WHITES SAND BEACHES: A BENIGN TOURIST ATTRACTION OR A HARMFUL DISTURBANCE TO THE REEF?

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Abstract. Coral reefs support a complex and biodiverse community by providing habitat, food and shelter for fish and marine invertebrates. Today, many coral reef ecosystems are heavily affected by anthropogenic forces. Corals are very sensitive to any changes in water quality, as well as nutrient and sediment inputs. In tropical islands, coastline developments, such as the construction of resorts and the creation of artificial beaches, are a source of sedimentation at the fringing reef. Different coral genera exhibit differences in their stress response to sedimentation, and will adapt their morphologies in response to changes in environmental factors. To determine if beach management has an affect on the fringing reef, raked and non raked beaches were compared by assessing reef health at each site. Beach raking was not found to increase sedimentation, but hotel presence was an important factor in determining reef health. Coral morphology did not show significant differences according to grain size. *Porites* was found to be the dominant coral present across sites, which is indicative of a disturbed community.

Keywords: anthropogenic impact; sedimentation; coral; morphology; hotel; beach; Porites*; Mo'orea.*

INTRODUCTION

Although the environment we live in has gone through many changes over geological time (Wilkinson 1999, Buddemeier and Smith 1999, Brown 1997), many processes today are influenced by human development (Rogers 1990, Moberg and Folke 1999, Richmond 1993, Nystom et al 2000). Reef ecosystems are particularly threatened by human activities as they are easily disturbed by changes in water quality (Cleary et al. 2008, Gardner et al. 2003, Hughes et al. 2003, Wilkinson 1999). Anthropogenic effects coupled with natural disturbances affect the resilience of coral reefs (Moberg and Folke 1999, Hughes et al. 2003, Nystom et al 2000). This in turn causes a decline in the populations of fish which depend on the reef as a food source as well as a habitat (Rogers 1990, Berumen and Pratchett 2006, Baker et al 2008, Polti 2001). Furthermore, the complex interactions between coral reefs and other tropical marine habitats, such as mangroves and sea grass beds, are poorly understood (Sheppard et al 2009), and human disturbance in one could affect the other (Rogers 1990). Even though sedimentation is part of natural reef processes, land use management has affected the quantity and quality of sedimentation and water, especially near the shore line (Piniak 2007, Cleary et al 2008, Nystom et al 2000). Therefore, it is important to consider local environmental conditions, such as the susceptibility of coral reef systems to anthropogenic influences, in coastal zone management decisions (Rogers 1990, Wilkinson 1999).

Sedimentation and turbidity are consequences of tourism development along the shoreline, due to recreational activities and the transformation of the landscape (Moberg and Folke 1999, Wong 1998).

Although the biological effects of sedimentation and turbidity on corals have been extensively studied (Rogers 1990 and 1970, Foster 1980, Hubbard 1987, Loya 1976, Roy and Smith 1971), there has been little work on the specific effects of beach management on reef health. The lack of knowledge on the relationship between coral biology and the ecological impacts of human management of beaches could be due to the economic incentive of coastal development, as well as the difficulty associated with trying to separate confounding factors (Rogers 1990).

Adding to the complexity of factors which play into the effects of sedimentation from coastal development on coral reefs, there are no known undisturbed sites from which to draw comparisons because of the continued human presence on island systems (Baldwin 2000). Although high values of sedimentation are required to damage reefs, chronic stress at lower levels is also important, and poorly studied (Rogers 1990, Nystrom et al 2000, Wilkinson 1999).

Hawkins and Roberts (1994) have used the development of the shoreline of the Red Sea as a historical case study of the impact of coastal tourism on coral reefs. They noted that dredging and sedimentation were important factors that have damaged the reef, but did not determine what parameters within these factors were most harmful. Other studies that investigated the human-driven change of the coastline focused on the effects of run-off and sewage deposition (Richmond 1993), dredging (Marsh and Gordon 1974), coral removal practices, and sedimentation resulting from the construction of resorts (Wong 1998, Baldwin 2000).

Even though sedimentation from human activities has been shown to be damaging for the fringing reef (Wilkinson 1999), there have been no studies of which I am aware on the effects of daily management and maintenance of resort beaches on the fringing reef.

The magnitude and duration of turbidity and sedimentation are influenced by hydrodynamic processes, such as wind, current and tides. (Storlazzi et al, 2009, Presto et al, 2006). They have been shown to cause the expulsion of symbionts from the coral, which breaks down the mutualistic relationship that is essential to its health, as well as causing reduced larval settlement of new coral colonies (Backrock and Davies 1991, Rogers 1990, Piniak 2007, Wilkinson 1999, Zubinsky and Stambler 1996).

Through laboratory experiments, sedimentation has been shown to have a greater effect on shallow coral communities, where a small increase in sedimentation had a disproportional effect on settlement patterns (Backrock and Davies, 1991). In the field, tidal fluctuations and topography could influence these results. Marissa Hirst (2002) showed through laboratory experimentation that smaller sediment size had a more harmful effect on *Porites* than greater grain size. Piniak (2007) showed that *Porites* recovered more quickly than *Montipora*, and is more susceptible to harbor mud than beach sand whereas *Montipora* was equally affected by both. He attributed these results to morphology instead of genera.

In general, morphology of coral reefs is more useful in determining susceptibility to stress than taxonomy (Marhsall 2000). Branching coral forms are less affected by sedimentation because the shape inhibits sediment from covering much of the total area (Rogers 1990, Zubinsky and Stambler 1996). Sediment type and abundance affect coral based on structure, growth rate and orientation. Rates of recovery from sedimentation also vary depending on coral morphology, and ability to remove sediment (Piniak 2007, Rogers 1990, Marshall 2000, Nystrom et al 2000). Usually, bigger coral communities are more susceptible to sedimentation because sediment removal at the surface is often random (Rogers 1990).

