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FIELD-EXPEDIENT ECOLOGICAL METHODS: A COMPARISON BETWEEN LIMITED VS. OPTIMAL RESOURCES FOR THE STUDY OF A UNIQUE CORAL REEF

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A spectacular mound-like reef formation (126 m in circumference, 10 m high) dominated by record-size colonies of the unattached mushroom coral Halomitra pileus, along with 17 other species of the family Fungiidae, was discovered 31 m deep on the Great Astrolabe Reef, Fiji. This unprecedented formation was first encountered in March 1995 during a taxonomic project with only three days of research time remaining. Nevertheless, a quantitative ecological survey was completed (9.4 diver-hrs) using a simple point-intercept technique, probability theory, and other field-expedient methodologies. We returned in February 1996, better equipped, and conducted a thorough area-based populational/geological analysis (23.1 diver-hrs). Although qualitative differences existed, both studies resulted in a surprisingly similar quantitative description of this unique coral reef.

INTRODUCTION

On sedimentary bottoms, mushroom corals (Fungiidae) occasionally play a role in the initiation of patch reef development by providing the solid-substratum nuclei for settlement of other massive and branching coral species (Sheppard, 1981). However, fungiid corals traditionally were thought to be ahermatypic (Chadwick, 1988; Hoeksema, 1989); *i.e.*, not known to produce enduring reef formations by themselves. Free-living members of Fungiidae frequently occur in large aggregations (Pichon, 1978), but the size and geological history of the spectacular bioherm described here provides an unprecedented record of coral reef formation by this group.

MATERIALS AND METHODS

1995 STUDY

On 10 March 1995, we discovered a unique mound dominated by highly arched and unusually large colonies of mushroom corals west of Vanuacula Island in the lagoon of the Great Astrolabe Reef, Fiji (178° 30.23' E, 18° 44.15' S, Garmin GPS). This unprecedented formation (Fig. 1) was first encountered near the end of a taxonomic expedition with only three days of research time remaining. The single item of ecological equipment available in this remote location was a 50 m surveyor's tape; nevertheless, a quantitative ecological survey was completed using a simple point-intercept technique and other field-expedient methods. Since the point-intercept sampling method is biased by colony size on a predictable scale (*i.e.*, smaller colonies have a lower probability of being hit), we constructed a theoretical probability table (see area-factor values in Table 1), based on the mean surface area for each size class, to estimate the actual populational demographics. The next day, fungiid corals were collected and two separate line transects were quantified to assess populational structure. The first ran north to south (magnetic) and extended from the southernmost margin at 26 m deep over the peak (at 21 m), to the northern margin at 25 m. The second transect ran east to west beginning at 24 m and ending at 31 m. The colonies intercepted under each meter mark were counted and measured for average diameter on the convex side and recorded on roughened plastic sheets.

