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A SURVEY OF MUSHROOM CORALS AND THE EFFECTS OF WATER FLOW ON SEDIMENT REMOVAL IN *FUNGIA* SPECIES

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Abstract. Free living corals are an important part of coral reef ecosystems. The members of the coral genus *Fungia* (*Scleractinia*, *Fungiidae*) exist as individual, free living, polyps. Fungiid corals can move actively, through excretion of body tissue, or passively, via being carried by strong currents. It was observed that fungiids were often found in close proximity to one another in the shallow reefs of Moorea, French Polynesia. This study set out to determine if fungiids were aggregated and if so, to test three factors which may be contributing to these aggregations; fungiid size, substrate preference and current speed. Furthermore, the effect of current on the rate at which fungiids can remove sediment from their bodies was tested. It was found that fungiids are aggregated. These aggregations consist of individuals of similar ages. Aggregations are found in branching corals much more often than expected and on sand much less often than expected. Aggregated fungiids are found in areas of lower current speed than solitary fungiids. Finally, high current speeds increase fungiids ability to remove sediment from their bodies.

Key words: Fungiid corals; *Fungia*; *Scleractinia*, *Fungiidae*, aggregations; water flow; Moorea, French Polynesia

INTRODUCTION

Coral reefs are fragile ecosystems which are constantly fighting a battle for survival. Free living corals are an important part of coral reef ecosystems. It has been argued that motile corals are able to extend the reef into previously un-colonized area and act as nuclei for establishment of new reefs (Sheppard, 1981). This is becoming extremely important with climate change leading to a higher stand of sea level, and warmer oceans. Most corals will be forced to adapt to these new conditions however motile corals will be able to move into areas with more favorable conditions.

The family of corals *fungiidae* has highly developed mobility (Hoeksema, 1989). They move by taking water into their body and using it to expand their tissue. The genus *Fungia* (*Scleractinia*, *fungiidae*) exist as, individual, free living, polyps. Out of the 41

species of *Fungia* 36 are known to have a free living adult life history stage (Hoeksema & Dai, 1991). Fungiids reproduce both sexually and asexually. Sexual reproduction occurs through different sexes releasing gametes into the water column during mass spawning events that are timed by moon phases. These gametes fuse to form planular larva and take up photosynthetic zooxanthellae. In between two weeks and two years these larva attach to hard substrate and begin a sessile life history stage (Grant & Makcenzie, 2000). Asexual recruitment occurs through a process in which juveniles bud off of dead or damaged adult individuals (Gilmore, 2002). Once young fungiids reach a large enough size they break off of their pedestal, which attach them to the substrate, and spend the rest of their lives as free living motile individuals (Chadwick, 1988). Most species of *Fungia* produce a dense discoid shaped skeleton that has been adapted

for stability and abrasion resistance in turbulent waters (Jokiel & Cowdin, 1976) (See FIG. 1). Passive hydromechanical adaptations of *fungiid* corals are important in shallow waters (Jokiel & Cowdin, 1976). Fungiids become sexually mature at 9 cm (Gilmour, 2002) and can reach up to 30 cm in diameter (Hoeksema, 1991). Fungiids have small tentacles, full of nematocysts, which they use to move food particles towards their mouths and sediment off of their body (Chadwick-Furman & Loya, 1992). These tentacles come out during the night and are retracted when disturbed. Individuals from the same cohort will be the same size (Gilmour, 2002). These corals can secrete a nematocyst filled discharge which is used as a defense mechanism to fight off corals which are encroaching on their space (Chadwick & Loya, 1992).

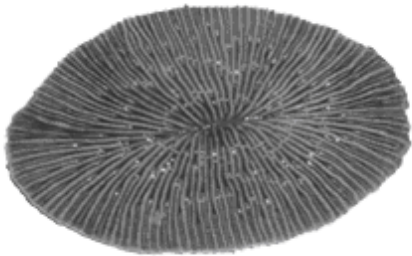


FIG.1. A *Fungia* sp.