Throughout Mo'orea, hotel advertisements attract tourists with images of perfect turquoise lagoons and pristine white sand beaches. The gradual erosion of the fringing reef brings to shore white coral rubble which eventually decomposes to form the fine sand that tourists crave (Polti 2001). It is a common practice to clean and comb the beaches to render the sand smooth; at the Sofitel in Temae, it is done monthly, and the rubble collected is thrown away on the higher slopes of the public beach nearby (Pers. comm, Sofitel staff). White sand beaches in Mo'orea represent around 18% of the shoreline, and are mainly located on the northern and western coast of the island. Since 1993, 16% of existing white sand beaches have slowly disappeared due to anthropogenic construction along the coastline, which has driven hotels, in particular, to create artificial beaches to match tourism's demand (Porti 2001).

With a rise from 488 hotels in 1966 to more than 3021 in 1998 in all of French Polynesia, alterations to the coastline have caused a denaturalization of the landscape (Fauchille 2003). On the island of Bora Bora, this phenomenon has transformed the coast into a metropolis, much like the shores of the Mediterranean (H. Murphy and T. You Sing, Gump Station, pers. communication). Although this type of development has not yet occurred on Mo'orea, tourist numbers increase every year in search of pristine coastline (Davenport and Davenport 2006, Hutchings et al 1994). In 1990, 93000 tourists debarked on the island throughout the year, occupying 59.7 hectares both on land and in maritime concessions (Aubanel 1993). Tourism activities are centered on the lagoon and their effects are visible on the fringing reef (Wilkinson 2004, Hutchings et al 1994). Although French Polynesia has experienced a decrease in tourism following 9/11 (Harrison 2004), cruise ship based tourism is on the rise (Ministère du Tourisme 2008). Aubanel projects that up to 80% of the coastline of Mo'orea will be developed for tourism in the years to come (1993). The intensity of tourism on Mo'orea makes it of paramount importance to understand the implications of resultant shoreline management for the island's coral reefs.

In this study I investigated the impact of beach management on the health of the fringing reef. Two questions were asked: Does the frequency of the raking and the general management of hotel beaches increase sedimentation at the shore? If so, does this affect coral community composition, morphology and cover? I hypothesized that the sand substrate on maintained hotel beaches is composed of much finer grains than nearby beaches, and that this negatively affects the diversity of the coral community by compromising the symbiotic relationship between the coral and the zooxanthellae. I hypothesized that there will be more branching coral where there is more sedimentation, as well as a more stress-tolerant community composition.

METHODS

Study sites

All the field work was conducted on the island of Mo'orea (17˚30'S, 149˚50'W) in French Polynesia between the months of October and November 2010. The scope of the research was limited to the northern part of the island where the reef has been subject to the same intensity of tourism activities and has the same water quality (CRIOBE maps). Beaches were selected on a paired basis, where one unmanaged beach was situated within 200m of a raked hotel beach. Hotel beaches in front of over water bungalows were not studied because of the effects of the construction of the structures onto the reef. No beaches with a seawall were selected; nor were coral communities studied if they were at a coral extraction site (CRIOBE convention n*81525, 1981, Fauchille 2003).

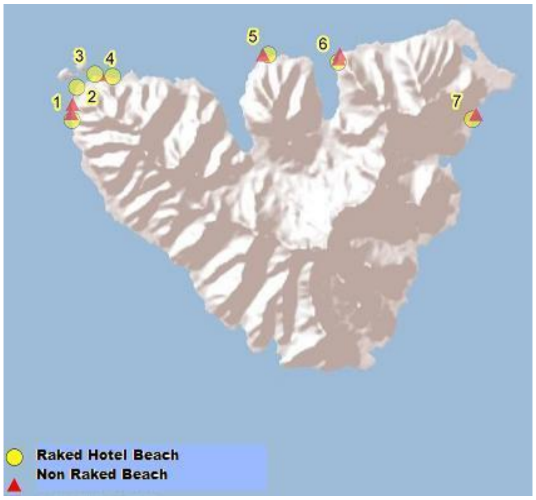

FIG 0. Map of study sites

1. Fare Miti paired sites
2. Club Med
3. Les Tipaniers paired sites
4. Intercontinental
5. Hilton paired sites
6. Kaveka paired sites
7. Sofitel paired sites

My sites included the Sofitel Hotel, the Kaveka Hotel, the Hilton Hotel, the InterContinental, Les Tipaniers, and the Fare Miti. Hotel impact was recorded using the following parameters: the number of bungalows, the presence and absence of over-water bungalows and their location, and the number of times raking is performed on the beach (Appendix). At each hotel, permission was granted from management to conduct my study. The hotel managers explained that beaches are public property and therefore free to access in any case. They added that they preferred if the study could be as minimally intrusive as possible to the general activities of the hotel.

During my survey, I found one abandoned hotel, the Club Med, which fits the environmental conditions of the research. Most of the Club Med's terrain is barred off from the beachfront by walls, but there is one site on the most northwestern point of the island which has a beach in front of a rundown amphitheater. Although too few sites were found to make a significant comparison to current managed hotel beaches, the same experiment was conducted at the Club Med to see if there are any changes in the coral community there.

