Opportunistic predation by small fishes on epibiota of jetty pilings in urban waterways

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Epibiota were sampled on nine small jetties in the tidal, urban canals of south-east Queensland, Australia, to determine if the small fishes that are associated with these jetties prey on the epibiota on the pilings of the jetties and whether these fishes depend on the epibiota as a source of food. Epibiota was dominated by barnacles, filamentous and foliose algae and ranged in thickness from 4 to 11 mm. The two species of fishes that associated most closely with jetty pilings, *Pandaka lidwilli* (Gobiidae) and *Monodactylus argenteus* (Monodactylidae), were sampled twice during the day and twice during the night for analysis of stomach contents. During the day, the diet of *P. lidwilli* was dominated by amphipods (*c.* 70%, by mass of organic content), with copepods, bivalves and bryozoans each contributing <10%. At night, amphipods contributed less (*c.* 45%) and copepods more (*c.* 35%). The diet of *M. argenteus* was dominated by filamentous algae (55%) and amphipods (20%) during the day and filamentous algae (70%) and barnacle cirri (23%) at night. Epibiota, therefore, made a substantial contribution to the diet of the fishes but were not the sole source of food for either species. As jetties were the only structures that supported epibiota in the area, fishes probably sourced their epibiota from the pilings of the jetties. Whether fishes depended on the epibiota was, therefore, tested using a manipulative before-after-control-impact (BACI) study. Three jetties were assigned randomly to each of three treatments: (1) epibiota removed from pilings, (2) epibiota cut and damaged (a procedural control) and (3) epibiota left undisturbed. Abundances of *P. lidwilli* and *M. argenteus* around jetty pilings remained similar across all treatments from before to after the removal of epibiota. These results indicate that although fishes consumed epibiota on the jetties, they did not depend on the epibiota of the jetties for food.   © 2008 The Authors

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Key words: artificial structures; canals; *Monodactylus argenteus*; *Pandaka lidwilli*; trophic ecology.

INTRODUCTION

Coastal urbanization has resulted in increasing numbers of artificial structures being deployed in the sea. Artificial structures, such as jetties and pontoons, support distinct epibiotic assemblages (Connell & Glasby, 1999; Glasby,

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1999) and are rapidly colonized by fishes (Molles, 1978; Beets, 1989; Ibrahim *et al.*, 1996; Rilov & Benayahu, 1998). In artificial waterways (*e.g.* canal estates), artificial structures may provide a significant, and sometimes the only, source of hard habitat available to fishes. Understanding the mechanism that attracts fishes to jetties is the first step towards maximizing their value as fish habitat in such systems.

Positive correlations have been observed between the amount of epibiota on artificial structures and abundance of fishes (Rooker *et al.*, 1997) but only two studies (Coleman & Connell, 2001; Clynick *et al.*, 2007) have used manipulative experiments to demonstrate a causal relationship between the presence of epibiota and some species of fishes. While epibiota is clearly important in attracting some fishes to artificial structures, it is still unclear why the epibiota is important. Fishes may associate with structures because the complexity of the epibiota provide a source of shelter (Beets, 1989; Steele, 1999; Coleman & Connell, 2001). Other fishes feed on the attached (Keough, 1984; Connell & Anderson, 1999; Connell, 2001*a*) or motile (Caine, 1987; Deudero & Morales-Nin, 2000; Relini *et al.*, 2002; Fabi *et al.*, 2006) epibiota associated with the structures and may, therefore, use the epibiota on artificial structures as a source of food. Studies that have observed predation by fishes on the epibiota of artificial structures, however, have not used manipulative experiments to determine the importance of epibiota in maintaining the relationship between fishes and artificial structures.

The addition of structures to coastal waters typically increases the biomass of fishes at a site (Bohnsack, 1989). This has led to a substantial research effort attempting to determine whether structures act to increase overall biomass of fishes (*i.e.* production) or concentrate fishes spatially from a larger area (*i.e.* attraction). The two factors are not easily separated (Pickering & Whitmarsh, 1997), and the current study does not aim to test their relative importance.

