Faunal composition within algal mats and adjacent habitats on Likuri Island, Fiji Islands

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The faunal composition within three mono-specific algal habitats was investigated at Likuri Island, southern Viti Levu, Fiji Islands. Gracilaria maramae *was the dominant alga within algal drift mat, seagrass bed, and rocky substrate habitats at the study site. This algal species exhibits two distinctive morphologies depending on whether it is attached or loose-lying. When attached to seagrass blades or rocky substrates, this alga has long straight branches stemming from a single holdfast, while detached individuals develop curled tendrils that re-attach to adjacent substrates. Re-attachment behaviour and high growth rates result in a dense mat of drift algae, which provides a suitable micro-habitat for macro-invertebrates. The sources of algal fragments that contribute to the algal mat appear to be nearby seagrass beds and rocky substrates, where this species may settle directly from spores. Storm events may detach these algae, although pulling experiments showed that the attachment to rocky substrates is 5 times stronger than the attachment to seagrass blades. Results from the macro-faunal samples indicate that the loose-lying algal mat habitat had the highest abundance and biodiversity of organisms, followed by the seagrass bed, and then the rocky substrate habitat. The ability of loose* G. maramae *fragments to re-attach, along with their high growth rate, may provide a unique micro-habitat for highly abundant and diverse faunal assemblages, which in turn may sustain adjacent near-shore communities. This study highlights the ecological importance of floating algal mats to coastal ecosystems, which should be considered in future management strategies throughout the Fiji Islands.*

Keywords: faunal composition, algal mats, beach-cast, seagrass beds, sand flats, Likuri Island, Fiji Islands

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INTRODUCTION

The community composition of near-shore environments is strongly determined by the physical and biological topography of the substrate. In sandy shore environments, above-ground structures are transient (i.e. loose-lying algal mats), and/or intermittent (i.e. shell beds). As a result, sandy shore communities are dependent on terrestrial nutrient runoffs (Mandeel, 2002; Fabricius, 2005) and/or offshore primary production inputs (Griffiths *et al.*, 1983; Brown & McLachlan, 1990), which may be unpredictable and sporadic. One of the most important sources of primary food supplies to sandy beaches is through loose-lying algae that accumulate in coastal environments, especially in the tropics (Stoner & Greening, 1984; Colombini *et al.*, 2000). Besides directly delivering an important food source to many grazers (Robertson & Mann, 1982; Inglis, 1989; Salovius & Bonsdorff, 2004), drifting algal clumps also provide habitats for fish (Kingsford & Choat, 1985; Kingsford, 1992; Davenport & Rees, 1993), and a dispersal mechanism for many invertebrate species (Highsmith, 1985; Locke & Corey, 1989; Alfaro *et al.*, 2004). Furthermore, many researchers have investigated the succession, energy flow and consumption rates for standing algal stocks (Griffiths & Stenton-Dozey, 1981; Koop *et al.*, 1982; Griffiths *et al.*, 1983; Stenton-Dozey & Griffiths, 1983).

An associated outcome of drifting algae is the accumulation of stranded seaweeds on beaches with high public amenity value. Tropical beaches are susceptible to algal beach-cast accumulation and degradation, because of increased fishing of grazers and high nutrient inputs from land activities that enhance algal production (Jackson, 1997; Bellwood *et al.*, 2004; McManus & Polsenberg, 2004). High algal biomass may accumulate and decompose in the surf zone over short periods of time (Robertson & Hansen, 1982; Zemke-White *et al.*, 2005), thus presenting a significant problem to commercial operations in the tourism sector (i.e. resorts and water sport operators). As a consequence, many coastal operations actively remove seaweed from sandy beaches, thus altering the ecological dynamics of associated fauna. At Likuri Island, Fiji Islands, large amounts of *Gracilaria maramae* accumulate and are removed regularly from the Robinson Crusoe resort beach front. These activities have resulted in a call for management strategies that take into account the ecological value of these transient communities. As a first step to evaluate their importance to algal mat microcosms, this study aims to identify the faunal composition of detached algal mats (bottom drifting on sandflats) and attached algae (on a nearby seagrass bed) at Likuri Island, Fiji Islands.