Reef Assessment

A random design was used to examine the coral and substrate diversity. Ten quadrats were used to assess substrate types into 3 categories: sand, coral rubble and coral. The percent live and dead coral cover was recorded as well as the level of sand, silt, and algae covering the organisms in the quadrat. Each coral which was at least 10cm inside the quadrat was recorded and categorized into the following different genera: *Porites*, *Acropora*, *Pocillopora* and *Montipora*. In past studies on reefs in Mo'orea, other coral genera covered so little area that they were not statistically significant in analyses, and therefore were not considered here (Pratchett et al. 2010). Morphology structure such as branching, massive, columnar, encrusting, foliaceous, laminar and free living was recorded, because past studies have shown that the structure of the reef is an indicator of stress responses (Marshall 2000, Foster 1980, Loya 1976). Size, algal cover and sand cover were recorded, and health was estimated by assigning numbers between 1 and 5; 1 being healthy and not bleached to 5 being over 90% dead.

Current was measured by standing 2m away from another person in the direction of the current by the reef and counting how many seconds it takes for a filled plastic water bottle to reach the other person.

Sedimentation

Sand samples were collected along a straight line from the beach to the reef using the same size glass containers. By pushing the container down into the sand and sliding the lid under to close it, all the fine sediment was contained. The first sample was taken at the water line, the second at 10m, the third at 20m, and the last one at 30m, substrate permitting. At some locations, the sand layer was too shallow and covered a conglomerate platform. In this case, the sand sample could not be collected. A third of cup was taken from each sample in order to standardize for size. The samples were allowed to dry for two weeks. Two samples were taken from samples in five different locations and analyzed under a microscope to see the percent composition of organic material. Since organic material represented less than 1% of the total sample, the samples were baked in an oven if they were still wet. The samples were then weighed and run though five sieves. The mass of sand in each sieve was recorded and divided by the total mass of the sample to calculate an accurate representation of the composition of the sand at each site. To measure turbidity, water samples were taken at the location of the grain analysis samples, at 0m, 10m, 20m and 30m. The samples were then analyzed in the lab using a turbidity meter.

Sediment traps were placed every 10m along a 30m transect starting from the water line to assess the sedimentation rate gradient at each site. Empty metal cans filled with rocks were left along the transect for 5 hours at the hotel beaches, and a full day at the public beaches. The reason the sediment traps were only left for 5 hours at the hotels was to respect the hotel manager's requests of minimizing the impact of my study. The sediment traps were empty after 5 hours, and the day long traps were gone.

New sediment traps were set: a PVC pipe cemented into a flower pot. The trial was executed for another week at 4 different locations. The traps were left for an entire week to ensure that they would collect enough sediment. Upon return at Temae, the traps were gone, and the pots set on the beach. At the InterContinental beaches, the sediment traps were turned over. Sediment traps were then set at the ClubMed and the Fare Miti beaches for a week because of lower human traffic at the sites. They were gone or displaced or turned over when I came back for them.

Statistical Analysis

All statistical analyses were done using JMP 9.0 and Microsoft Excel. Two-tailed T Tests were used to test for statistical differences of substrate, coral cover and health between paired sites. ANOVAs were used to assess significant differences in turbidity, coral community composition, and distribution of grain size between raked and non raked beaches. A Tukey-Kamer test was used to determine what parameters in the reef assessment were different between hotels. A regression analysis was performed to assess correlations between morphology and grain size.

RESULTS

Reef Assessment

1. Paired Sites

Although no trend was found throughout all sites, differences were found between paired sites in some categories such as sand cover, live and dead coral cover, silt cover and algal cover. Between reefs at paired sites, two tailed T-Tests were used to test for statistically significant differences between substrate, percent live and dead coral as well as silt and algal cover (Figure 1). Signification differences at Temae (Figure 1A) were seen for sand substrate ($p=0.001$), with sand representing 41% of the substrate at the raked beach and only 20% of the substrate at the non-raked public beach.

Similarly, there is a significant difference between both silt cover (p= 0.0015) and algal cover (p=0.0277) at the Temae paired sites. Both silt and algal cover were greater at the raked beach then the non-raked beach.

Algal cover was also statistically different (p=0.0451) at the Hilton paired sites, where algal cover was greater at the raked beach than the non raked beach (Figure 1B). Additionally, the live coral cover was also different (p=0.0007) between the sites, where live coral represented a smaller proportion of the total cover at the raked beach than the non-raked beach.

At the Kaveka sites (Figure 1C), statistical differences were found in the sand substrate and silt cover of coral (p=0.05 and p=0.0096) where the raked site had a greater percentage of sand and silt than the non-raked site. However, live coral (p=0.0006) was present in greater proportions at the non-raked site.

The same tests were run for the paired sites at Les Tipaniers and the Fare Miti. The substrate had more sand (p=0.0212) at the raked beach of the Tipaniers paired sites, but there were no statistical differences in other categories of the reef assessment. At the Fare Miti, only dead coral showed a significant difference (p=0.0099) with greater proportions of dead coral found at the non-raked beach than the raked beach.

2. Hotel Size

There were statistical differences between substrate, coral cover, and sediment and algal cover of coral between hotel sites. Intercontinental, the largest hotel, showed statistical differences when compared with other sites in all the categories (Figure 2). ANOVAS were used to determine statistical differences. For example, the percentage of rubble substrate at Intercontinental was greater than in all other hotels (p<0.0001). Percent silt cover of coral at Intercontinental was statistically different than all other hotels (p<0.0001). However, there were statistical differences in percentage of sand substrate with only three other hotels: the Hilton, the Sofitel and Les Tipaniers (p=0.0003) where the hotels had a greater proportion of sand substrate than Intercontinental. All hotels except the Sofitel had a greater percentage of dead coral compared to Intercontinental (p<0.0001). The Tukey-Hamer test showed that the Club Med has more live coral than all other hotels except the Sofitel (p<0.0001). Both the Hilton and the Kaveka hotel showed more algal cover than Intercontinental (p=0.021) and more dead coral cover than Sofitel (p<0.0001).