Canal estates are increasingly being constructed in coastal regions throughout the world to provide waterfront residential housing. Canal estates provide unique habitats for fishes and other biota (Lindall *et al.*, 1975; Baird *et al.*, 1981; Connolly, 2003). In south-east Queensland, hundreds of kilometres of artificial waterways have been constructed since the 1970s (Connolly, 2003) and approximately one third of the waterfront houses have small jetties or pontoons for mooring boats. These artificial structures provide the major source of hard substratum in the canals, support epibiota and attract large numbers of fishes.

The aims of this study were to (1) characterize the epibiota on the pilings of jetties in the canals, (2) use stomach content analysis to test the hypothesis that fishes that associate closely with jetties feed on epibiota and (3) use a manipulative experiment to test the hypothesis that abundances of fishes that prey on epibiota would decrease around jetty pilings after epibiota was removed.

MATERIALS AND METHODS

STUDY SITE AND JETTIES

The study was undertaken in two adjoining artificial lakes (Wonderland and Rumrunner) that form part of the extensive system of canals associated with the

Nerang River (27°56′ S; 153°26′ E), south-east Queensland, Australia (Morton, 1989). The lakes are located *c.* 15 km from the Nerang River's entrance to the ocean, have a tidal range of *c.* 1 m and a salinity of *c.* 17 during the period of the study (L. Hughes & E. Mondon, unpubl. data). Twelve jetties were sampled. Nine jetties (five in Lake Rumrunner, four in Lake Wonderland) were used to quantify the distribution, abundance and thickness of epibiota and to assess the effects of removing epibiota on abundances of fishes. Fishes for stomach content analyses were sampled from three additional jetties (two in Lake Rumrunner, one in Lake Wonderland) to avoid removing fishes from jetties that were to be used in the manipulative experiment. Jetties ranged in size from 11 to 24 m² (area of deck) and had between five and 13 pilings. All jetties occurred on sandy substrata. Narrow sandy beaches lined the lakes and the canal walls were not inundated with water, even at a high tide. In Lake Wonderland, a small rocky berm lined the edges of some parts of the lake. The berm was, however, only inundated at high tide and supported little epibiota. The jetties, therefore, were the dominant hard substrata in the area and the major source of epibiota. The jetties were separated by >30 m and were considered to be independent sampling units because although small fishes may be capable of swimming >30 m, the species targeted have never been caught away from jetty pilings, despite extensive sampling in this area (M. Brickhill, unpubl. data). It was assumed, therefore, that the fishes rarely swam distances >30 m over open sand. The jetties were constructed of three different types of materials. Five had pilings made of PVC, six of fibreglass and one had concrete pilings. Pilings ranged in circumference from 560 to 790 mm. The jetties that were constructed from different materials and had different circumferences were spatially interspersed.

PERCENTAGE COVER AND THICKNESS OF EPIBIOTA

Percentage cover of epibiota were measured using a 250×250 mm quadrat with 49 intersection points (Connell, 2001*b*; Bacchiocchi & Airoldi, 2003). Quadrats were placed 250 mm below the high water line, which was defined as the highest point at which epibiota occurred (Coleman & Connell, 2001). The primary and secondary covers of epibiota were recorded under each intersection point (Bacchiocchi & Airoldi, 2003). Primary cover was defined as growth directly attached to the piling, and secondary cover as growth attached to the primary cover. Three pilings were randomly selected on each jetty and one quadrat was placed at each cardinal direction on each piling (*i.e. n* = 4). Only sessile organisms were recorded. Rare species that were observed in quadrats but did not occur under an intersection point were given a nominal value of 0·5% (Holloway & Connell, 2002; Bacchiocchi & Airoldi, 2003).

Percentage covers of dominant taxa were analysed using two-way ANOVA. The factors were jetty (random) and piling (random, nested within jetty). Prior to analyses, the assumption of homoscedasticity was tested using Cochran's test. When ANOVAs detected significant differences, *post hoc* Student–Newman–Keul's (SNK) tests were used to determine where the differences occurred.