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MATERIALS AND METHODS

The study site is located at Likuri Island, southern Viti Levu, Fiji Islands (18° 03′15.64S and 177° 17′18.83E) (Figure 1). The island is about 1 km long and 400 m wide, and is about 2 km from the mainland. A reef and mudflats are located to the south-east, and a channel to the north. Sample collections were undertaken on the western side of the island, where algal mats accumulate on sandflats and adjacent seagrass beds (Figure 1). *Gracilaria maramae* is the predominant alga at the study site, and it is found loose-lying and attached to seagrasses and offshore rocks (Figure 1).

Quantification of the size of the contiguous mat along the beach was undertaken by selecting 20 stations 10 m apart along the shore where the mat was lying (Figure 1). From these stations, transect lines were laid perpendicular to the shore. The thickness (vertical distance from the bottom to the top of the mat) of the loose-lying algal aggregation was measured every 2 m along the transect line. While some material was stranded out of the water on the beach, only the submerged, fresh material was mapped and sampled.

In order to determine the strength of *Gracilaria maramae* attachment to their primary substrates (seagrass blades and rocks), pulling experiments were conducted with a spring scale (OBA Instrument Works Ltd, Tokyo, Japan) (Friedland & Denny, 1995). Twenty seagrass plants and small rocks (~15 cm in diameter) with attached *G. maramae* were collected and taken to shore. Immediately after collection, a cable tie (5 mm width) was secured to the holdfast or point of attachment to the respective substrate. The cable tie was then connected to the scale with a nylon monofilament. The scale was pulled horizontally (parallel to the substratum) to simulate drag and acceleration forces until the alga was detached (*sensu* Friedland & Denny, 1995). The force required to detach each alga was recorded and compared between substrate types.
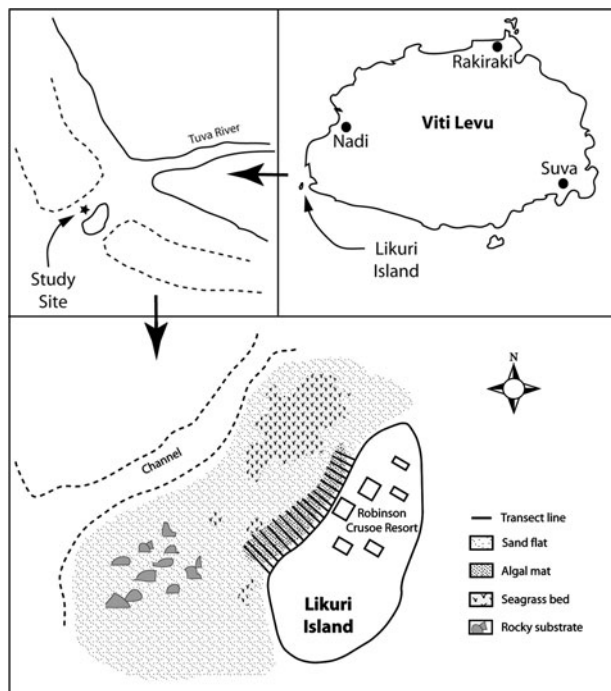

Fig. 1. Map of the study site at Likuri Island, southern Viti Levu, Fiji Islands. The three sampling habitats were algal mat, seagrass bed and rocky substrate.

Characterization of algal aggregations was undertaken within three habitats—bottom-drifting algal mats, algal canopies attached to seagrass beds, and algae attached to rocky substrates. Fifteen replicate quadrats (0.25 m²) were randomly placed within each habitat to sample all above-ground biomass during April 2006. All samples were sorted and weighed immediately after collection. The algal and plant material was classified within the following categories: detached *Gracilaria maramae* (DG), attached *G. maramae* (AG), seagrass blades (SB) and other algae (OA). The fauna found within each quadrat were identified to the lowest possible taxonomic level. The density of macro-fauna and biodiversity indices for each habitat were calculated and compared between habitats.