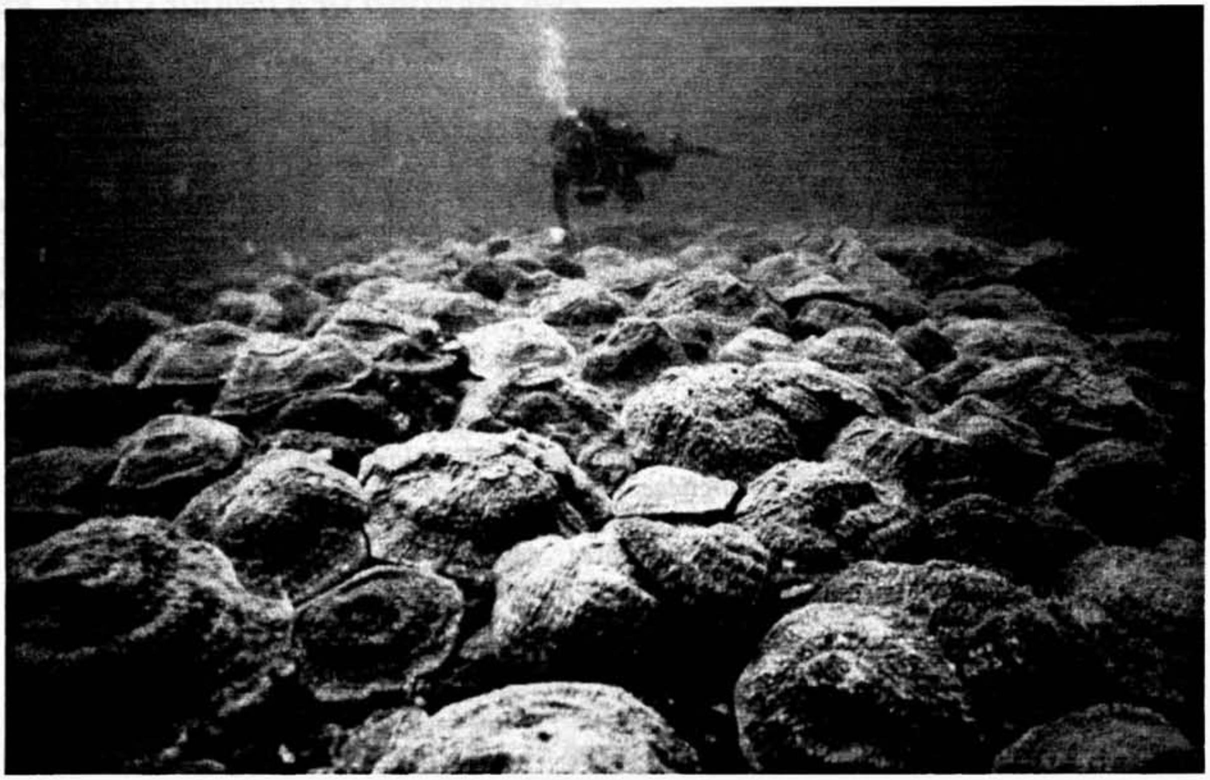

Figure 1. Diver conducting photographic survey 21 m deep on the 10 m high, 40 m diameter, mound-like, Fungiidae reef (north side).

Table 1. Populational distribution of *Halomitra pileus* colonies on the mound.

Colony size class (cm in diam.)	Numbers under point intercepts	Area factor values (based on size class differences)	Corrected numbers transected	Percent of total cover on mound	Total numbers on mound
1-10	2	169.0	338	3	5477
11-20	5	42.0	210	8	3630
21-30	8	19.0	152	13	2618
31-40	8	10.6	85	13	1473
41-50	8	6.8	54	13	943
51-60	10	4.7	47	16	803
61-70	14	3.4	48	22	811
71-80	4	2.6	10	6	169
81-90	4	2.1	8	5	112
91-100	0	0.0	0	0	0
101-110	0	0.0	0	0	0

Geological samples were taken on 13 March 1995 for radiocarbon dating and for taxonomic purposes 1.0 m to the north of the east-west transect, near the peak of the mound, by digging and probing as far as possible with a titanium bar (0.7 m and 1.0 m below the depositional surface).

1996 STUDY

During February 1996, 64 photographic quadrats (1.0 x 1.0 m) were taken perpendicular to two 1.0 m-wide belt transects, each delimited by two parallel surveyor's tapes (Fig. 2A), using Kodachrome-64 film and a Nikonos RS underwater camera, 20- to 35-mm RS zoom lens, and Nikon 102 strobe (see Littler and Littler, 1985). The transects ran north to south and east to west in the same locations as in 1995. In the laboratory, the transparencies were projected and scored for percent cover by digitizing (Zeiss MOP-3 tablet).