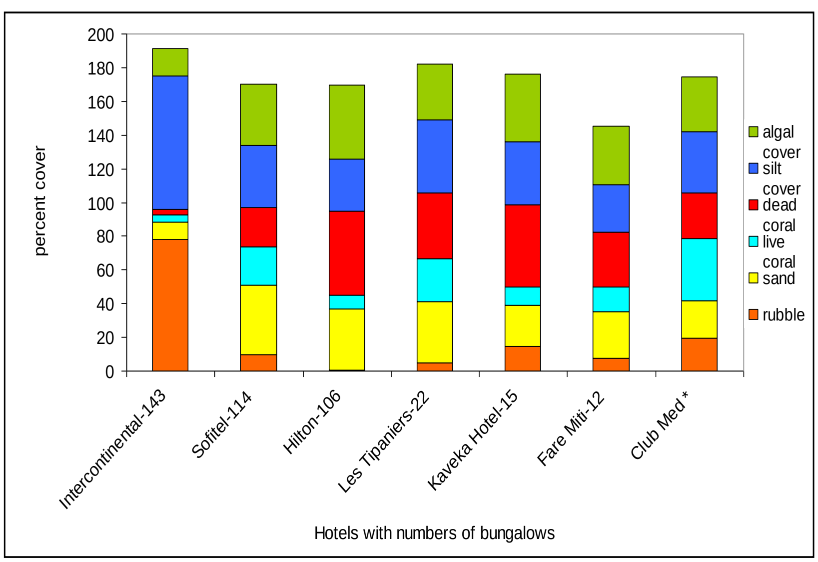

FIG. 2. Hotel Size. Substrate, live/dead coral cover and silt/algal cover were assessed at each hotel. Hotels are arranged in order of size (measured in number of bungalows). Percent cover adds up to more than a 100% because the parameters measured overlap each other (algal cover and silt cover were sometimes part of the substrate, or measured on top of live and dead coral).

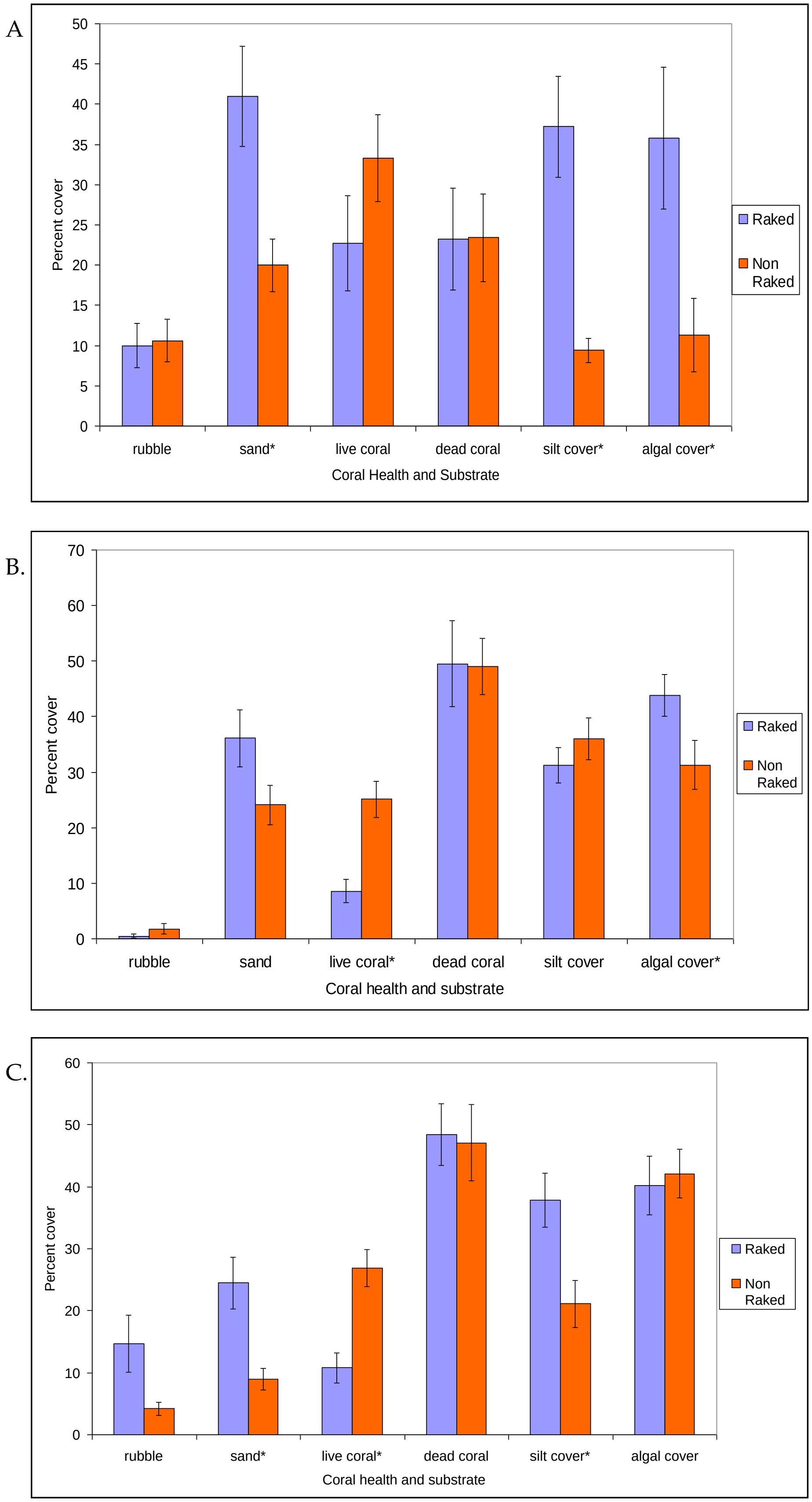

FIG 1. Reef Assessment at Paired Sites.