Analysis of variance was used to analyse the data, after checking for any violations of all parametric requirements. None of the data sets required transformations, except for macro-faunal densities, which were log (X + 1) transformed. Shannon–Weiner indices were calculated to compare biodiversity among habitats.

RESULTS

Field observations indicate that *Gracilaria maramae* appears to have two distinctive morphologies. Attached *G. maramae* tend to have long and straight branches stemming from a single holdfast (Figure 2A). Detached *G. maramae* develop curled tendrils (Figure 2B), presumably to re-attach to any adjacent substrate, such as seagrass blades (Figure 2C) and other algal thalli. As a consequence, loose-lying algae are intimately intertwined within the mat, at some points attached to underlying shell and coral cobbles or seagrasses, providing a relatively protective and stable environment for macro-invertebrates. The algae continue to grow while detached, and may have considerably more sprouting buds (Figure 2D) than attached individuals. In addition, *G. maramae* may have two attachment modes—through direct settlement of spores on a hard substrate (Figure 2E), and through curling and re-attachment around a seagrass blade or similar structure (Figure 2F) (Jones, 1962).

Results from the pulling experiments indicate that *Gracilaria maramae* is more strongly attached to rocky substrates compared to seagrass blades (Figure 3). The force (±SE) required to detach *G. maramae* from the rocks was 331 ± 50 g, while detachment from seagrass blades required 65 ± 33 g. A one-way ANOVA test indicated that these differences were highly significant (ANOVA; $F_{(1,38)}=392.3$; $P < 0.001$). A general survey of the region points to the rocky substrate and seagrass bed as the likely sources of *G. maramae* that contribute to beach-cast accumulation. These algae may detach after strong hydrodynamic conditions, and then accumulate in the surf zone, where they continue to grow and entangle. Measurements of the loose-lying algal mat area indicate that the mat extended 180 m along the shore with an average width of 9.8 m and an average depth (±SE) of 0.22 ± 0.76 m, giving an approximate volume of 447 m³ and covering an area of 2015 m².

As expected, the majority of the algae in the mat were detached, although a small percentage (~5%) was attached to shell and coral rubble found on the sandy substrate (Figure 4). All the *Gracilaria maramae* found in the rocky substrate habitat was attached to the rocks (single upright
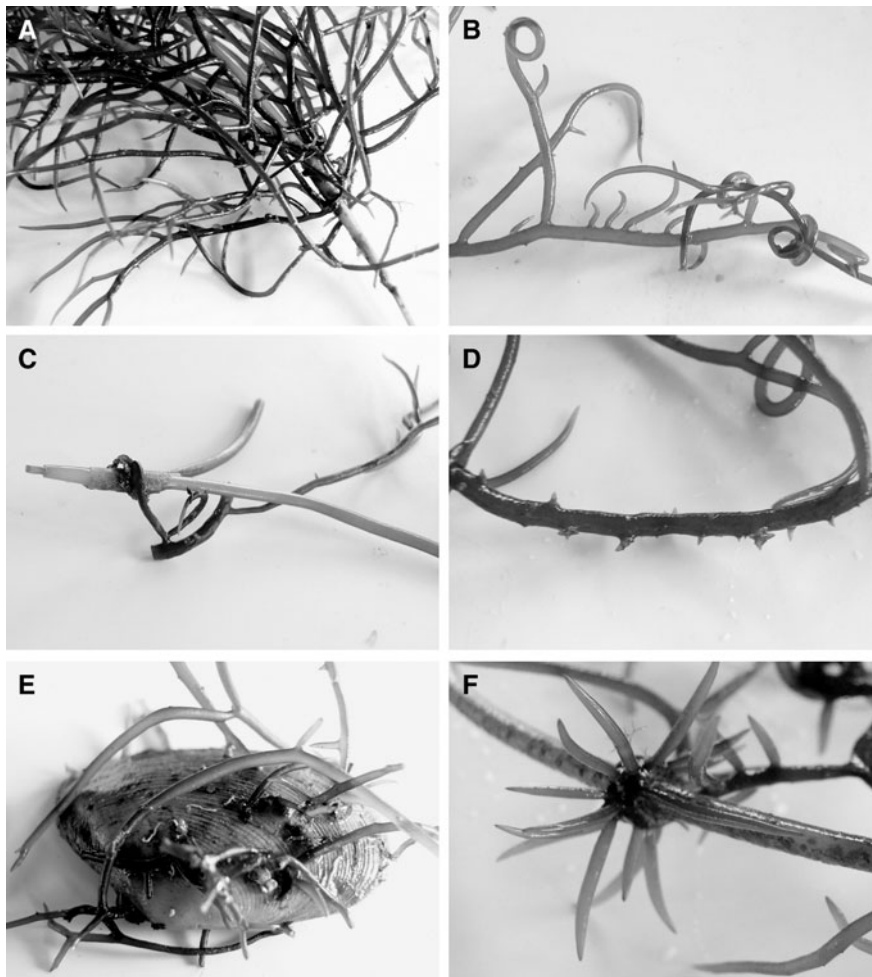
Fig. 2. Photographs of (A) *Gracilaria maramae* attached to seagrass blade; (B) detached curling *Gracilaria maramae*; (C) holdfast re-attachment to seagrass; (D) sprouting buds in *Gracilaria maramae* thallus; (E) attachment to hard substrate (shell); and (F) re-attachment around seagrass.

