984) and this may also explain the distribution of *B. lolo* on the small fish in this study.

Variation in the pigmentation of *B. lolo*, which may serve as camouflage against predators (Kearn, 1994; Whittington, 1996), may have influenced the cleaning efficiency of *L. dimidiatus*. *Benedenia* probably obtain their pigmentation from their diet (the epithelium of fishes) as shown for *Dendromonocotyle kuhlii* Young (Kearn, 1979). Worms on areas of the fish that bear white pigment would therefore probably have had a white pigmentation. Small monogeneans were found on the white head and anterior part of the body more often than the larger worms, thus small worms would have often been white coloured. If these then migrated to the dark green part of the body (most likely their definitive habitat) they would not have been as camouflaged as the large individuals.

Small fish also had higher densities per unit area of small monogeneans than did large fish. This may also explain why smaller monogeneans appeared to be more vulnerable to cleaner fish on small fish.

Cleaner fish spent 60 to 154 times more time cleaning large clients (>12·5 cm L_S) than medium (9·5 to 12·5 cm L_S) or small sized fish (<9·5 cm L_S), respectively. Direct comparison with wild fish, however, is difficult because different size classes have been used. The median duration that large clients (>12·5 cm L_S) were cleaned in aquaria (384 s per 30 min) appears to be higher, while the median duration for medium sized fish (6·4 s per 30 min) was lower than the rate seen in wild fish (20 s per 30 min for fish 10 to 15 cm L_S) (Grutter, 1995). Why cleaner fish cleaned larger fish for so much longer is unclear. Such behaviour, however, has been observed across species and within *H. melapterus* (Grutter, 1995). The possibility that larger, and thus more dominant fish, monopolized the services of the cleaner fish cannot be ruled out.

Labroides dimidiatus is found across the Indo-Pacific (Randall *et al.*, 1997), is ubiquitous across reef habitats zones (Green, 1996), engages in cleaning in all its post-settlement life stages (Grutter, 2000), is known to eat large quantities of other parasites (Grutter, 1996; 1997*a*, *b*), and adapts well to captivity. These factors and the finding of this study, which indicate that cleaner fish have the capacity to affect monogeneans, suggests that cleaner fish are potential candidates for the biological control of ectoparasites of tropical captive fishes. More importantly, it suggests the role of cleaner fish in monogenean ecology cannot be ignored.

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