Paired comparisons of substrate, live/dead coral cover, sediment and algal cover at A) Temae, B) Hilton and C) Kaveka.

Significant differences are indicated with an *. Standard error bars are shown.

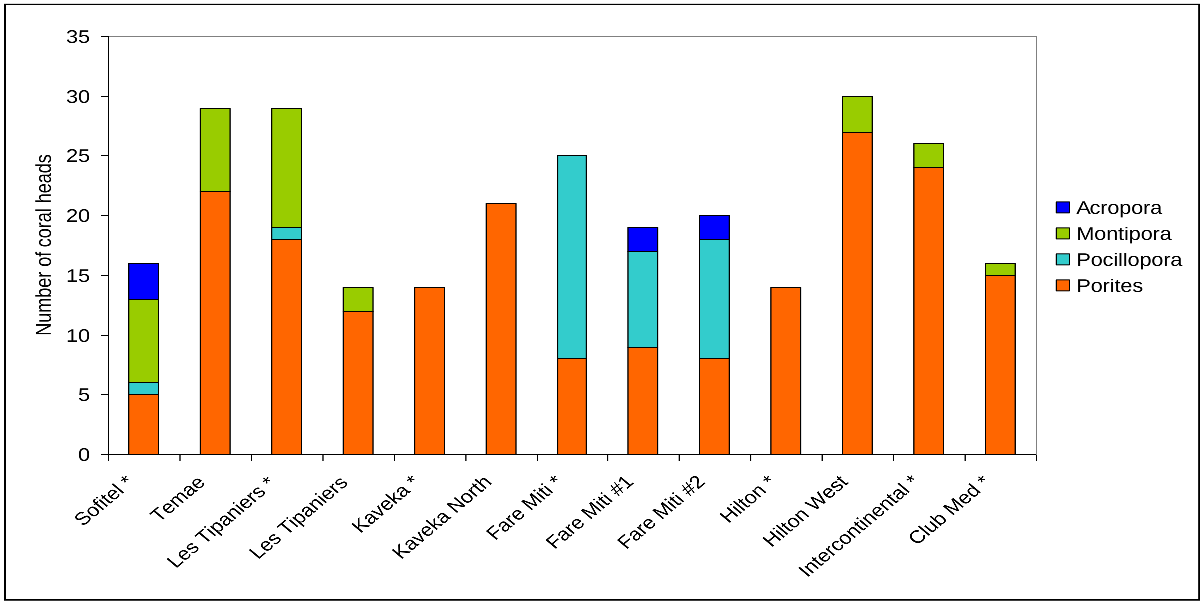

FIG. 3. Coral Community Composition. Number of coral heads of the following genera were recorded at each site: *Acropora*, *Montipora*, *Pocillopora* and *Porites*. Names with asterisks are hotels.

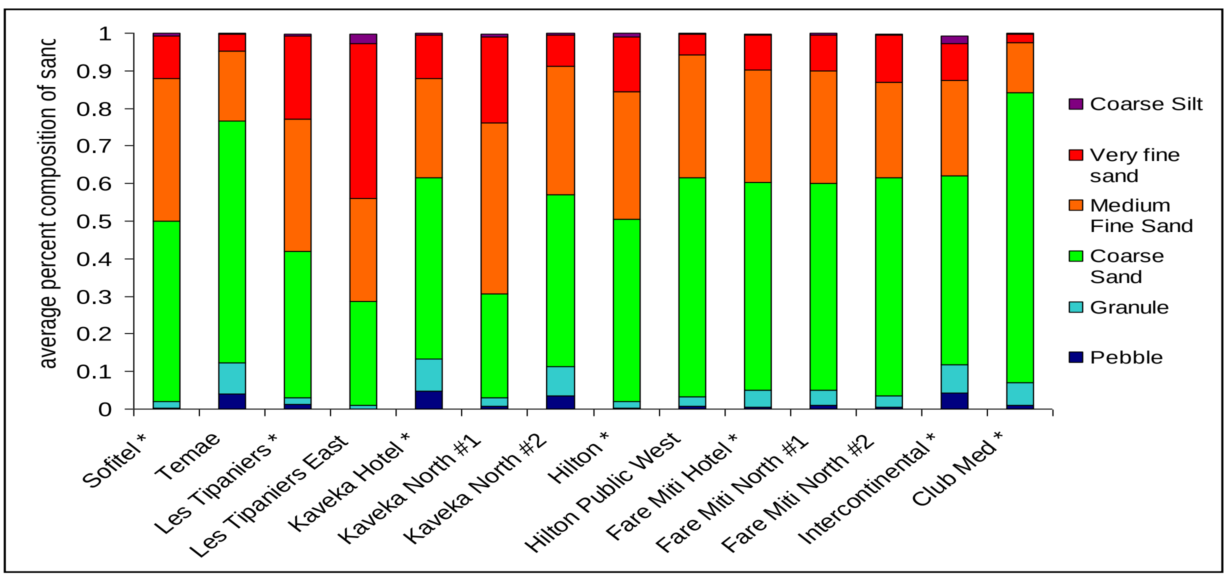

FIG. 4. Grain Size Across Sites.
This figure shows the average proportion of different grain size at all sites using the Wentworth scale. Hotels are shown with an *.