holdfast attachment), while a mixture of detached (∼64%) and attached (∼21%) algae was found in the seagrass bed habitat. Most of the attached algae in the seagrass bed was associated with seagrass blades, apparently re-attached after curling. The greatest mean wet weight of algal/plant material (±SE) collected within the 0.25 m² quadrats was found in the algal mat with 1171 ± 499 g, followed by the rocky substrate with 913 ± 260 g, and the seagrass bed with 343 ± 128 g. A one-way ANOVA resulted in significant differences among habitats (ANOVA; $F_{(2,42)}$ = 24.9; P < 0.001), although a Tukey test showed no significant difference between algal mat and rocky substrate habitats only.

Results from the macro-faunal samples indicate that the algal mat habitat had the highest total number (±SE) of individuals
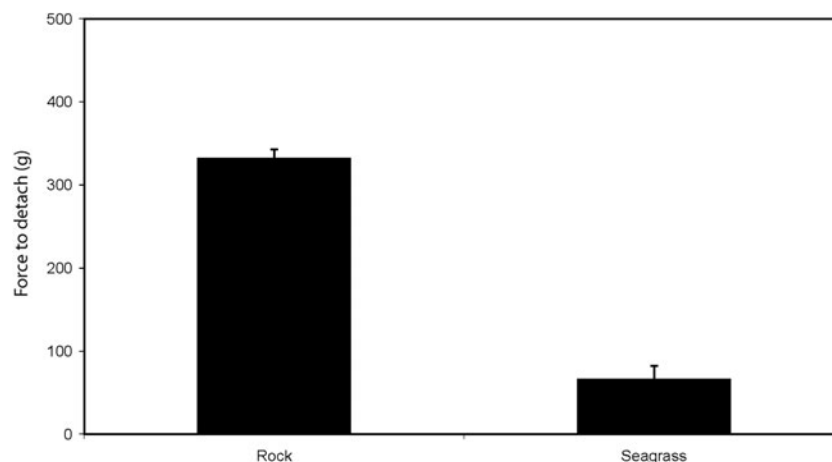

