MATURING MOTU? THE GEOMORPHOLOGY OF MOTU TIAHURA WITH A FOCUS ON HUMAN IMPACT

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Abstract. Geomorphological changes occur on a range of spatial and temporal scales. In the past, they have been primarily driven by abiotic factors like storm events and wave action. More recently, human impacts have begun to affect geomorphological processes. It is critical to understand where and how humans impact such processes in order to minimize environmental impact of activities like boating and adding infrastructure. I studied human impacts on the formation and continuous alteration of Motu Tiahura, Mo'orea, French Polynesia. By studying velocities, sediment distribution, beach profiles and wave heights in areas with and without human activity, it was found that humans are in fact having a geomorphological impact on Motu Tiahura.

Key words: geomorphology; human impact; erosion*; deposition; boat waves; beach profiles ; French Polynesia; Mo'orea, Motu, Tiahura*

INTRODUCTION

Every aspect of the world is constantly in motion. Landscapes can change on a geologic timescale, like the subducting, uplifting or drifting of continental and oceanic plates - 4.5cm/yr in the South Pacific (Vine, 1966); on the order of decades like cliff erosion - 3cm/yr to 43cm/yr in San Diego, California (Benumof and Griggs, 1999); or even on the order of days, such as shifting sand dunes - 17.5m/yr along the Ceará coast, Brazil (Jimenez et al., 1999). It is essential to understand the geomorphological processes on both short and long-term scales to determine how, if and why humans can live in certain areas.

Volcanic islands themselves are a model for long-term dynamic systems. According to Darwin's 1842 Theory of Coral Reef Evolution, they start as oceanic volcanoes, become islands, develop barrier reefs and motu, and eventually form atolls (Hickman 2009). Life is always shifting in order to work in sync with these dynamic geomorphological processes . Volcanic islands in the Pacific have a lifespan of about five million years. As younger islands form, flora and fauna can disperse to them as the older ones erode away (Hickman 2009).

The delicate balance of dynamic coastal landscapes is easily disrupted. Coastal areas are commonly subjected to human interference which results in serious erosion (Goudie, 2006). Certain human activities disrupt the natural flow of sand supply such as sand mining, dredging, barrier walls, and the construction of harbors. Other activities such as agriculture, recreation, landscaping, edification of buildings and structures like jetties affect other natural geophysical and biological processes. Unsustainable construction of urban homes or buildings close to eroding shores contributes largely to existing erosion (Mangor 2004).

In Mo'orea, French Polynesia, islets known as motu form on the barrier reef. They are very fragile due to their unstable make-up of mostly unconsolidated materials (Nunn 1994). They are considered ephemeral because they are always changing and therefore somewhat temporary; entire motus can be created or destroyed in one cyclone, hurricane or tsunami (Murphy 1992). Their usual width is under a quarter of a mile while their length can vary between "a few yards and several miles" (Darwin, 1851). Other destructive forces include long-term wave action, changing currents, bio-erosion, chemical dissolution and typhoon waves (Lobban, C.S. And Schefter, M, 1997).The motu have very diverse components. Conglomerate platforms form on the reef side of the motu, depositional sand bars form where the oncoming waves slow down, and exposed beach rock appears from rapid erosion in areas of high-energy wave action (Murphy 1992). Strong water movement from currents also contribute to sand distribution (Lobban, C.S. And Schefter, M, 1997).

Along with the many natural geophysical processes that occur on the motu, anthropogenic interactions might also play a significant role. People have lived on the motu for generations (Murphy, Kirch and Mishler, personal communication). More recently motus have become tourist attractions and there has been increased infrastructure construction in response. For example, deposited coral rubble has been raked aside to create more pleasant sandy beaches and walls have been built which prevent natural erosion. Alongside the physical changes humans have made to the motu, and because they are such an attractive spot, boats, jet skis, and kayaks are constantly traveling in the areas around and between the motu and the main island of Mo'orea. This extra wave action probably contributes to the net impact that humans have on the motu. Channels have also been dredged in order to let boats pass through (Augustin et al. 1999). It is important to asses these affects in order to determine how much of an impact humans have on the motu.