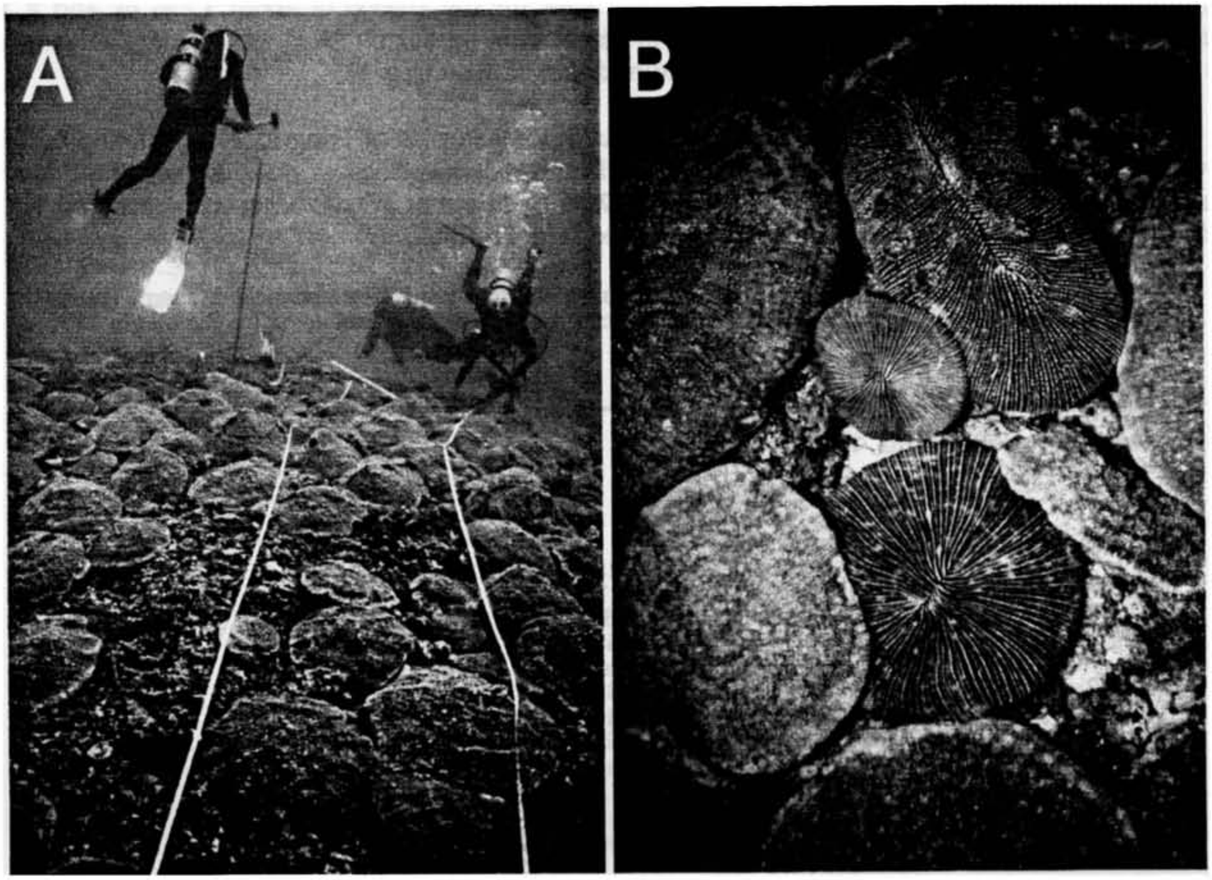

Figure 2. A. Divers drilling and laying transects for photographic survey 21 m deep near the apex. B. Close view showing fungiid diversity in areas between large *Halomitra pileus* colonies.

The two 1.0 m-wide belt transects also were examined to assess fungiid size-density populational structure. Within the transects, all of the coral colonies (Figs. 1, 2A and B) were counted and measured *in situ* for average diameter on the convex side and recorded on waterproof Nalgene Polypaper along with the taxonomic identity. All measurements of diameter were made by using aluminum meter sticks across the centers of the colonies at right angles to the transect tapes to obtain "average" values. Only those corals with >50% of their colonies within the transect area were counted.

A general size-density survey of large fungiid taxa (mostly *Zoopilus echinatus*), not abundant enough to occur in the belt transects, was made for each quarter of the mound. Taxonomic collections of fungiid taxa were taken during 11 person-dives in 1996 (vs. one in 1995) and cleaned by bleaching in sodium hypochlorite until only carbonate skeletal material remained. Vouchers were returned to the Smithsonian Institution where they were identified to species (taxonomy followed Hoeksema, 1989).

In 1996, geological samples of fossil coral skeletons were taken by drilling vertically near the center of the formation (Fig. 2A) with a 2.5 cm-diameter, 6.5 m-long galvanized steel pipe and sledge hammer. We removed 20 cm core increments from 6 levels (0.7 m, 1.0 m, 3.0 m, 4.5 m, 5.8 m, and 6.0 m) within the mound. These geological samples were returned to the laboratory in plastic bags and air dried for taxonomic purposes and radiocarbon dating.

RESULTS

Dimensions of the coral mound, measured during 1995 and1996 were identical. Diameters from the northernmost to the southernmost perimeters and from the easternmost to the westernmost perimeters were both 40 m in length, giving a total surface area for the mound of about 1,256 m^2 and a mean circumference of 126 m. The bioherm rose 10 m in height from the surrounding sedimentary substratum of the Great Astrolabe Reef Lagoon from a maximum depth of 31 m (Fig. 1).