The thickness of epibiota on each jetty piling was estimated by comparing the circumferences of each piling below and above the high water mark (*i.e.* where no epibiota grew) (Coleman & Connell, 2001). The average circumference below the high water mark was calculated from measurements at three heights distributed evenly between the high water mark and the substratum. The average thickness of epibiota on each piling was estimated by subtracting the radius of the bare piling from the below-water radius that included epibiota.

DIETARY ANALYSIS OF FISHES

Two species of fishes, *Pandaka lidwilli* (McCulloch) (Gobiidae) and *Monodactylus argenteus* L. (Monodactylidae), occurred abundantly around the jetty pilings. Since these two species only occur around jetty pilings within these lakes (M. Brickhill, unpubl. data) and occurred in reasonable numbers, they were selected to test the hypotheses.

Pandaka lidwilli and *M. argenteus* were collected for stomach content analysis at low tide using a hand-net. Fishes were collected from the pilings of three jetties that were independent of those used in the epibiota removal experiment. Fishes were collected twice during the day (14 and 28 March 2006) and twice during the night (23 and 28 March 2006) and were frozen immediately upon capture. Stomach contents were quantified separately for animal prey and algae.

Prey were identified by taxon or functional group, counted and measured using a graticule on a dissecting microscope. Frequency of occurrence (F_{OC}) of each type of prey was calculated as the percentage of fishes with that prey in their stomachs (Berg, 1979). Given that different types of prey vary in size, the dietary importance of prey was quantified using ash-free dry mass (M_{AFD}). M_{AFD} of each prey taxon was estimated in each individual fish by summing the M_{AFD} of individual prey (Hollingsworth & Connolly, 2006), using Edgar's (1990) algorithms relating prey size and M_{AFD}.

Dry masses for filamentous and foliose algae were estimated by suspending the algae in 1 ml of water in a haemacytometer and then counting under the microscope the proportion of 25 grid points on the haemacytometer under which algae occurred. Prior to this, algae from fishes not included in the present study had been used to calculate a relationship between grid point scores and algal masses (measured directly after drying, which for algae is equivalent to M_{AFD} since there is negligible inorganic matter). This relationship was used to convert point estimates to masses.

EXPERIMENTAL REMOVAL OF EPIBIOTA

A before-after-control-impact (BACI) experimental design was used to test the hypothesis that abundances of *P. lidwilli* and *M. argenteus* around the jetty pilings would decrease after epibiota was removed. The same nine jetties used for the epibiota surveys were used for this experiment. The experiment consisted of three treatments: a removal treatment, a control and a procedural control. Each treatment was applied to three randomly chosen jetties. For the removal treatment, all epibiota was removed from all the pilings of each jetty using a paint scraper. Care was taken to collect all debris from around the base of the pilings, since the accumulation of damaged epibiota could have artificially attracted fishes. Epibiotic assemblages were left undisturbed for the control jetties. The aim of the procedural control was to control for the disturbance created during removal of the epibiota (*e.g.* the release of attractive or repellent chemicals) and consisted of cutting and damaging the epibiota on all pilings on the jetties within this treatment. Fishes were sampled twice before (10–11 and 18–19 March 2006) and twice after (5–6 and 13–14 April 2006) the removal of the epibiota. The first 'after' sampling occurred 5 days after the removal of the epibiota to allow the effects of the initial disturbance to dissipate. Based on previous studies (Coleman & Connell, 2001; Clynick *et al.*, 2007), 5 days was considered sufficient time for an effect to be detected, should there be one. Fishes were sampled using a 1 m deep net with a mesh-size of 1 mm. Fishes were sampled from around three pilings that were randomly selected from the pilings that were covered with water to a depth of 1 m at the time of sampling. The bottom of the net was first tied around the base of the piling and the two edges of the net were drawn together and fastened using Velcro, to encircle the piling. The net was narrower at the base so that when it was raised it formed a cone. The top of the net was quickly raised to the surface of the water to trap the fishes around the piling. The epibiota was gently tickled by hand to ensure that fishes sheltering within the epibiota were dislodged and collected. All fishes caught in the net were identified, counted and released at the piling from which they had been captured. The net was efficient at capturing fishes that associate closely with pilings (*e.g. P. lidwilli*) but was not efficient at capturing schooling species that swam rapidly among pilings (*e.g.* Ambassidae). *Monodactylus argenteus* can move rapidly and was sometimes observed to dart between pilings during the study. Numbers of *M. argenteus* around each piling, therefore, were counted visually by divers before the net was deployed. The numbers caught