Eight species of *Fungia* are present in Moorea, French Polynesia (Vernon, 2000). On protected reefs in Moorea, fungiids were observed to prefer a substrate covered with algae, that was sheltered from direct sunlight (Hart, 2005). It has been observed that fungiid corals tend to form aggregations however not much is known about the dispersion patterns of fungiids on shallow sheltered reefs (Chadwick-Furman & Loya, 1992). Fungiid aggregations are actually detrimental to individual growth since they cause calcification rates to decrease when compared to individuals which are not aggregated (Elahi, 2008). Although living in groups slows down growth, fungiids may have

reproductive benefits from living in aggregations (Elahi, 2008).

This study has both field and laboratory components. Field observations look at the distribution of the *fungiid* corals. This study sets out to test if fungiids are randomly distributed or aggregated. The hypothesis is that fungiids will be located much closer together than a random distribution would predict, thus fungiids will be aggregated. An investigation of possible factors contributing to fungiid aggregations is also conducted. There are many possible factors such as; light intensity, currents, reproductive preference (sexual or asexual), salinity, pH, substrate type, substrate condition, water temperature, turbidity, depth and predation. It will not be possible to test all of these factors so this paper focuses on three factors that may be contributing to aggregations; age, relative current speed, and substrate type. The experimental section of this project will look at hydrodynamics of fungiid corals. An experiment looking at how current speed affects the rate at which fungiids can remove sediment from their bodies is conducted.

METHODS

Study site: Temae

The main study site for this project was the reef at Temae public beach, on the north east coast of the island of Moorea, French Polynesia (-17.50°, -149.76°) (See FIG. 2). This area is one of the six marine protected zones on the island. Temae is a shallow (1-2 meters deep) lagoon, protected by a sizable barrier reef. The lagoon is characterized by a mostly sandy substrate with many patches of corals. The most prominent corals present in the lagoon are species of *Acropora*, *Fungia*, *Monopora*, *Porities*, and *Pocillopora*. Wave energy from the open ocean is blocked, most of the time, in the lagoon at Temae due to the barrier reef. However, during large swells and high tides waves come flooding over the barrier reef into the lagoon. Winds play a large

role in creating currents in the lagoon. Being that Moorea is located at a low latitude, the tradewinds blow, from the east, very constantly. During midday the tradewinds pickup and cause a strong current to flow through the lagoon; from north to south.

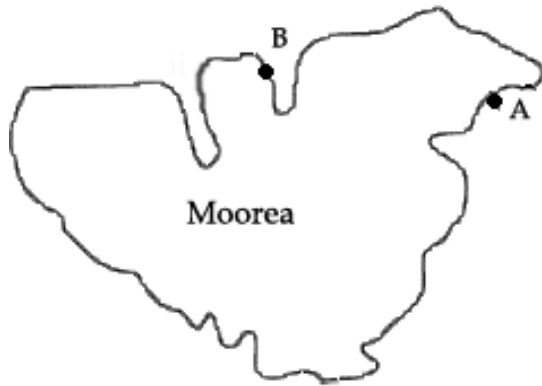


FIG. 2. Study sites on Moorea, French Polynesia. (A) Temae, (B) Gump Station reef.

Study site: Gump Reef

The reef in front of Gump Station(-17.49°, -149.83°) on the northwest side of Cooks Bay, Moorea, was the second study site (See Fig. 2). This is a very shallow(1 meter) patch reef which very steeply drops into the depths of Cooks Bay(80 meters). This fringing reef lies in another marine protected zone. The reef has a sandy substrate with small coral heads interspersed throughout. Algae are very prevalent on this reef with species of *Turbinaria*, *Sargassum*, and *Padina*, being the most abundant. As with Temae, the major process contributing to current formation on this reef are the persistent midday tradewinds.