3. Coral community composition

There were no statistical differences in coral community composition between raked and non raked beaches. An ANOVA was run to test the relationship between raked and non raked beaches and the different coral genera, but it was found to be insignificant ($p=0.78$).

Although Porites was the dominant coral over all sites (Figure 3), it was not the dominant coral genera present at all sites. A Tukey-Kamer test showed that Porites was significantly different than other genera ($p<0.0001$), with a much higher mean across sites than Acropora, Montipora and Pocillopora.

Sedimentation

1. Sediment traps and turbidity

Sediment traps were largely unsuccessful, and often removed or displaced at each site. No trap was found upright, but all the ones that were found contained some sediment. Although a gradient analysis away from shore was not possible, sedimentation is confirmed but not quantifiable. The traps left out for one day only had no sediment.

An ANOVA was run to identify significant differences in turbidity among all sites and among raked and non-raked sites. No significant differences were found ($p=0.28$).

2. Grain Analysis

Grain size shows some differences across sites, although no overarching trend is present (FIG 4). An ANOVA was run to find if there were statistical differences in grain size between raked and non raked beaches as well as between paired sites. No statistical differences were found ($p=0.9$ for all grain sizes). There were statistical differences in grain size between sites overall ($p<0.0001$ for all grain sizes).

3. Grain size and morphology

The relative abundance of a particular morphology in coral does not show a relationship to the proportion of a particular size of grain. Regression analyses were run for all grain sizes to determine statistical differences between proportions of different grain sizes at both branching and massive columnar morphologies of coral. No statistical differences were found for all grain sizes: pebble ($p=0.80$), granule ($p=0.73$), coarse sand ($p=0.29$), medium fine sand ($p=0.76$), very fine sand ($p=0.44$) and coarse silt ($p=0.22$).

DISCUSSION

Reef Assessment

1. Paired site analysis

There were significant differences in sand substrate cover, live coral cover and silt cover at the Kaveka paired sites (figure 1C), where the raked beach had more sand and silt cover, and less live coral than the non-raked site. One of the Kaveka paired site was thrown out of the analysis because most of the reef at the site was dead, covered in algae, and in worst conditions than the sites around it. The site was located between a ferry dock and a sewage pipe. I assumed the data was different due to high pollution, since coral reefs have been shown to be negatively influenced by increases in nutrient inputs (Dubinsky and Stambler 1996, Sealey 2004).

The Kaveka paired sites are the only sites located inside a bay, in Cook's Bay. Cook's Bay's reef is covered in sediment and algae due to intense coastal development and land clearing (Hutchings et el 1994, Lenihan et al 2008). There are reports of increases in sedimentation around Maharepa between 2000 and 2003 (Salvat et al 2003). During the time of the sampling, extensive deforestation was conducted behind the Kaveka Hotel. These kinds of alterations to the coastline are particularly damaging to the fringing reefs because they expose the topsoil which is eventually washed out into the ocean during rainstorms (Kuhlmann 1988, Sealey 2004). This type of land use could explain the amount of silt and sedimentation at the site. However, the hotel raked beach has a lower live coral cover, and a higher sand and silt cover, which suggests that the hotel site is influencing the amount of sedimentation, which in turn is affecting the reef's health.

At the Temae paired sites, there was more sand substrate, silt cover and algal cover at the raked beach than the non-raked beach (figure 1A). Studies have shown that the vulnerability of shallow water substrate depends on positioning from the opening to the ocean (Umezawa et al 2009). Since both sites are so close together, their location compared to the wave energy and the pass of the reef is not a factor which influences the substrate. Therefore, other factors have to explain the observed differences.

Observations suggest an accelerated erosion of the beach at the hotel. In the Marquesas and the Great Barrier Reef, studies suggest that the alteration of coastline has increased erosion, which contributes to the degradation of the reef (Aswani and Allen 2009, Wolanski et al 2004). The two paired sites at Temae are relatively closer compared to other sites, but differences in sand substrate are striking. The beaches themselves have different morphologies, where the hotel beach is flat and the public beach has a sharp incline, with grasses growing on the slope. In the Bahamas, a study suggests that acute and chronic sedimentation increased because of vegetation removed along the coastline (Sealey 2004). It could be that the removal of the vegetation from the construction of the resort has increased the sedimentation process at the site. The reef at the hotel site begins much farther than at the public beach, with a difference of about 40m. There is a large sand flat which leads to a very sparse reef made of large *Acropora* colonies. In heavily sedimented areas, one would assume larger colonies because sedimentation reduces recruitment and more sedimentation resistant branching coral forms (Rogers 1990). This prediction is accurate at the raked hotel beach, which suggests that sedimentation is higher there than at the non-raked beach.

There is a shift from hard coral dominated to algal dominated reef substrate in areas where coral resilience has been affected, especially because of anthropogenic influence (Berumen et al 2006). At the raked beach at Temae, there is a significant difference in the algal cover of coral at the raked beach versus the non-raked beach, which suggests a higher nutrient input at the hotel site. Resorts in French Polynesia do not have strict waste regulations (Harrison 2004), which could explain the change in algal cover at the reef closest to the hotel bungalows.