Fig. 3. Mean force (±SE) required to dislodge *Gracilaria maramae* from rocky and seagrass blade substrates at Likuri Island, Fiji Islands.
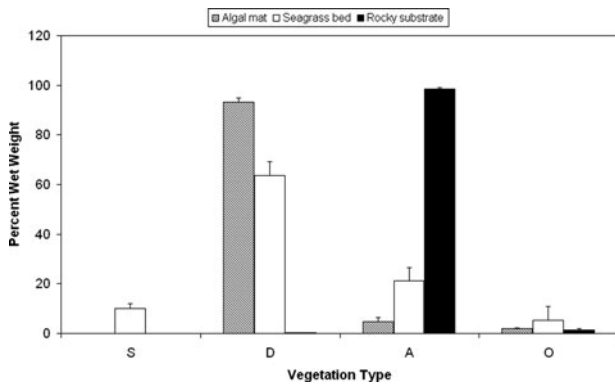
Fig. 4. Mean per cent (±SE) algal and plant material (S, seagrass; D, detached *Gracilaria maramae*; A, attached *Gracilaria maramae*; O, other algae) found within three subtidal habitats (algal mat, seagrass bed, and rocky substrate) at Likuri Island, Fiji Islands.

and taxa (44.9 ± 7.2 and 11.6 ± 1.1 individuals/0.25 m², respectively) among the three habitats, and that the rocky substrate had the lowest total number (±SE) of individuals and taxa (6.4 ± 1.1 and 3.8 ± 1.5 individuals/0.25 m², respectively). This density pattern also is persistent for each of the major macro-faunal groups encountered, including crabs, shrimp, polychaetes, amphipods, grazing snails, and carnivorous snails (Figure 5). One-way ANOVA tests for the total number of individuals and taxa and for each of the major faunal groups all resulted in significant differences among habitats, except for polychaete worms (Table 1). Non-significant Tukey tests were
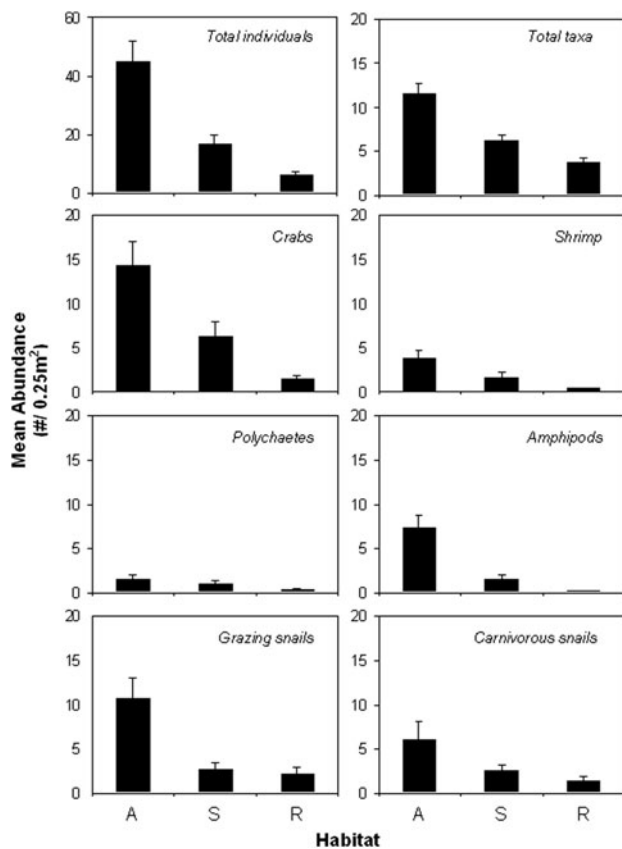

Fig. 5. Mean density (±SE) of total individuals, total taxa, crabs, shrimp, polychaetes, amphipods, grazing snails and carnivorous snails within three habitats (A, algal mat; S, seagrass bed; R, rocky substrate) at Likuri Island, Fiji Islands. Note different scales.

Table 1. One-way ANOVA testing mean macro-faunal density among habitats (Algal mat, Seagrass bed, and Rocky substrate) at Likuri Island, Fiji Islands. Non-significant test is indicated with "ns".