Field observations

Fifteen, randomly located, 10m², quadrats were surveyed on the patch reef at Tamae between the dates of October 12th and November 2nd 2008. The locations of these quadrates were generated by breaking the site up into a numbered grid and then generating 15 random numbers. The grid points in which the random numbers fell were surveyed (See

FIG. 3). To determine where these points were in the field, UTM coordinates were determined using the program Quantum GIS. The UTM coordinates were recorded onto an underwater tablet which was taken into the field. A GPS device in a waterproof case was used to locate the survey points in the field. Surveys were conducted using standard snorkeling equipment.

Within each quadrat data was collected for each individual fungiid present. The information collected was; distance to each individuals nearest neighboring fungiid, size (largest diameter) of each individual and, substrate under each individual. In addition, three, random, 50 meter transects were surveyed at Temae to determine the total percent cover of different substrates.(See FIG. 3) The substrates recorded were classified as Sand(SD), Coral Rubble(CR), Branching Coral(BC), Sub-massive Coral(SM), and Massive Coral(MC).



FIG. 3. This map show the Temae Site with quadrat and transect locations displayed as points and lines respectively.

Finally, to collect data on current speed moving past fungiids, plaster of paris cubes were placed near aggregations and solitary individuals on the patch reef at Gump Station. Prior to deployment the cubes dry weights were measured. After two days in the water the cubes were retrieved and placed in a desiccator for another two days. After this

time the cubes had fully dried and their new weight was measured. The erosion per unit time of the cubes was used as a proxy for water movement past the individual and aggregated fungiids.

Statistics

Field observations

Nearest neighbor distances were compared to a data set of random nearest neighbor distances that were generated using Microsoft Excel. A model was created in which two individuals were randomly generated into an imaginary ten by ten meter quadrat. Random X and Y values (between 0 and 10 meters) were generated for the individuals and then the distance between them was calculated. This was run 1000 times to come up with a distribution for random nearest neighbor distances for two individuals in a quadrat. A Kolmogorov-Smirnov comparison of two data sets was used to determine if the difference between the random and observed data sets was statistically significant. The random data set was used to come up with a neighbor distance that would be considered an aggregation. Any fungiid with a neighbor closer than this distance was considered to be in an aggregation and any fungiid whose nearest neighbor was greater than this distance was considered a solitary individual. This distance was 1.645 standard deviations below the mean which represented only 5% of population if they were randomly scattered.

Size data (which is a proxy for age), collected for fungiids considered to be members of an aggregation (based on the nearest neighbor distance above), was used to determine if aggregations were constructed of similar aged individuals. The fungiids were broken up into two size classes; sexual mature (over 8 cm in diameter) and sexually immature (less than 8 cm in diameter). Using a Chi Squared Test it was possible to determine if the number of mature and immature

individuals in 17 aggregations had statistical significance. Another Chi Squared test was used to determine statistical significance of the differences in the distribution of naturally occurring substrates and the substrates on which aggregated fungiids occur. This was used to see if fungiids were aggregating on a specific substrate more often than would be expected. Finally, a T-test was used to determine if water speed near aggregations was different than near individuals based on data from the plaster of paris cubes. All statistical test, except for the K-S comparison, were done in the statistical program JMP.

Laboratory Experiments

Fourteen different individuals were tested to determine a rate of sediment removal in three different current speeds; No Flow (0 cm/s), Low Flow (7.58 cm/s), and High Flow (43.6 cm/s). The first trials were conducted in a small tank in the wet laboratory at Gump Station. These trials were done with no flow. Sediment, from Temae, was sprinkled on the fungiid until they were completely covered. Digital photographs were taken every 15 minutes for a total of 90 minutes. Using Adobe Photoshop 6.0 the percent cover of sediment was calculated at every time interval. Graphs of percent cover verses time were constructed for each individual. The times at which the fungiid removed 10% and 50% of the sediment were determined.