in the net were comparable to those assessed visually, indicating that the net was efficient at capturing this species. Jetties were sampled within 2 h either side of the low tide. Since the pilings of different jetties varied in circumference, abundances of fishes were standardized to numbers per m^2 of piling.

Abundances of *P. lidwilli* and *M. argenteus* were analysed using ANOVAs. Although three pilings were selected randomly at each jetty, at each sampling time, due to the small number of pilings available to be sampled on each jetty, some pilings were sampled multiple times. Due to concerns regarding independence of data, separate two-way ANOVAs were done for each of the four times sampled. The factors were treatment (fixed, orthogonal) and jetty (random, nested in treatment).

RESULTS

DISTRIBUTION OF EPIBIOTA

Barnacles (*Balanus variegatus* and *Balanus trigonus*) and filamentous and foliose algae were the most common epibiota on the jetties. The primary cover was dominated by barnacles with mean ± S.E. cover of 73 ± 4%. Bare space occupied 20 ± 4% of primary cover. A mean ± S.E. 54 ± 14% of the epibiota had a secondary cover growing on it. The secondary cover was dominated by foliose algae with mean ± S.E. cover of 45 ± 8%. The hairy mussel *Trichomya hirsuta* and bryozoans occurred rarely on pilings. Percentage cover of barnacles and bare space did not vary among jetties but did vary among pilings within some jetties (Table I). Percentage cover of foliose algae did vary among jetties but *post hoc* tests revealed that the difference only occurred between the jetties with the largest and smallest cover. The average thickness of epibiota ranged from 4 to 11 mm.

DIETS OF FISHES

The stomachs of most (78%) *P. lidwilli* specimens contained food. Of these, amphipods and copepods occurred in *c.* 70% and bivalves and lophophores of bryozoans were found in *c.* 20% [Fig. 1(a)]. The different types of prey occurred in similar frequencies during the day and night. Amphipods comprised >70% of the M_{AFD} in the stomachs of *P. lidwilli* during the day, with copepods, bivalves and bryozoans each contributing <10% [Fig. 1(b)]. At night, amphipods contributed less (*c.* 45%) and copepods more (*c.* 35%).

Food was found in the stomachs of all *M. argenteus* during the day and in 69% at night. Filamentous algae occurred in *c.* 80% of stomachs during both the day

TABLE I. Results of ANOVA of percentage cover of dominant taxa on pilings. All Cochran's tests were non-significant

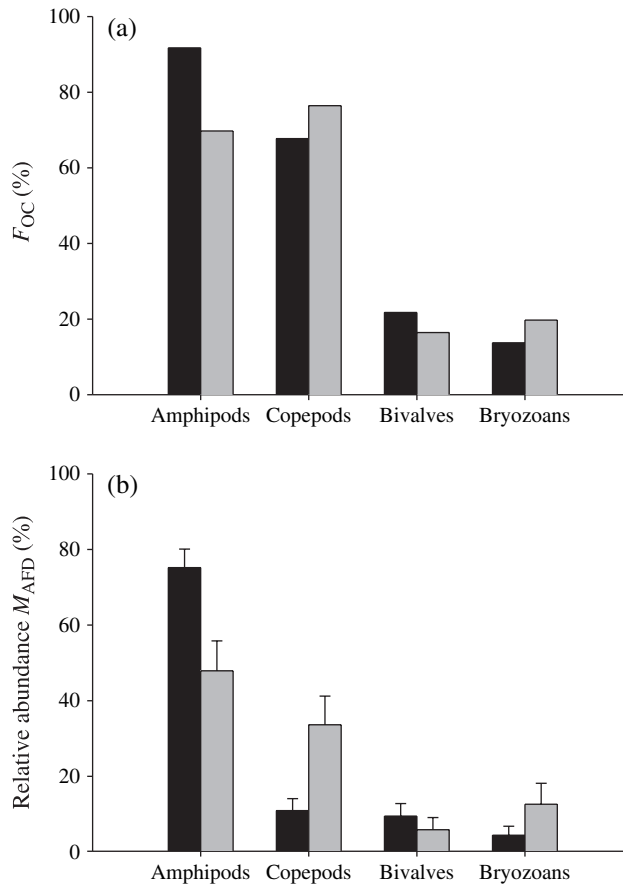|	*P* values		
Source of variation	Barnacles (I)	Bare space (I)	Foliose algae (II)
Jetty	>0·05	>0·05	<0·01
Piling	<0·01	<0·01	<0·01