Investigation of natural geomorphological processes can help determine where human impact might be the least destructive. It is also necessary to evaluate existing human impact to assess and maybe prevent accelerated erosion. In order to do this, I conducted a study on the coastal environment of a motu in Mo'orea, French Polynesia: Motu Tiahura. This lies on the North Eastern corner of the reef around Mo'orea, which is a high volcanic island in the South Pacific. I looked at current depositional and erosional areas of the motu in concurrence with present day human activities, with the goal of determining whether human activities have a significant impact on natural erosional and depositional processes.

It is hypothesized that human activity is significantly disrupting the natural processes of active deposition and erosion. In areas of high energy wave action and water movement, I hypothesized that human impact will be much larger than in areas of lower energy wave action. With the current sea-level rising and the global climate changing, the rate of erosion may be faster than the rate of sediment deposition, unless more storms come to replenish the eroding sediment.

The main goal of this paper is to determine human impact on the Motu Tiahura from a geomorphological standpoint. This was done by analyzing and quantifying human impact and comparing them to the natural depositional and erosional processes. Beach profiles, sediment samples, wave heights, and velocities were measured and analyzed statistically to find out if human impacts are contributing to a faster rate of erosion on the motu.

METHODS

Study site

Motu Tiahura is located on the northwestern tip of the island of Mo'orea, French Polynesia, in the Society Islands archipelago, GPS point 17º29'12.66”, 149º54'43.82” (fig. 1).

FIG. 1. Satellite Image of Mo'orea, French Polynesia from Google Earth Pro 2009. Circled in the NW corner are Motu Tiahura and Motu Fareone
Google Earth Pro. 2009
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image 2009 DigitalGlobe
Image 2009 TerraMetrics

FIG. 2. Satellite image of Motu Fareone to the west and Tiahura to th east, Google Earth Pro. 2009

Motu Tiahura is to the east of Motu Fareone and is the smaller of the two islets, situated offshore at Haru Point (fig 2).

Each side of Motu Tiahura is geologically distinct. The northern ocean side faces the barrier reef, where a conglomerate platform has formed as a result of coral detritus and sediment that has accumulated and cemented together. The eastern side has large areas of unconsolidated sand deposits while the western facing side has a channel that runs between the two motu. The southern facing point along with the adjacent side has a mixture of both erosional and depositional properties; at this point a boat channel runs between the motu and the main island of Mo'orea.

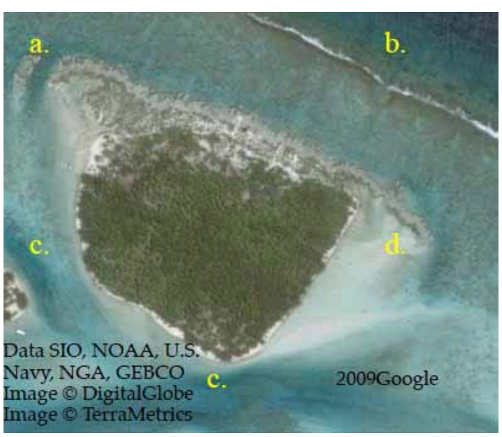

FIG. 3. Satellite image of Motu Tiahura. Google Earth Pro. 2009. (a) Shows conglomerate platform, (b) barrier reef and ocean to the north, (c) the 2 channels along the western and southern facing sides, and (d) the sand deposits on the eastern facing side.

Methods and Rationale

Velocities

Velocities of top-currents were measured along every side of the motu except the ocean facing side of the conglomerate platform. These were taken using a transect tape, an empty plastic bottle and a timer.

Measurement sites were chosen based on changes in the substrate along the shore and into the water. The top-current velocities were taken 10m from the high tide line into the water. I dropped a floating bottle at 0m and then waited for the bottle to traverse 5m. Each site was repeated 5 times in order to account for inaccuracies or inconsistencies in wind, current or boat action.