Source	df	MS	F	P
Total individuals				
Habitat	2	2.16	24.55	0.001
Error	42	0.09		
Total taxa				
Time	2	0.73	19.51	0.001
Error	42	0.04		
Crabs				
Time	2	2.28	25.44	0.001
Error	42	0.09		
Shrimp				
Time	2	0.77	8.69	0.001
Error	42	0.09		
Polychaetes				
Time	2	0.13	1.92	0.159 ns
Error	42	0.07		
Amphipods				
Time	2	2.28	28.10	0.001
Error	42	0.08		
Grazing snails				
Time	2	1.20	7.74	0.001
Error	42	0.15		
Carnivorous snails				
Time	2	0.46	3.26	0.048
Error	42	0.14		

found for shrimp, amphipods, and grazing and carnivorous snails between seagrass beds and rocky substrates, and for grazing snails between algal mat and seagrass bed habitats. Crabs (7.4 ± 1.3 individuals/0.25 m²) and grazing snails (5.2 ± 1.0 individuals/0.25 m²) were the most abundant organisms encountered in all habitats, while polychaete worms (0.9 ± 0.2 individuals/0.25 m²) were the least abundant of the groups investigated (Figure 5). The taxa found within the three habitats are listed in Table 2.

The Shannon–Weiner index calculations resulted in higher species diversity for the algal mat habitat (5.8), followed by seagrass bed (5.1), and rocky substrate habitat (4.8).

DISCUSSION

Macro-algal communities provide habitats and food sources for a variety of marine organisms. The transient and sporadic nature of algal mats results in a dynamic microcosm, where organisms come and go, and populations increase and decrease in density over short periods of time. At Likuri Island, there is a unique opportunity to compare mono-specific algal stands within floating mats, attached to seagrass blades, and attached to rocks. *Gracilaria maramae* was found to be the most abundant alga within all three habitats (algal mat, seagrass bed and rocky substrate), with two distinctive morphologies depending on whether it was attached or free-floating. It appears that *G. maramae* can attach to suitable substrates through direct settlement of spores and/or development of attachment points after curling around a substrate.

Table 2. List of taxa within three habitats (algal mat, seagrass bed and rocky substrate) at Likuri Island, Fiji Islands.