I, primary cover; II, secondary cover.

FIG. 1. (a) Frequency of occurrence (F_{OC}) and (b) mean ± S.E. relative abundances of ash-free dry mass (M_{AFD}) of different taxa in the stomachs of *Pandaka lidwilli* during the day (■; $n = 50$) and night (□; $n = 30$).

and night but, although barnacle cirri and foliose algae occurred in >40% during the night, they occurred in <15% of stomachs during the day [Fig. 2(a)]. Amphipods occurred in 70% of stomachs during the day but only 20% at night, and copepods, bivalves and the lophophores of bryozoans occurred infrequently (in <20% of the stomachs) and only during the day. By mass, *M. argenteus* stomach contents were dominated by filamentous algae (55%) and amphipods (20%) during the day [Fig. 2(b)]. Filamentous algae dominated by mass at night (70%) but barnacle cirri were also relatively abundant (23%).

IMPACT OF REMOVAL OF EPIBIOTA ON ABUNDANCES OF FISHES

Abundances of *P. lidwilli* did not vary among treatments at any of the four times sampled [Table II and Fig. 3(a)]. Abundances also did not vary among jetties within treatments during the two 'before' or first 'after' sampling times,
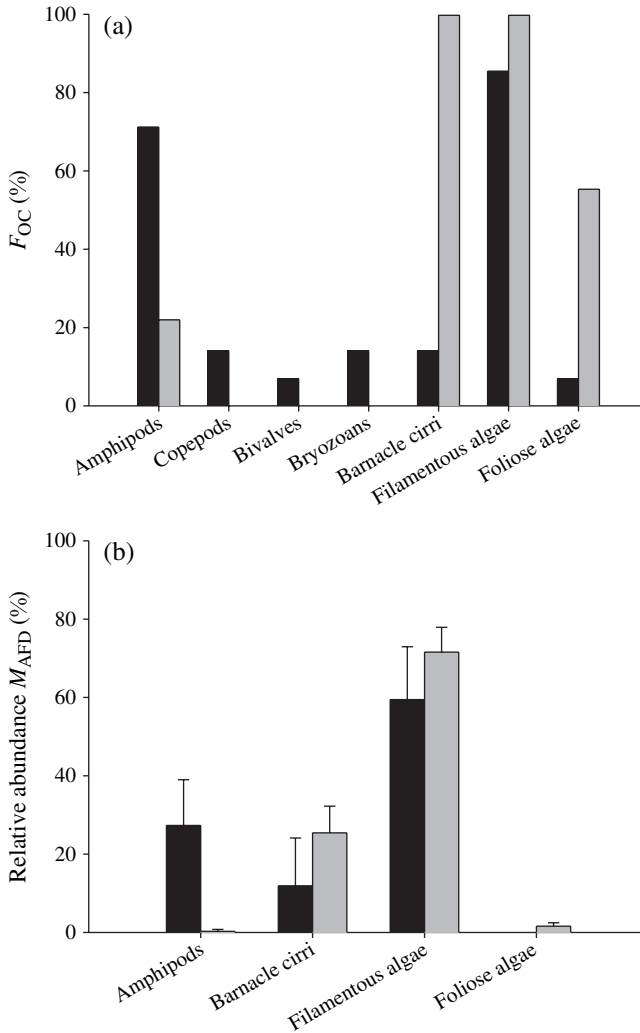
FIG. 2. (a) Frequency of occurrence (F_{OC}) and (b) mean ± S.E. relative abundances of ash-free dry mass (M_{AFD}) of different taxa in the stomachs of *Monodactylus argenteus* during the day (■; $n = 14$) and night (▨; $n = 9$). Uncommon taxa were omitted.