During the single day of taxonomic collection in 1995, 9 species of Fungiidae were found (Table 2). However, during 1996, 18 species (nearly half of the 40 known species worldwide) of Fungiidae were located on the mound (Table 2), which constitute 70% (= 12 out of 17) of the species recorded for Fiji, with an additional 6 species not previously reported (Hoeksema, 1989).

Table 2. Taxa and coverages of 18 Fungiidae recorded on the hemispherical bioherm during extensive 1996 collections. The asterisks indicate the 9 species documented by the single 1995 collection.

Taxa	Mean Percent Cover (±SE,N=64)
Halomitra pileus (Linnaeus, 1758)*	84.6 ±2.6
Zoopilus echinatus Dana, 1846*	0.6 ±0.2
Other Fungiidae	3.0 ±0.6
Ctenactis albitentaculata Hoeksema	
Ctenactis crassa Dana, 1846	
Ctenactis echinata Pallis, 1766*	
Fungia (Cycloseris) costulata Ortmann, 1889	
Fungia (Cycloseris) cyclolites Lamarck, 1816*	
Fungia (Cycloseris) distorta Michelin, 1842	
Fungia (Danafungia) horrida Dana, 1846*	
Fungia (Danafungia) scruposa Klunzinger, 1879*	
Fungia (Fungia) fungites Linnaeus, 1758	
Fungia (Lobactis) scutaria Lamarck, 1801*	
Fungia (Pleuractis) gravis Nemenzo, 1955	
Fungia (Pleuractis) paumotensis Stutchbury, 1833	
Fungia (Verrillofungia) concinna Verrill, 1864*	
Fungia (Verrillofungia) repanda Dana, 1846	
Fungia (Wellsofungia) granulosa Klunzinger, 1879	
Herpolitha limax Esper, 1797*	
Total Cover of Fungiidae	88.2

Colonies (up to 1.0 m in diam.) of *Halomitra pileus*, as determined by the 1996 belt transects, covered 84.6 (± 2.6 SE) percent of the quadrats examined (N=64) on the hemispherical bioherm (see Figs. 1 & 2A; Table 2). Sixty-six colonies (11-90 cm diam.) of another giant dome-shaped fungiid, *Zoopilus echinatus*, provided 0.6 (± 0.2 SE) percent of the living cover. Coverages of 5,400 other fungiid colonies (16 species, 3.0% cover), and dead fungiid rubble (>10%) comprised the rest (Table 2, Fig. 2B).

The 1995 point-intercept size-density assessment estimated that 73% of the *Halomitra pileus* colonies ranged between 1 and 30 cm in mean diameter, while 25% ranged from 31 to 70 m (Table 1, Fig. 3). The majority of the living cover was contributed by colonies between 51 and 70 cm mean diameter (38%, Table 1, Fig. 4), whereas those 31 to 50 cm covered 26%, those 11 to 30 cm covered 22%, and individual colonies greater than 71 cm provided 11% cover.

Based on the 1996 belt-transect data, 76% of the *Halomitra pileus* colonies were between 1 and 30 cm in diameter, while a further 32% ranged from 31 to 70 cm (Fig. 3). The largest colony of *H. pileus* encountered within the belt transects was 100 cm mean diameter, with some in the 1.2 to 1.5 m range elsewhere on the mound. The majority of the living cover was contributed by colonies between 41 and 70 cm mean diameter (59%, Fig. 4), whereas those 21 to 40 cm covered 20%, and colonies greater than 71 cm provided 14% cover.

By considering the 1,256 m^2 total area of the mound and the numbers sampled in the 80 m^2 belt-transect area, we arrived at a conservative estimate (the multitude of tiny colonies in crevices or beneath larger colonies were not quantified, see Fig. 2B) of 14,400 living *Halomitra pileus* colonies (vs. 16,000 based on 1995 point intercepts, Table 1) on the mound.