Velocities of currents are an accurate way of determining sediment carrying capacity. The faster the water movement, the more energy it has. The amount of energy it takes to pick up sediment particles is directly proportional to the size of the particle (Kirch, 2009). Velocity is a measure of energy, so the faster the velocity, the larger the grain size that can be moved. Inversely, if the velocities are slow enough, the smallest grains can drop out and deposit

Shorelines

Profiles are a good way of determining the shape of an erosional or depositional beach. If the profile is very gradual, then it shows a depositional beach as opposed to a very steep or even cut out profile which shows erosion. Profiles were also taken along each side of the motu except the ocean facing side of the conglomerate platform. These were taken using two transect tapes and a level with the aid of a partner.

Profile sites were also chosen based on geomorphological changes along the shore. The starting point for all the sites was at the vegetation line, and the length depended on the width of the beach itself.

Wave Measurements

The two motu are a significant tourist attraction and many people take boats there to sight see, relax or do recreational sports. As a consequence, many boats go back and forth transporting people every day, and at times there were up to 10 trips in an hour passing by. These boats create large wakes and residual waves.

Boat induced waves were measured and compared to normal waves under the same conditions without boats present. These were taken to help determine the human impact on the geomorphological processes. The largest waves from each passing boat were measured from crest to trough along a meter stick.

Sediment Distribution

Grain size is another way of determining if an area is depositional or erosional, so sediment samples were also taken. If an area has slow enough moving water, even the smallest grains will drop out and deposit.

Sites for grain size sampling were chosen based on differences in substrate. The samples were air dried, weighed and then sieved for five minutes each using a nested set of geologic sieves. Then each grain size was weighed and compared to the other samples.

6 sites were chosen for sediment distribution comparison; 3 where boats pass by frequently and 3 where boats do not pass by at all. Statistical analysis is detailed later in the paper.

Other materials used were a compass to determine the direction of waves, wind and which way shored were facing, a GPS Garmin unit, the Arc GIS computer program and Google Earth Pro. 2009.

Statistical Analysis

A one-way ANOVA test was used to compare the average velocities in site with and without boats; wave heights when boats were and were not present; and sediment sizes in areas where boats were and were not present.A Kolmogorov-Smirnov Comparison of two data sets was used to compare profiles in areas of human impact and no human impact.A Tukey-Kramer test was also used to determine which results were significant from each other.

RESULTS

Velocities

I found that the average velocities on the North Eastern Inside of the Conglomerate Platform and Western side of Motu Tiahura have significantly slower average velocities (F=9.15, p=0.0151) than on the on the Southern Point (Table 1). The average velocities from the Southern Point were statistically higher than those of the Conglomerate Platform (p=0.0176).The average velocities from the West side were significantly lower than those of the Southern Point (p=0.0339).The average velocities from the West Side were not significantly different from the West Side (p=0.841).

TABLE 1. The velocities of three sites were compared; the South Western Point, the West side and the Northeastern corner, inside the Conglomerate Platform.

Site	Average Velocity
SW Point	*21.2*
SW Point	*18.4*
SW Point	*23.4*
West Side	*46.8*
West Side	*35*
West Side	*34.8*
NE Inside Conglomerate	*43.8*
NE Inside Conglomerate	*49.2*
NE Inside Conglomerate	*32.6*

Note: ANOVA, F=9.15, p=0.0151

Grain sizes

In comparing 6 sites, I found that in those areas where there are boats present the relative percentage of 500µm grain size is significantly greater (F=20.94, p=0.0102) than in areas where boats are not present (fig 4).