but did vary among jetties within the removal and control treatments during the last sampling time. The abundances of *M. argenteus* did not vary among any of the factors (Table II) although there was a slight trend for abundances of *M. argenteus* to decrease across all treatments after the removal of epibiota [Fig. 3(b)].

DISCUSSION

Epibiota was ingested by both *P. lidwilli* and *M. argenteus* and as the jetties were the only major source of hard substratum supporting epibiota in the area, it is likely that both species of fishes grazed directly on the epibiota attached to

TABLE II. Results of one-way ANOVA of abundance of *Pandaka lidwilli* and *Monodactylus argenteus* around pilings at four times during the study. All Cochran's tests were non-significant

	P-values			
Source of variation	10–11 March	18–19 March	5–6 April	13–14 April
P. lidwilli				
Treatment	>0·05	>0·05	>0·05	>0·05
Jetty (treatment)	>0·05	>0·05	>0·05	<0·01
M. argenteus				
Treatment	>0·05	>0·05	>0·05	>0·05
Jetty (treatment)	>0·05	>0·05	>0·05	>0·05

the pilings of the jetties. *Monodactylus argenteus* appeared to ingest more epibiota than *P. lidwilli*, with filamentous algae contributing >60% of the organic content overall and barnacle cirri contributing >20% at night. *Pandaka lidwilli* grazed on bivalves and bryozoans but these made up a relatively small proportion of the organic content in the stomachs. Instead, amphipods and copepods were the dominant prey captured. Amphipods were very abundant among the epibiota on the pilings (pers. obs.) and other studies have shown that amphipods associated with artificial structures are preyed upon by fishes (Caine, 1987). The jetties, therefore, may have provided a readily available source of amphipods for the fishes, but the possibility that amphipods were captured from other habitats cannot be excluded.