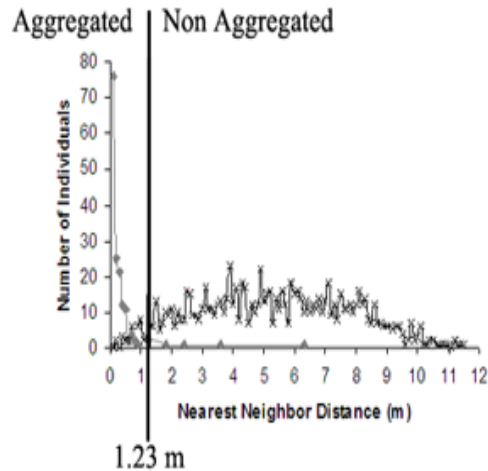
In order to run the low flow and high flow trials a flow tank, in which water moved at a constant rate down a sloped channel, was constructed using fiber board, Plexiglas, fiberglass, and marine calking. The flow tank was 6 ft long 3 ft wide and 1ft deep and was propped up at an angle of 2.82°, to allow for water to drain out. Two hoses carrying pressurized sea water were attached to the floor of the tank. The speed of the water moving in the tank was controlled by adjusting the water pressure out of the hoses. Floricine dye was used to determine the velocity of the water in the tank. The fungiids

were placed 30cm in front of the hoses to allow for the flow to spread out and become more laminar before it reached the coral. The same processes of covering the fungiids with sediment and then taking pictures every 15 minutes, or until all the sediment was removed, was employed for the low flow trials. During high flow trials pictures were taken every five minutes for 45 minutes. The times at which 10% and 50% of the sand was removed, in the three different flow regimes for each individual, were compared using an Analysis of Variance (ANOVA) test. An Analysis of Covariance (ANCOVA) was used to determine if the size of each individual was contributing to the rate at which it could remove sediment. All statistics were calculated in JMP.

RESULTS

Field Observations

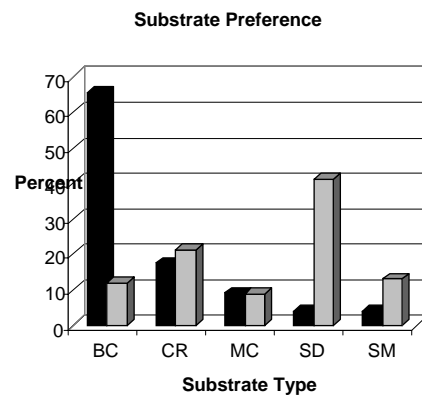
Nearest neighbor distances for the observed data set and random data set were found to be statistically different from a Kolmogorov-Smirnov comparison. The maximum difference between the cumulative distributions, D , is: 0.9537 with a corresponding P of: 0.0001. The observed individuals were much more aggregated than would be expected from a random distribution (See FIG. 4). The random data set had a mean of 5.261 meters with a standard deviation of 2.45 meters. It was determined that only 5% of the randomly generated individuals were less than 1.23 meters away from another individual. Therefore, any individual observed in the field that had a nearest neighbor distance less than or equal to 1.23 meters was considered to be a member of an aggregation. Of the 160 individuals surveyed 154, or 96.25%, were found to be members of an aggregation.



●- Observed -x- Randomly generated

FIG. 4. This graph shows the differences between the observed and randomly generated nearest neighbor distances for fungiid corals. The observed corals are much more aggregated than would be expected from a random distribution

It was determined using a Chi Squared test that aggregations of fungiids are dominated by either sexually mature or sexually immature individuals ($\chi^2 = 57.455$ $p < .0001$).



■ Substrate under aggregated fungiids ■ Substrate available

FIG. 5. This graph shows that aggregated fungiids are not located on substrates in quantities that would be expected from the types of substrates available.

Aggregated fungiids were found not to be located in or on the substrate that was most

common (See FIG 5). 66% of the aggregated fungiids were found in branching coral which made up only 12% of the substrate available. At Temae, 41% of the substrate is sand yet only 4% of aggregated fungiids were located on sand. 13% available substrate was massive coral yet only 4% of aggregated fungiids were located on massive corals. A Chi squared test was run, and it was found that the substrates that aggregated fungiids were located on was statistically different than the substrates available to them ($\chi^2 = 82.636$ $p < .0001$).