Taxa	Algal mat	Seagrass bed	Rocky substrate
Polychaeta			
Euniciidae 1		✓	
Cirratulidae 1	✓		
Nereidae 1	✓		
Nereidae 2	✓		
Serpulidae 1			✓
Oligochaeta	✓	✓	✓
Polyplacophora			
Acanthozostera gemmata			✓
Gastropoda			
Buccinidae 1	✓		
Bulla sp. 1	✓	✓	✓
Cerithiidae 1	✓		
Cerithium alveolus	✓	✓	
Cerithium coralium	✓		
Cerithium sp. 1	✓		
Clypeomorus moniliferus	✓	✓	✓
Clypeomorus sp. 1	✓		
Clypeomorus sp. 2	✓		
Clypeomorus sp. 3	✓		
Columbellidae 1	✓		
Conus ebraeus	✓	✓	
Conus litteratus	✓	✓	
Conus lividus	✓		
Conus marmoreus	✓		
Conus miles		✓	
Conus sp. 1	✓		
Conus sp. 2	✓		
Conus sp. 3		✓	
Cymatium pileare	✓		
Cymatium sp. 1	✓	✓	
Cypraea sp.1			✓
Distorsio anus		✓	
Engina alveolata	✓		
Engina mendicaria	✓		
Fasciolariidae 1	✓		
Lambis lambis			✓
Liotina peronii	✓	✓	✓
Mitra cardinalis	✓		
Mitra eremitarum	✓		
Morula marginalba	✓		✓
Morula marginata	✓		
Muricidae 1	✓		
Muricidae 2		✓	
Nassariidae 1	✓		
Nassarius albescens	✓	✓	✓
Natica onca	✓	✓	✓
Nerita polita	✓		
Oliva annulata	✓		✓
Oliva carneola	✓	✓	
Oliva oliva	✓	✓	✓
Phasianella variegata	✓	✓	✓
Polinices melanostomus	✓	✓	✓
Polinices albumen	✓	✓	
Polinices sp. 1		✓	
Pupa sulcata	✓	✓	
Pupa sp. 1	✓		
Pyramidella terebellum	✓	✓	
Pyramidella sp. 1	✓		
Pyrene scripta	✓		
Rhinoclavis sinensis	✓	✓	✓
Rhinoclavis ventagus	✓	✓	
Rhinoclavis sp. 1	✓	✓	
Strombus labiatus	✓	✓	✓
Strombus gibberulus		✓	✓
Terebra babylonia	✓		
Thyca crystallina	✓	✓	
Tona perdix		✓	
Tricolia sp. 1	✓	✓	✓
Trochus maculatus	✓		
Trochus pyramis	✓		
Turridae 1	✓		
Turridae 2		✓	
Umbonium vestiarium	✓		
Vexilla vexillum	✓		
Vexillum rugosum	✓		
Vexillum sp. 1	✓		
Bivalvia			
Anodontia alba		✓	
Arca avellana		✓	
Atactodea stricta		✓	
Callista impar	✓	✓	
Codakia punctata		✓	
Fragum unedo	✓	✓	
Tellina sp. 1		✓	
Cirripoda			
Chthamalus intertextus	✓		✓
Tetraclita porosa			✓
Amphipoda			
Ampithoe sp.1		✓	
Bougisidae 1	✓	✓	✓
Bougisidae 2	✓	✓	
Cerapus sp.1	✓		
Elasmopus spinidactylus	✓		✓
Gammaropsis sp.1	✓		
Gammaridea 1	✓	✓	✓
Gammaridea 2	✓	✓	
Maera sp.1	✓		
Melita simplex	✓	✓	
Isopoda			
Anthuridae 1	✓	✓	
Idotea sp.1	✓	✓	✓
Idotea sp.2	✓	✓	
Idotea sp.3	✓		
Mesanthura sp.1	✓		
Decapoda			
Alpheus sp.	✓		
Aniculus sp.1	✓	✓	
Calappa calappa	✓		
Calcinus herbstii	✓		
Calcinus elegans	✓	✓	
Calcinus sp.1	✓		
Callianassa sp.1	✓		✓
Carpilius maculates	✓	✓	
Clistocoeloma sp.1	✓	✓	
Cyclograpsus sp.1		✓	
Dardanus megistos	✓	✓	
Dardanus sanguinolentus	✓		
Dardanus sp.1	✓		
Eriphia sebana	✓	✓	
Galathea sp.1	✓		
Gonodactylus falcatus	✓		

Continued

Continued

Table 2. Continued

Taxa	Algal mat	Seagrass bed	Rocky substrate
Hemigrapsus sp.1	✓		
Huenia proteus	✓	✓	
Menaethius monoceros	✓		
Metopograpsus messor	✓	✓	
Naxioides taurus	✓	✓	
Pachycheles sp.1	✓	✓	
Pachycheles sp.2	✓		✓
Pagurus sp.1	✓		
Parhippolyte uveae			✓
Penaeus japonicus	✓	✓	✓
Periclimenes sp.1	✓		
Petrolisthes sp.1	✓		✓
Pilumnus sp.1	✓		
Sesarma erythrodactyla	✓		
Thalamita crenata	✓		
Trigonoplax sp.1	✓	✓	✓
Cirripoda			
Balanus sp.1			✓
Chtyamalus intertextus		✓	✓
Ophiuroidea			
Ophiomastix sp.1	✓		
Ophiomastix sp.2	✓		✓

Re-attachment of fragments is not uncommon in this genus (Jones, 1962) and other red algae (Santelices & Varela, 1994). The versatility of this species allows it to continue to grow, even after detachment by storms and other hydrodynamic processes, and may be the reason for its dominance at the study site. Biomass estimates during April 2006 indicated that the algal mat may contain 447 m^3 of mostly *G. maramae*. While only one sampling event was conducted in this investigation, similar algal biomasses are commonly found at the study site, although densities may increase after storm events (Wayne Latter, Robinson Crusoe resort, personal communication). Future studies of community composition throughout the year may provide further information regarding seasonal variability.