Despite a strong apparent trophic link between *P. lidwilli* and *M. argenteus* and the jetty pilings, removal of epibiota had no significant influence on the abundances of fishes. If epibiota was an important source of food for fishes associated with jetties, then fishes would have either left jetties from which epibiota was removed or would have suffered greater mortality on these jetties due to lack of food. Instead, numbers of fishes did not change around the jetties where epibiota was removed or around the control and procedural control jetties. The lack of change around the procedural control jetties indicated that the disturbance created by removal of epibiota had no influence on the numbers of fishes and the lack of change around control jetties suggested that no large-scale processes (such as recruitment or immigration) occurred concurrently with the experiment, which may have confounded interpretation of the results. The duration of the experiment should have been sufficient to detect changes in abundances of fishes due to emigration, since in previous studies, emigration has been detected within 5 days (Coleman & Connell, 2001; Clynick *et al.*, 2007). Starvation would probably have acted more slowly to reduce abundances of fishes around jetties from which epibiota were removed, and it is possible that the effects of starvation were not detected within the timeframe of the experiment. Small fishes, however, tend to be less able to withstand periods of starvation (Byström *et al.*, 2006). Given that the average size of *P. lidwilli* caught was 12·5 ± 0·13 mm, it is probably unlikely that this species could endure starvation for periods of >2 weeks. Starved fishes are also more susceptible
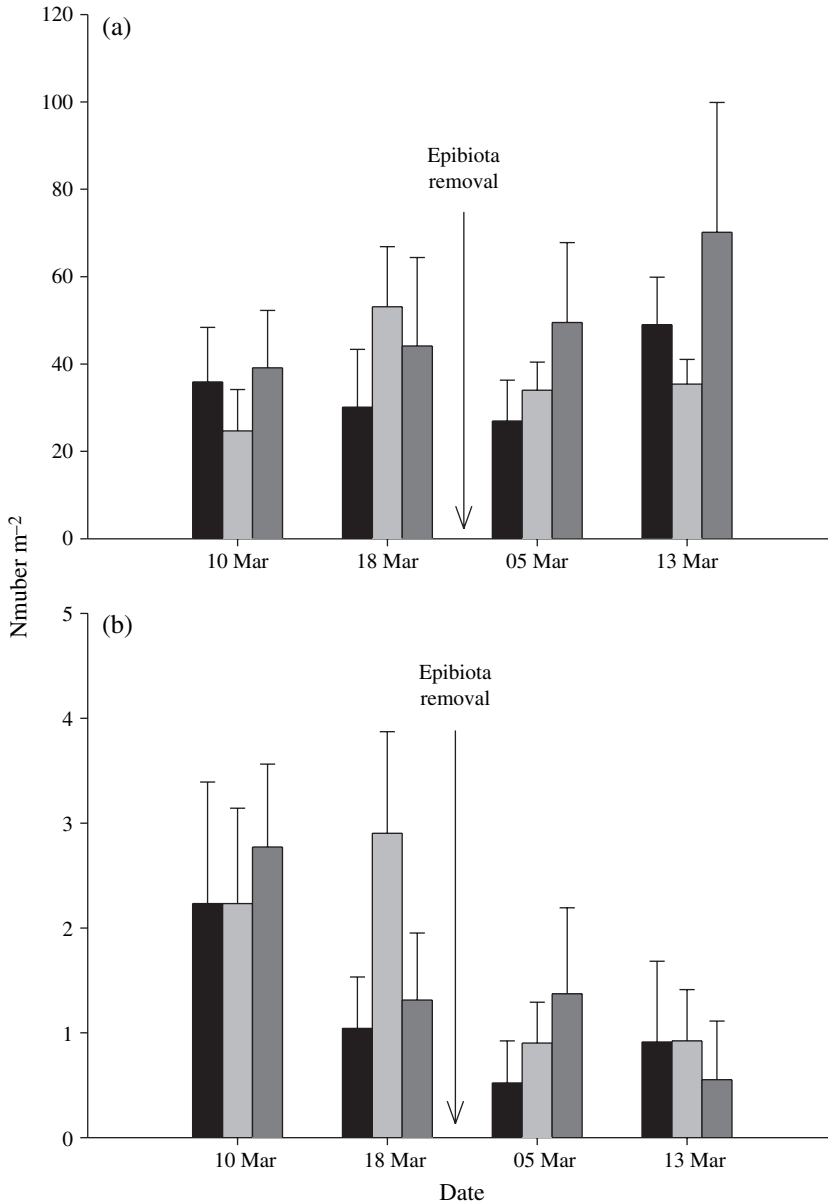
FIG. 3. Mean ± S.E. abundances of (a) *Pandaka lidwilli* and (b) *Monodactylus argenteus* on pilings of jetties in the epibiota removal (■), procedural control (▢) and control (▦) treatments before (10 and 18 March 2006) and after (5 and 13 April 2006) the removal of epibiota.

to predation (Jonas & Wahl, 1998) and are more likely to take risks when feeding, which further increases mortality (Biro *et al.*, 2005). Consequently, it is likely that, had *P. lidwilli* been dependent on the epibiota for food, a decrease in abundance of this species would have been apparent following removal of epibiota, within the timeframe of the experiment.