The plaster of paris cubes deployed at Gump Station were found to have a mean erosion rate of .1114 grams/hr around aggregations of fungiids. The mean erosion rate around solitary individuals was .1274. (See FIG. 6) Using a T-test it was determine that the erosion rates around aggregations are statistically different than erosion rates around solitary individuals ($p < .05$).

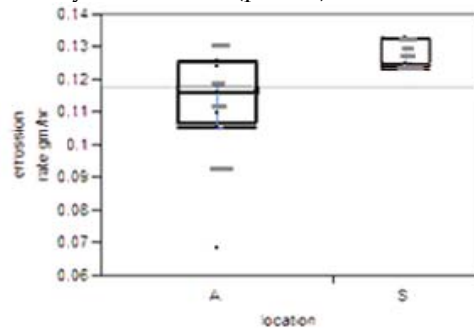


FIG. 6. This graph illustrates the erosion rates of the plaster of paris around aggregated fungiids (A) and solitary individuals (S). The rate is higher around solitary individuals

Laboratory Experiments

For all 14 individuals tested sediment removal was faster in the high flow trials than in the no flow trials. This was proved to be statistically significant, from an ANOVA, for removal of 10% and 50% of the sediment (See TABLE 1). However it was more statistically significant for 50% removal time. The time of sediment removal in the low flow trials was not statistically different than high flow or no flow trials.

TABLE 1. Analysis of Variance for 14 fungiids tested for time of 10% and 50% sediment removal in 3 different current speeds. The current speeds were proven to affect the rate at which the fungiids removed sediment in a statistically significant way.

Source	F ratio	D of F	P <
Time of 10% sed. Removal			
Current Speed	5.41	2	.0109
Individual	.80	13	.6509
Time of 50% sed. removal			
Current Speed	9.65	2	.0012
Individual	.55	13	.8631

Using an ANCOVA it was determined that smaller fungiids remove sediment faster than larger fungiids in all three flow regiments (See TABLE 2 and FIG. 7).

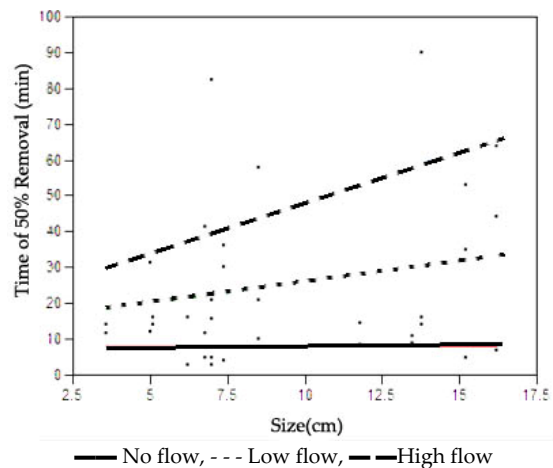


FIG. 7. This graph show that in all three flow regiments smaller fungiids remove 50% of the sediment on them faster than larger fungiids.

TABLE 2. ANCOVA of current speed and fungiid size for the time to remove 50% of sediment. Current speed and fungiid size effect the time for removal of 50% of sediment in a statistically significant way. The faster the current, and the smaller the fungiid, the faster the time.

Effect	F ratio	D of F	P <
Current Speed	14.9	2	.0001
Size	4.19	1	.0495
Current Speed X Size	1.43	2	.2556

DISCUSSION

It has been proven that fungiids are located much closer together than would be expected from a random distribution; meaning that they are aggregated. This paper set out to test some hypotheses about factors leading to fungiid aggregations. The first was that substrate preference may be contributing to the formation of fungiid aggregations. It was determined that fungiids are aggregating in branching corals much more often than would be expected based on the substrate available to them. In addition, fungiids are aggregating on sand much less often than would be expected. These discoveries may prove that fungiids are actively choosing to aggregate on one substrate as opposed to another. However, there are many other factors involved.

An explanation for why fungiids are aggregated in certain areas may have to do with their larval form from which eventually attach to hard substratum. At Temae only six individuals were observed to be attached to the substrate. However, all of them were attached to branching coral. Some substrates, such as branching coral, may be easier for larval fungiids to attach to. Once they break off their pedestals they may remain in the branching coral. Future studies on larval fungiid and their attachment to hard substrates would be very useful in understanding aggregations of fungiid corals.