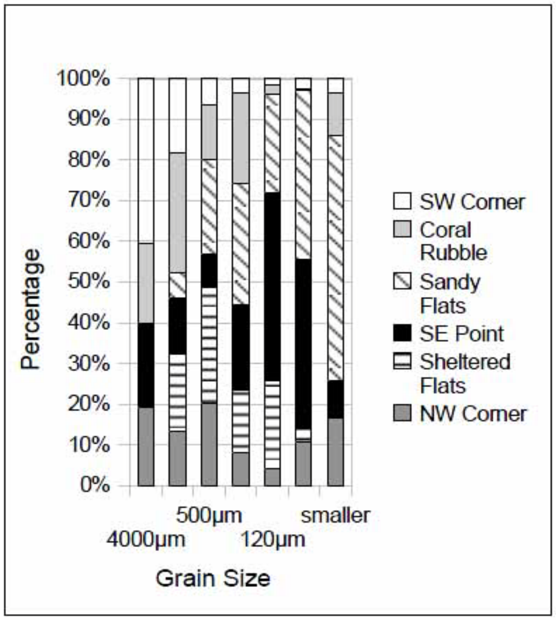

FIG. 4. Shows the sediment distribution for 6 different sites along Motu Tiahura.

Wave Measurements

In both study sites waves when boats passed by were significantly larger than when boats were not present (site 96 – F=18.29, p=0.0007 and site 112 – F=24.07, p=0.0002).

Image Comparison

Comparing the 1955 image of Motu Tiahura (*fig. 5*) the Google Earth Pro. 2009 (*fig. 6*) show that some erosion has taken place in the past 50 years. The general shape appears to be similar, although the sand bar build-up on the east side does not seem to extend as far onto the reef flat.

FIG. 5. The 1955 U.S. Navy aerial photograph of Motu Tiahura to the east and Motu Fareone to the west. Provided by the University of California, Santa Barbara Map and Image Laboratory, Davidson Library.

FIG. 6. Google Earth Pro. 2009 satellite images of Motu Tiahura to the east and Motu Fareone to the west. There has been some change in shape to the SW corner of Motu Tiahura and the sand bar distribution to the east. Most notable is the amount of development on Mo'orea proper (bottom right corner).

Google Earth Pro. 2009
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image 2009 DigitalGlobe
Image 2009 TerraMetrics

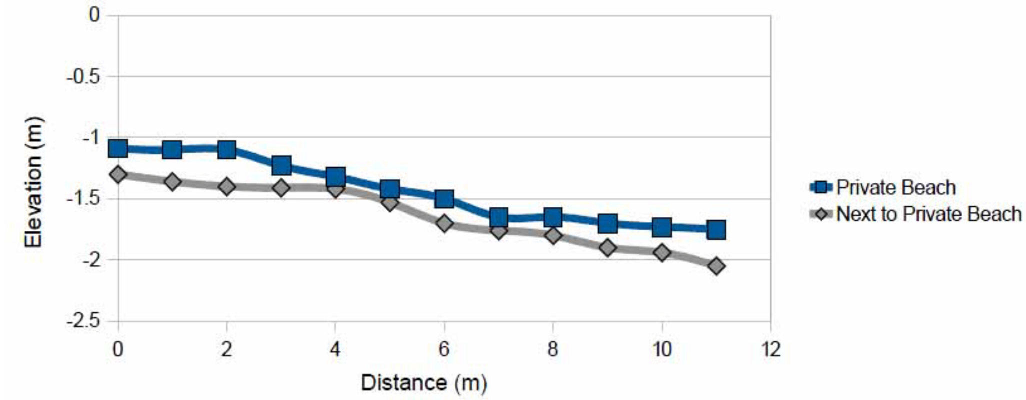

FIG. 7. Comparisons of a private and public beach profile on the west side of Motu Tiahura.

Shorelines

Statistical tests showed that the private beach and the adjacent public beach did not have significantly different profiles (*fig 7.*; D=0.1923, p=0.674).