At the Hilton paired sites, significant differences were found only in live coral cover and algal cover, where the raked beach had lower live coral cover and higher algal cover (figure 1B). This suggests that the Hilton hotel is having a greater impact on the reef than the beaches nearby. These results support past research that has shown that corals are negatively impacted by nutrient input, which is seen in a shift from hard coral cover to macro-algal dominance (Dubinksy and Stambler 1996, Sealey 2004, Kuhlmann 1988). My data support findings from the Global Coral Reef Monitoring Network which explained that the fringing reef in Mo'orea has changed into a macro-algae dominated community, especially near sources of anthropogenic disturbance (Wilkinson 1999).

At Les Tipaniers paired sites, only sand substrate was significantly different between the raked hotel beach and the non-raked hotel beach. The manager of the hotel explained that in the past 10 years, his beach has eroded to almost half its size (Les Tipaniers Management, pers. comm.). The density of tourists at his beach was greater than at all other beaches of Mo'orea because he accepts the cruise ship crowds to increase business. It could be that the increase in tourist numbers at that particular location explains the notable difference in sand substrate between the hotel and the public beach because it influences erosional processes.

At the Fare Miti paired sites, only dead coral cover was statistically different, where dead coral cover was greater at the non-raked site. Because this was the only significant result in the reef assessment, and because it is different than all other sites, there could be confounding factors involved, such as current. The effect of sedimentation is lessened by stronger currents (Rogers 1990). Furthermore, in shallow waters under 10m, the complexity of flow and current patterns varies greatly, so suspended sediment can be transported in many directions (Storlazzi and Jaffe 2006, Storlazzi et al 2009). Currents have been shown to cause differences in coral communities, and usually, more delicately branched forms are found in high current (Brown 1997). Water flow is an important factor in the feeding success (Sebens et al 1998), and the respiration processes of corals (Sebens et al 2003). At the Fare Miti paired sites, there is a different coral community than at other sites on the island (figure 3), mainly composed of branching *Pocillopora,* which is less stress resistant than *Porites*. A study conducted in the Red Sea showed that although *Pocillopora* can settle on a wide range of current velocity, their survival is diminished in low current habitats (Perkol-Finkel and Yehuda 2008). The northwestern tip of the island gets very strong currents due to strong south swells (pers. Comm. Les Tipaniers dive shop), which could explain why the population of *Pocillopora* is greater at those sites. Although I did not take enough data on currents during my research, there could be a relationship between the observed differences in coral and current strength. Future studies could research the current patterns on Mo'orea to understand the variability of hydrological processes and its effect on the fringing reef.

2. Hotel size

The notion of a threshold for coral reefs explains that there will be a collapse in the reef community after water conditions reach a critical point, usually due to an increase in chronic stress (Wilkinson 1999). It seems that in Mo'orea, hotel size is creating a threshold effect (figure 2). Intercontinental, the largest resort on the island, has the greatest silt levels and a notably more damaged reef than all other hotels, with over 80% of the reef either dead or composed of coral rubble. All other hotels have a higher proportion of dead coral because the substrate at Intercontinental has not conserved dead coral structures. Is there a size limit at which the human impact is too harmful for the reef system? Large resorts in French Polynesia have to submit an environmental impact statement, which is reviewed by the Ministère de l'Environnement, but it remains unclear which factors are considered (Hutchings et al 1994).

Interestingly, Club Med, which is now abandoned, has the greatest proportion of live coral than all other hotels except Sofitel (figure 2). Ten years ago, this hotel was the largest on the island. Could the reef at the site be in a stage of recovery? The access to the Club Med is restricted from the road, and the reef there is only accessible from the beaches at Les Tipaniers and Hotel Hibiscus. The lack of access limits the numbers of tourists at the site, which could have a positive impact on the regeneration of the reef.

3. Coral community composition

According to this study, *Porites* dominates the fringing reef of the northern side of Mo'orea (figure 3). Massive and submassive corals are more tolerant of high sedimentation and eutrophication and usually dominate disturbed reefs (Edinger and Risk 2000). In Indonesia, inshore sites of altered shores show a higher presence of stress-tolerant coral such as *Porites* (Cleary et al 2008). Massive *Porites* in the Java Sea is considered a survivor because of high rates of recruitment and growth as well as its ability to propagate asexually; it has replaced *Acropora* as the dominant coral present (Baker et al 2008). Similarly, past studies have recorded a shift in the coral community in Mo'orea, going from an *Acropora* dominated state to a *Porites* dominated reef (Pratchett et al 2010, Lenihan et al 2008). This shift could be due to multiple factors. The four past bleaching events at Mo'orea affected the community composition differently, and although both *Acropora* and *Pocillopora* were severly affected, *Porites* was not affected by the disturbances (Adjeroud et al 2009, Kalish 1994). Similarly, studies have shown that massive *Porites* has a high resistance to mechanical force, whereas *Acropora* is easily damaged by storms, boat anchoring, reef walking and other anthropogenic activities (Marshall 2000).

The domination of the Mo'orea reefs by massive Porites could have strong implications for the biodiversity and the productivity of the reef, because it lowers not only the availability of different habitats for reef dwelling organisms, but also the topographical complexity of the reef (Pratchett et al 2010). Furthermore, studies have shown that there are variations in bleaching because of reef structure (Lenihan et al 2008), which could further decrease the topographical complexity of the reef.