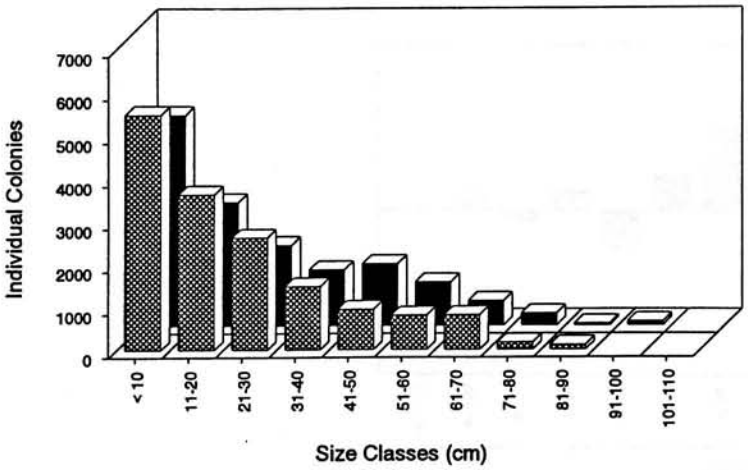

Figure 3. Numbers of *Halomitra pileus* colonies by size class on the 1,256-m² bioherm. Histograms in front are from 1995 point-intercepts, while those in rear are based on 1996 belt transects (80 m²).

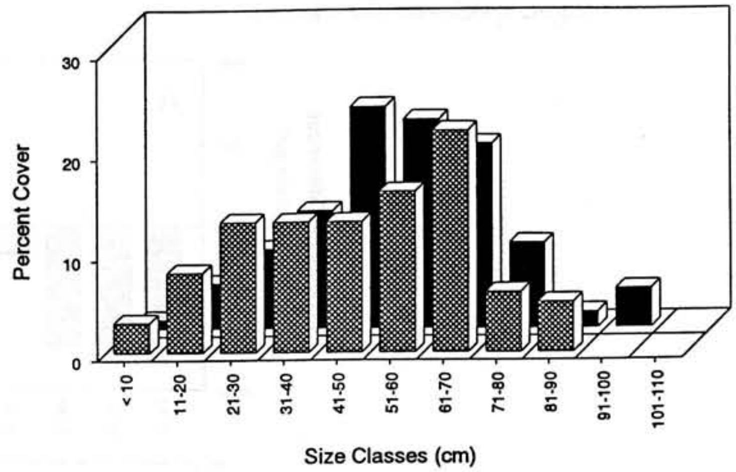

Figure 4. Percent cover of *Halomitra pileus* colonies by size class on the bioherm. Histograms in front are from 1995 point-intercepts, while those in rear are based on 1996 belt transects (80 m²).

The underlying uniform bioherm consisted mostly of well-preserved, densely-packed, fragmented skeletons of *Halomitra pileus* completely filled in with white silty clay. Extrapolation from the two radiocarbon samples in 1995 suggested that the entire depositional formation was about 5,000 yrs old, with a calculated mean upward accretion rate of 2.0 mm per yr. However, the formation proved to be closer to 4,500 yrs old, based on the depths of the 1996 cores and the mean radiocarbon ages at 0.7 m (430 ±70 RCYBP), 1.0 m (580 ±60), 3.0 m (660 ±80), 4.5 m (1,460 ±80), 5.8 m (2,520 ±70), and 6.0 m (2,800 ±90). The estimated mean upward accretion rate from 1996 samples was 9% greater, at 2.2 mm per year.

DISCUSSION

This study documents an important new discovery of unusual reef formation by mushroom corals. It shows for the first time that free-living mushroom corals by themselves are capable of building a substantial enduring reef structure. Interestingly, this 4,500 yrs old mound reef was surrounded by sedimentary environs and occurred rather deep (31 m). These conditions suggest that the free-living mushroom corals colonized and built the reef directly on soft substratum. This ability of fungiids to move and survive on soft substrata (Chadwick-Furman and Loya, 1992) is unique among corals, most of which require hard surfaces as a reef base.