DISCUSSION

Summary and Interpretation of Results

Velocities were taken and analyzed around Motu Tiahura along every side except the Conglomerate Platform. This is one way of quantifying the wave energy that is contributing to the natural geomorphological processes of the motu. It was found that in locations of high boat traffic, there were also areas of significantly higher velocity. The Northwestern and Northeastern sides that are protected by the Conglomerate Platform are very shallow (depth 3-10cm) and by default boats cannot pass through. These areas therefore make a good comparison with the Southern Point that is subjected to both boat traffic that just pass the two motu, and also the boats that actually enter the channel between them. It was also found that the two protected areas were statistically similar to each other. Velocities represent how fast currents move, which is directly related to the size of the sediment they can carry (Kirch, personal communication). It is important to look at the carrying capacity of the waters around the motu to help determine where there is active erosion or deposition.

Seventeen beach profiles were taken around the motu to gather further evidence of erosion and deposition. Areas of erosion have steep profiles or obvious cuts whereas profiles in areas of deposition have a very gradual and shallow slope. The beach profiles of obvious depositional locations such as the Southwestern side where there are sandbar build-ups (GPS 17°29'18.10"S, 149°54'37.30"W) and locations of obvious erosion such as the Southeastern corner where there are eroding beaches under coconut trees (GPS 17°29'24.7”S, 149°49'35.2”W) were compared to two adjacent beaches, similar in composition, location, and wave action, one raked and one not raked. This was done to determine if the human activity of raking the beach would have a significant impact on the slope of the beach, an indicator of erosion or deposition. It was found that the slopes were not significantly different. After some investigation with local natives and the private beach manager, I learned that the raked beach was only 8 month old (Bertreux, personal communication), which on a geologic timescale is virtually no time at all. Since human disturbance in this area is so recent, it might explain why the beach profiles were not significantly different.

Sediment distribution was analyzed by looking at relative percentages of the grain size 500μm of several samples. Paired comparisons were chosen based on if boats passed by that location or not. Of the twenty-three samples sieved, 6 were chosen based on amount of replicates and their distance from each other and spacing around the motu. It was found that grains of 500μm had the most significant differences among sites with boats and no boats. It was shown that locations with boat traffic had a significantly smaller percentage of 500µm grains than locations that did not have boats.

Wave heights were analyzed at two sites that had frequent boat action. Pt. 96 is on the south side directly across from Mo'orea proper (GPS 17°29'20.01"S, 149°54'41.49"W) and Pt. 112 is just to the west of the SW corner in the channel between the two motu, Fareone and Tiahura (GPS 17°29'20.00"S, 149°54'46.02"W). The heights from trough to crest were significantly larger in both locations when boats passed by compared to when boats were not there.

The U.S. Navy aerial photographs taken in 1955 of Mo'orea and the motu compared to Google Earth Pro. 2009 satellite images show a difference in landscape as well as development (fig. 5 and fig. 6). The shape of the southwestern side looks as though there is some build up or filling in since 1955. The northern side behind the conglomerate platform seems as though it has started to deteriorate in the 2009 satellite image. This may be from the residences that occupy that region of the motu. The people who live on Motu Tiahura live on the inside away from shore or along the conglomerate platform. The change in plant coverage from 1955 to 2009 may be the human activities associated with living, like building houses and cutting back plants, or the many chickens and roosters that locals keep on their properties which eat plants and seeds.

Hypothesis and Limitations

Human Impact

There is a lot of human activity on Motu Tiahura as well as many other motu, such as Motu Fareone. As mentioned earlier, there is raking of private beaches. This is done by removing all the large coral rubble and exposing only the fine grains. I hypothesized that by removing the large rubble the exposed fine grained sediments would be more susceptible to erosion by wave action. Since there was not a significant difference in beach profile slopes, a new question arises, in 20 years, will there be a significant difference in slopes?