Sedimentation

1. Sediment traps and turbidity

Sediment traps are usually widely used to determine sedimentation rates in both observational and experimental studies, even though they give biased results when current is too strong, or if environmental conditions are suboptimal (Thomas and Ridd 2004). The sediment traps in the field in Mo'orea were often turned over due to current, perhaps because they were placed in very shallow water. Additionally, there are problems with the standardizing of sediment traps (Rogers 1979). Future studies should be done to experiment with different sediment traps to determine which methods are most successful, and how to reduce the vulnerability of the traps to environmental factors. On Mo'orea, the traps that were collected had sediment in them, which confirms that sedimentation is happening, although the rate remains unknown.

Turbidity is similar across sites and shows no difference between raked beaches and non-raked beaches. Therefore, beach raking is not increasing turbidity at the shore. In shallow water, the transport of turbid water is seasonal, and usually greater during storm events (Storlazzi and Jaffe 2007), which could explain the lack of variability in my data.

2. Grain analysis

Although grain size was different between sites, there was no significant difference in grain size between raked and non raked beaches. This suggests that beach raking is not having an effect on the distribution of grain size along the beach. A study in the Bahamas which compared differences in coral communities on developed and non developed islands found no significant differences between communities due to sediment movement along the islands (Sealey 2004). Sediment transfer could also be happening along the beaches in Mo'orea. Locals have reported that sand from the resorts drifts to their beach during storms (F. Murphy and J. You Sing, Gump Station, and S. Lloyd, personal communication), which could explain the lack of difference in grain size between raked and non-raked beaches on Mo'orea.

3. Grain size and morphology

Coral morphology was not significant across grain size (figure 5). This is consistent with an experimental study by Riegl, in which he tested the responses of genera of coral to different grain sizes (1995). He found that there were no differences in response to different grain sizes, although both corals experienced severe damage from long term exposure to sedimentation.

Encrusting coral was removed from the morphology analysis because numbers of encrusting corals were low. Additionally, morphology studies showed that sedimentation have an effect mainly on the morphologies of branching and massive coral, where branching forms tend to be found in areas of higher sedimentation (Brown 1997, Riegl 1995, Dubinsky and Stambler 1996, Marshall 2000). I grouped columnar forms with the massive forms because both coral morphologies are from *Porites.* I observed in the field that columnar forms of Porites are usually found on massive coral heads, and that there are little differences between these two morphologies.

My data does not support past studies that show that branching forms should be found in areas of greater sedimentation (Marshall 2000, Rogers 1990). This could be due to the fact that I was unable to determine which of the sites were actually experiencing high levels of sedimentation. Additionally, if the sampling size was bigger, I could have found more significant results for morphology across sites.

CONCLUSION

Although the results of this study do not support the hypothesis that beach raking is increasing sedimentation, they suggest that hotels are having negative impacts on the coral reef, especially once the hotel has reached a certain size. Studies have shown that there is a worldwide increase in anthropogenic effects on the reef (Aswani and Allen 2009, Hutchings et al 1994, Sealey 2004, Dubinsky and Stambler 1996, Kuhlmann 1988, Wolanski et al 2004, Wilkinson 2004, Sheppard et al 2009, Wilkinson 1999, Hughes et al 2003, Polti 2001, Richmond 1993). However, it is important to note that although reefs can change in community composition after disturbance, the ecosystem does not simply collapse (Adjeroud et al 2009). Some argue that reefs have persisted through geological time and countless disturbances, reappearing and always changing (Brown 1997, Nystrom et al 2000), and that we should attempt to understand what it is that makes them so adaptive instead of focusing on conservation (Buddemeier and Smith 1999, pers.comm J. Lipps). Nonetheless, it has been determined that local processes will affect the future direction of change within the reef (Done et al, 1991, Gleason 1993, Dubinsky and Stambler 1996). Confronted with increasing population pressure on our environment, will we decide to mitigate our impact?

ACKNOWLEDGMENTS

Mauruuru to all the class professors: George Roderick, Vince Resh, Pat Kirck and Brent Mishler. A big thank you to all the GSIs: Erin Meyer, Sonja Schwartz and Justin Lawrence for sharing your personal time and precious advice. Mauruuru to all the station staff, especially Hinano, Frank, Irma, Jacques and Toni. Thank you to the all the hotel management at the Hilton, the Sofitel, the Fare Miti, the Kaveka and Les Tipaniers for allowing me to access their property. Another thank you for the GIF laboratory at UC Berkeley, especially Sam Blanchard. And a lastly, mauruuru to all my classmates for a beautiful experience in a beautiful place. Et puis bien sur, un grand merci à mes parents.

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APPENDIX

Hotels	number of bungalows	over water bungalows	construction on reef	sea walls	private* hotel beach	boat dock	beach raking	Health
Sofitel	114	yes	yes	yes	yes	no	1/month	3.6
Hilton	106	yes	yes	yes	yes	yes	1/day	4.6
Intercontinental	143	yes	yes	yes	yes	yes	1/day	4.2
Moorea Pearl	95	yes	yes	yes	yes	no	1/day	n/a
Les Tipaniers	22	no	no	no	yes	yes	2/month	3.7
Hotel Hibiscus	41	no	no	yes	yes	yes	1/day	n/a
Fare Miti	12	no	no	no	yes	yes	2/week	3.4
Kaveka	12	no	yes	yes	yes	yes	1/day	4.6
Club Med	unoccupied	no	no	yes	yes	yes	never	3.2

Health is assessed according to the following scale:
1=perfectly healthy
2= 25% of area is covered in algae/bleached
3= half dead: covered in algae/bleached
4= 70% covered in algae/bleached
5= over 90% dead

* On Mo'orea, all beaches are public but hotels can restrict access to their beach.