Although epibiota were ingested by both *P. lidwilli* and *M. argenteus*, epibiota were not the sole source of food for either species. Indeed, copepods comprised, on average, >20% of the organic content found in the stomachs of *P. lidwilli* and also occurred in the stomachs of *M. argenteus*. Both species of fishes, therefore, may be considered generalist predators that preyed opportunistically on the epibiota but were not entirely dependent on it as a source of food. Other studies have similarly found that fishes that associate with artificial structures feed in habitats adjacent to the artificial structure as well as on the epibiota of the structure itself (Lindquist *et al.*, 1994; Relini *et al.*, 2002). Following removal of epibiota, both *P. lidwilli* and *M. argenteus* may have preyed more intensively on copepods or amphipods that may have been available in adjacent habitats. Removal of the epibiota, however, clearly did not significantly reduce the abundance or accessibility of food for the species of fishes studied. Predation on epibiota, therefore, can be excluded as being the reason why these fishes associate with jetties.

An alternative model to explain the association of fishes and epibiota is that the epibiota provide refuge for fishes (Coleman & Connell, 2001). The epibiota on the pilings in this study consisted mainly of small barnacles (diameter *c.* 20 mm) and was less structurally complex and much thinner than that observed in other studies (maximum of *c.* 30 mm thick compared to *c.* 100 mm; M. Coleman, pers. comm.). The interstices between adjacent barnacles may have still provided suitable-sized shelters for *P. lidwilli*. The speckled brown colouration of *P. lidwilli* would have also camouflaged it well against the epibiota. This species was observed to remain within 10–20 mm of the epibiota and it was considered probable, therefore, that it may use the epibiota as a refuge. In contrast, *M. argenteus* is a longer and deeper bodied species, and although the individuals caught in this study were juveniles, they were nevertheless larger than *P. lidwilli* (maximum 42 mm and mean 25 mm total length, L_T). Individual *M. argenteus* remained several centimetres away from the pilings and often darted between adjacent pilings and it is less likely that this species used the epibiota as a source of shelter. Despite the different sizes and behavioural characteristics, both species failed to respond to removal of epibiota. Predators can remove up to 60% of small fishes over periods of 96 h when access to refugia is limited (Holbrook & Schmitt, 2002). As numbers of fishes in the present study did not vary over a period of 2 weeks following removal of epibiota, epibiota was concluded to not be a critical source of shelter for either species.

Although Clynick *et al.* (2007) found that several species of fishes responded to removal of epibiota, small cryptic blennies, which appeared to associate very closely with the epibiota, did not respond to removal of epibiota. Clynick *et al.* (2007) suggested that difficulties in using visual censuses to sample small cryptic species may have contributed to their inability to detect a difference in abundances of blennies. The net used to sample fishes in the present study was considered to be efficient at sampling the small fishes that associated closely with the pilings and that the lack of a response by the fishes was a real effect and unrelated to sampling efficiency.

The lack of change in abundances of fishes following the removal of epibiota indicates that the fishes associate with the pilings themselves, rather than the epibiota growing on them. Jetties without epibiota may still provide a source

of refuge. In particular, the shade created by the jetties and pilings may reduce the visibility of fishes to both aerial and aquatic predators (Helfman, 1981; Hair *et al.*, 1994). The pilings themselves may also provide a physical barrier behind which fishes may seek refuge from predators, in the same way coarse woody debris provide a refuge from predation (Everett & Ruiz, 1993). Indeed, when captured within the conical net, both *P. lidwilli* and *M. argenteus* rapidly retreated to the opposite side of the piling to the person doing the sampling. The presence of pilings is likely, therefore, to reduce the risk of predation for these two species, but further experiments are required to test these models. This study, however, provided insights into the mechanisms underlying the links between structures and densities of fishes, an important step towards separating production and attraction (Brickhill *et al.*, 2005).

Artificial structures provide a significant habitat for fishes in artificial waterways. Given that increasing numbers of artificial structures are likely to be deployed, the design of these structures should be optimized so that they provide the best quality habitat for fishes. The first step to achieving this is to identify what attracts fishes to these structures. Although *P. lidwilli* and *M. argenteus* prey opportunistically on the epibiota associated with jetty pilings, the association of small fishes and jetties does not depend on the presence of epibiota. Alternative models involving factors such as the shade and refuge provided by jetties need to be tested.

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