Based on the pulling experiments, it is apparent that the attachment of *Gracilaria maramae* to rocky substrates is 5 times stronger than the attachment to seagrass blades. These results suggest that re-attachment to seagrass blades and entanglement through curling of tendrils in the algal mat may be secondary strategies to remain in shallow water environments (higher sunlight and growth rates) and avoid offshore transport. While pelagic algal species, such as *Macrocystis pyrifera* and *Sargassum* spp., can maintain their surface position with air bladders through their long-distance dispersal (Kingsford, 1995; Woodcock, 1995), *G. maramae* is more negatively buoyant (no air bladders), and tumbles on the bottom. Thus, the ability of *G. maramae* to curl and re-attach, together with its fast growth rates, allow for the unusual formation of semi-stable micro-habitats on near-shore sandy shores, where transient and stationary organisms may reside. Although not measured in this study, it is likely that this algal biomass also contributes a significant amount of nutrients to infauna living in these sandy environments.

Results from the faunal composition analyses indicate that the algal mat habitat had the highest density and biodiversity among the three *Gracilaria maramae* habitats studied at Likuri Island. Conversely, the rocky substrate had the lowest number of individuals and taxa. Many mobile organisms, such as shrimp and carnivorous snails, were present in all three habitats, although they appeared to be attracted in higher densities to food resources in the algal mat. A range of grazing snails and crabs, especially juveniles, were common in the algal mat, which suggests that this habitat may favour young grazers and scavengers. In addition, a high density of amphipods and isopods also was found associated with the drifting algal material, which is in agreement with previous work (Koop & Field, 1980; Robertson & Lucas, 1983; Ingólfsson, 1995; Salovius & Bonsdorff, 2004). Seagrass beds had a higher density of bivalves, which were found at the surface of the sediment when the quadrats were sampled. This group of organisms may represent an important link between epifaunal and infaunal communities, which was not strongly represented in the other two habitats.

Seagrass beds have been known to support a high diversity and abundance of organisms, especially juveniles, which use this habitat as nursery or feeding grounds (Edgar, 1990; Connolly, 1997; Sheridan, 1997; Duarte, 1999). In this study, the density and biodiversity within the algal mat habitat were higher than those in the seagrass bed. Comprehensive comparisons between seagrass beds and algal drifting habitats are lacking. However, while there is strong evidence for high associated biomass and diversity within seagrass beds (Sheridan, 1997; Duarte, 1999; Alfaro, 2006), the level of secondary production within algal mats is less clear (Holmquist, 1994; Tzetlin *et al.*, 1997; Norkko *et al.*, 2000; Alfaro *et al.*, 2004). Previous studies have reported on the ephemeral nature of non-pelagic drift algae (Hily *et al.*, 1992; Alfaro *et al.*, 2004), which may deter long-term residents. Contrary to floating algal rafts, bottom drifting algae tend to undergo rapid fragmentation and decomposition after being detached (Smith & Foreman, 1984; Salovius & Bonsdorff, 2004). Degradation may be accelerated when algae reach the surf zone and are exposed to the air or buried in the sand (Robertson & Hansen, 1982; Talbot & Bate, 1988). The unusual life strategies of *Gracilaria maramae* (rapid growth and entanglement) may provide a unique opportunity for the development of highly abundant and diverse faunal assemblages, which in turn may sustain adjacent near-shore communities. Active removal of this primary production source and habitat may have significant effects on the food web dynamics of coastal ecosystems adjacent to managed beaches. Further investigations on the trophic links and nutrient cycling between algal mat and adjacent habitats would need to be conducted before undertaking management strategies.

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