The local population of Motu Tiahura do not seem to disturb the erosional and depositional geomorphological processes. When examining the aerial photographs from 1955 and Google Earth Pro. 2009 satellite images, it seems that the area behind the conglomerate platform, where people do reside, has changed. The most striking difference, however, is the amount of development on Mo'orea proper. From many discussions with a local resident (Anita Pahio, personal communication), I learned that since the area across from the two motu has been developed, the natural erosion that occurs there and associated redistribution of sand to the two motu has largely decreased. It appears as if the infrastructure on Mo'orea proper put in place to prevent erosion has worked, but has not to the advantage of the motu. From the Satellite images, it is apparent that the beaches along the west coast of Motu Tiahura are visibly narrower, and the sand bar along the east coast is also smaller. Perhaps this observation is accurate. From speaking with another local motu inhabitant, Maire Maiau, a private beach owner, I learned that during seasons there is also a change in current coming from the ocean, which also has an effect on the distribution of sediments. So it is important to keep in mind that these images might not have been taken during the same season.

Boats pass by Motu Tiahura and Motu Fareone daily, and during the tourist seasons and when it is not raining, boats can pass by multiple times a day. One day I observed 11 boats in 1 hour. Their wakes have shown to cause significantly higher waves and therefore energy that can erode the shorelines. Along with natural erosion, this added affect could increase the rates of erosion. A study of the impact of tourism and personal leisure on coastal environments has shown increased erosion in areas associated with coastal transport infrastructure (Davenport and Davenport 2005). With increase transport and prosperity, Davenport and Davenport point out that there is a non-liner increase in tourism, and also environmental costs.

Human impact on geomorphology is not a new phenomenon. After the initial arrival and colonization of seafaring Polynesians to a Central Pacific Island (Mangia, Cook Islands), rates of volcanic hillside erosion increased during the Holocene (Kirch, 1996).

Along with geomorphological impacts, human activity also has a large ecological impact. A recent study at Motu Tiahura, Mo'orea raises questions on human impact on the mollusc communities from tourists collecting shells, hotel pollution, dredging of the channels causing sedimentation and turbidity (Wilson 2009). In a meta analysis of streams though-out Europe, it has been shown that boats are the main cause of ecological detriment (Statzer and Resh, personal communication).

The human population over time on a small islet like Motu Tiahura can also cause other environmental effects. Sewage and biological waste that is not removed can get into the ground water and contaminate the fresh water lens. Although small, significant amount of these chemicals are nutrients and when introduced into this small island system can increase primary productivity, but with an increase in time can accumulate in concentration and become pollutants (Lovenburg, personal communication).

Conclusion

As a part of global society, humans have shown in a multitude of studies to have some sort of impact on their surrounding environments, whether it is geological or ecological. It is essential that we are always aware of impacts from our collective everyday activities. This can be done by continually conducting studies to monitor areas that might be impacted. We can also decrease our negative effect by education to increase social and environmental consciousness.

Further studies on the geomorphology of Motu Tiahura or other motu of Mo'orea would certainly increase understanding of the human impact. In order to account for limitations from my study, I recommend that more replicates of each section be done in order to get more accurate and significant results, such as sediment samples, profiles in more locations, velocities taken in the same location on different days and conditions, and wave measurements in more locations with more replicates. Also, experiments with sand might be conducted to gather further evidence of boat induced wave erosion.

Dynamic and ephemeral systems all over the world are subjected to human interference. With increased studies and consciousness this processes may be prevented or slowed.

Acknowledgments

I would like to thank all of the Professors and Graduate Student Instructors of the Mo'orea Class of 2009: Pat Kirch, Brent Mishler, Vincent Resh, George Roderick, Stephanie Bush, Maya deVries, David Hembry, the entire Mo'orea class of 2009, especially Amanda Minnich, Katie Henrickson, Vanessa Lovenburg, Conner Dibble, Ryan Wilson and Chris Ahlgren, the local people at and around Motu Tiahura: Anita and Congo Pahio, Maire Maiau, Olivier Bertreux, Heifara Dutertre, Gino and Jessie Teriipaia, The Gump Station, Frank Murphy, Merv Lovenburg, The University of California, Santa Barbara, Map and Image Laboratory, Davidson Library.

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