Fungiid aggregations are comprised of individuals of similar ages. This may again have to do with where and how larval fungiids disperse and become attached to the substrate. If many larval corals end up attaching in one area they can form an aggregation from a very early life history stage. These individuals may "grow up" together and remain members of the same aggregation throughout their lives.

Erosion rates of the plaster of paris cubes were found to be greater near solitary individuals than near aggregations of Fungia. This means that the average current speed,

over the two day period of the trial, was greater near solitary individuals than near aggregated fungiids.

The experimental section of this project found that the faster the current speed is, the faster a fungiid can remove sediment from its body. Being able to remove sediment is very important for fungiid corals because if they can not remove sediment from their bodies, in a timely manner, they run the risk of getting buried and dying (Jokiel & Cowdin, 1976). From this standpoint, it is beneficial for fungiid corals to be in areas that experience higher flows. However, it was found that aggregated fungiids are located in areas of lower flow than solitary fungiids. Fungiids are aggregated in areas that are not the most beneficial to their survival. Going back to the issue of aggregated fungiids being located more often in branching coral and less often on open sand than expected this may have to do again with current speed. Current speed in and around branching coral will be relatively low, and current speed on sand flats will be relatively high. Again, this information shows that fungiids are aggregated in areas which are not the most beneficial for sediment removal, a life sustaining process.

Fungiids can actively locomote or can move passively. It is uncertain whether fungiids are aggregating actively, for some beneficial reason, or passively. Fungiids are capable of actively moving short distances (<10 cm day) but can move large distances (>1 m day) passively, from strong currents (Chadwick, 1988; Chadwick-Furman & Loya, 1992). It may be that these fungiids are passively aggregating in areas of low current. During large storm events fungiids can move large distances but then may settle down in areas where water is not moving as fast (branching corals). If this is the case it may not be true that motile corals are able to extend the reef into previously un-colonized area and act as nuclei for establishment of new reefs. It may be the other way around. Free living corals are passively moved away from un-colonized to colonized reefs which have areas

of relatively low current speeds. However, this is just a theory.

Sources of error in this project include a small sample size for the plaster of paris cube experiment. The cubes were deployed 3 separate times and most of them were either nibbled on by fish or washed away by high current speed. Another source of error has to do with fluxuating water speed in the flow tank due to fluxuating water pressure for the hoses. The bursts of higher flow may have aided in removal of sediment from the corals.

Even with potential errors in this study, much has been learned about the life history or fungiid corals in shallow lagoons of Moorea, French Polynesia. However, there is much more to be learned about fungiid corals. Knowing their life history is necessary in understanding how coral reefs extend into new areas. This is important to know for predicting how coral reefs will react to changes in their environment, such as those induced by global climate change.

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APPENDIX A

A Compilation of photographs of *Fungia* spp. of different shapes and sizes.



APPENDIX B

Erosion rates, in grams per hour, of plaster of paris cubes placed near solitary and aggregations of Fungiids on the fringing reef at Gump Station

Solitary	Aggregated
0.123093 g/hr	0.068318 g/hr
0.124769 g/hr	0.105426 g/hr
0.124795 g/hr	0.109965 g/hr
0.131812 g/hr	0.116011 g/hr
0.132716 g/hr	0.116082 g/hr
	0.123994 g/hr
	0.125695 g/hr
	0.125798 g/hr

APPENDIX C

TABLE 1. This table shows the substrate under aggregated fungiids and the composition of the total substrate at Tamae. BC, Branching Coral, CR, Coral Rubble, MC, Massive Coral, SD, Sand and, SM, Sub-massive Coral

Substrate	Percent of aggregated Fungia on substrate	Percent of total substrate at Tamae
BC	65.6	11.9
CR	17.5	21.3
MC	9.1	8.9
SD	3.9	41.3
SM	3.9	13.1