Although differences existed, both 1995 and 1996 studies produced a remarkably similar quantitative description of this unique coral reef. The dimensions of the coral mound, measured during 1995 vs. 1996, were essentially identical. The populational and percent cover deviations of the 1995 point-intercept data from the more precise 1996 area-based data (Figs. 3 & 4) are shown on an expanded scale in Figure 5. The 1996 populational density data-set recorded 145 fewer *Halomitra* colonies overall, with a mean difference from 1995 values of 312 colonies per size class; ranging from a low of 741 fewer individuals in the 11 to 20 cm range to a high of 501 more in the 41 to 50 cm group (Fig. 5A). The 1996 percent cover data-set (Fig. 5B) showed a mere 0.1% greater overall cover compared to the 1995 data-set, and a mean difference of only 3.6% cover per size class, ranging from a low of 5.1% less cover in the 21 to 30 cm group to a high of 9.0% greater cover in the 41 to 50 cm range. The 1995 radiocarbon dates (N=2) projected a slightly greater age and concomitant slower accretion rate than the more extensive 1996 radiocarbon core profile (N=6). Such quantitative similarities are surprising, given that the March 1995 study was completed in 3 days, involving only 16 person-dives and 9.4 diver-hrs; whereas the February 1996 survey required more than double this effort; *i.e.*, 6 days, 44 person-dives, and 23.1 diver-hrs. The most significant difference between the two studies was qualitative and arose from the 10-fold greater taxonomic sampling effort in 1996, which resulted in the discovery of twice as many fungiid species on the mound.

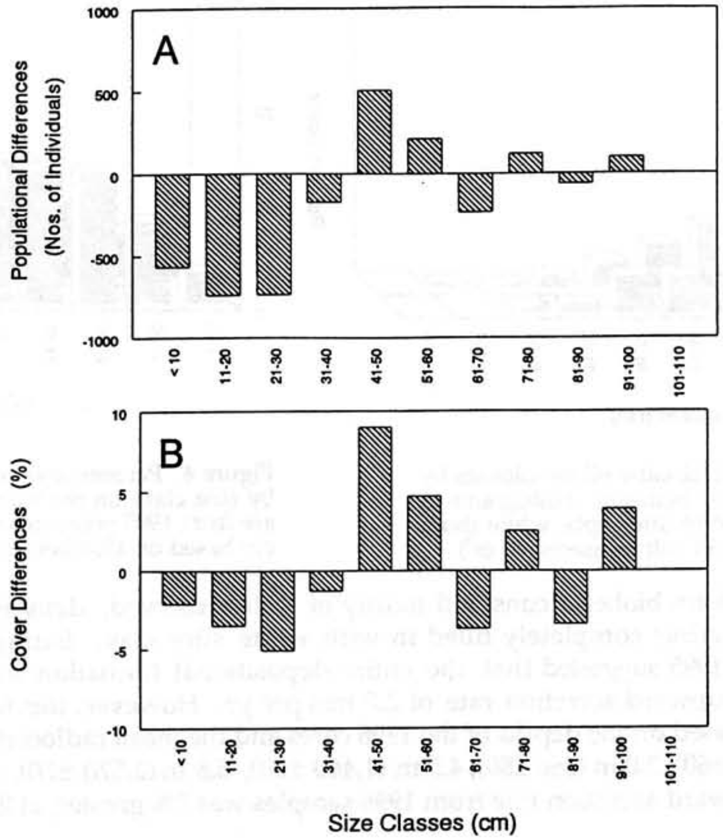

Figure 5. Populational density (upper) and cover (lower) deviations of 1995 point-intercept data, in respect to the more extensive 1996 area-based data, by size class.

Little was previously known about the demography of mushroom corals (as indicated by Highsmith, 1982; Fadlallah, 1983; Harrison, 1985; Richmond, 1987; Hoeksema, 1989). The size class-density and cover patterns of extraordinarily large colonies (14% cover contributed by individuals > 71 cm diam., Fig. 4) on the bioherm were unprecedented, as was the fungiid diversity (18 species). Species such as *Halomitra pileus* and *Zoopilus echinatus*, which formed most of the biomass on the mound, are the two largest members of the Fungiidae, with published (Hoeksema, 1989) colony diameters of up to 63 cm and 93 cm, respectively. On the mound, we recorded colonies of *H. pileus* of over twice the record diameter, and *Z. echinatus* colonies equal to the record.

Mushroom corals often behave aggressively towards other families of corals when they come into contact (Sheppard, 1979; Chadwick, 1988, Chadwick-Furman and Loya, 1992), but do not directly affect other fungiid taxa through aggression (Sheppard, 1979; Hoeksema, 1989). Such interference interactions may explain the low abundances of other families of Scleractinia on the mound and the co-existence of the remarkably diverse 18-species fungiid assemblage.

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