

The Biology and Geomorphology of Tropical Islands, Mo'orea, French Polynesia

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1993 Mo'orea Class Report

15 December 1993

Berkeley, California, USA

This presents the research papers prepared by the fifteen undergraduate students of the 1993 U.C. Berkeley course, the Biology and Geomorphology of Tropical Islands.

This course focused on the ecology and geomorphology of terrestrial and marine environments on tropical islands and included a seven-week field component at the Gump Research Station on Mo'orea, French Polynesia.

The principal instructor, Dr. Mary Power, orchestrated an impressive array of lectures by leading scholars on various aspects of Polynesian natural history and culture. Special thanks are given to the following individual lecturers: Werner Loher, David Stoddart, Bill Dietrich, Keith Loage, Jere Lipps, Vince Resh, Roy Caldwell, Carla D'Antonio, George Barlow, Patrick Kirch, David Lindberg, Eric Edlund, Fred Booker and Tim Krantz.

7 - TO THE REST OF THE STREET

The Biology and Geomorphology of Tropical Islands IDS 158, Fall 1993

J. Michael Daniels Sediment production and transport in response to land use

in Mo'orea, French Polynesia

Bryn Sakagawa Family plot agriculture on Mo'orea: Past, present and

future

Kathryn Bickel A survey of the dominant sessile macroorganisms on

Mo'orea in relation to possible human impact

Russell Iwanchuck A population survey: Echinoderms of the Cook's and

Opunohu Bays of Mo'orea, French Polynesia

Eric Sandstedt Responses of fungid corals to environmental variation in

Cook's and Opunohu Bays, Mo'orea, F.P.

Lisa M. Angeloni Disturbance on a coral reef flat: the effects of rock

inversion on associated organisms

Jeffrey Goldman Aggregations of <u>Diadema savignyi</u> in the high energy

channel at Temae Public Beach, Mo'orea

Katherine Colburn Islands within the sea: the theory of coralline boulder

and Jason Rice biogeography

Larry Bernstone Calcium budgeting on a tropical reef

Jeremy Schwartz

Distribution of an invasive introduced plant, Miconia

calvescens, on the island of Mo'orea, French Polynesia

Christina Underwood Invasion patterns of Miconia calvescens on Mo'orea, French

Polynesia

Ute Gigler Factors influencing the establishment of Miconia

calvescens, and invasive weed, on Mo'orea

Kristin Gade Comparison of leaf tissue losses in a tropical island stream

by riparian trees and an invading plant

Stacey L. Smith Factors limiting the density and distribution of gobiids

in a tropical stream in the Opunohu Valley, Mo'orea, F.P.

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Preface

These papers report the results of field investigations by undergraduates of the University of California, Berkeley, on the island of Mo'orea, French Polynesia. These fifteen students participated in the third field class of IDS 158, "The Biology and Geomorphology of Tropical Islands", during the fall of 1993. After spending seven weeks on the Berkeley campus, receiving lectures from faculty from the departments of Anthropology, Geology and Geophysics, Geography, Integrative Biology, Entomology, and Soil Sciences, the students embarked for the Gump Marine Biological Field Station. Here, they engaged in seven weeks of field work, with the primary focus being their own independent research projects. After returning to Berkeley, they gave an oral symposium on their projects to interested members of the campus community, and wrote the reports in this volume.

The 1993 class projects ranged over a variety of disciplines and ecosystems. The first two papers, by Daniels and Sakagawa, explore impacts of the increasing human population and the intensification of agriculture on the environment. One potential impact is the release of sediment and agrochemicals to the bays on the north side of the island. Papers by Bickel, Iwanchuck, and Sandstedt survey contrasts in components of the coral reef ecosystem between the more heavily impacted Cook's Bay, and the less impacted Opunohu Bay. Angeloni's paper deals with another potential source of human disturbance: the potential consequences of overturning of boulders for the marine algae and invertebrates inhabiting these substrates. Goldman, Colburn, and Rice explore basic physical factors influencing the distributions and abundance of invertebrates: substrate attributes, flow, and depth. Bernstone carried out a water sampling program to assess the calcium flux over the reef.

The replacement of native vegetation by the aggressive invading alien plant, Miconia calvescens, is now obvious in Tahiti and is becoming so on Mo'orea. Schwartz, Underwood, and Gigler report studies that look at variation in the establishment of Miconia on Mo'orea from landscape to micro-site scales. If Miconia comes to dominate Mo'orea's watersheds, its leaves will dominate the litter input to river food webs. The study by Gade assesses the degree to which this alien leaf is consumed by shredding detritivores in the Opunohu River, relative to consumption by shredders of indigenous tree leaves. Canopy cover over streams is also a major determinant of the production of algal biomass. The distribution of algivorous gobies relative to light and primary production is the subject of Smith's paper.

These reports reflect the students' interest in the natural environment of a remarkable tropical island, and their concern for its future in the face of human impacts. Many who have supported the course in variety of ways have made it possible for these students to develop skills that could enable them to make positive contributions toward understanding this changing environment. To the Director of the Gump Station Werner Loher and its stalwart Station Manager Frank Murphy, to the members of the Antenne Museum (merci a Assistant Director Rene Galzin), and personnel of ORSTQM (Dr. Bernard Boccas, Jean Yves Meyer) who freely shared knowledge, literature, and equipment, and to the Economie Rurale who gave access to study sites; to the parents of students for their support, to the Berkeley professors and staff (special thanks to Julie Myers and David Crabill for dealing with financial and logistic headaches) and to the Tahitians (Looana, Tony, Jacques) for their hospitality, hard work, and kindness:

Maruru Roa!

Mary Power Berkeley, December 1993 The product of the second

Sediment Production and Transport in Response to Land Use Moorea, French Polynesia

James Michael Daniels 21270 Glenmont Drive Saratoga, CA 95070

Geography 142 October, November 1993

ABSTRACT

Evaluation of several prominent land use practices in the Paopao drainage basin, Moorea, French Polynesia (17° 31'S, 149° 49'W), identifies rural roads as the primary sites of sediment production and transport within the basin. Commercial pineapple plantations in various stages of maturity were examined along with respective access roads to determine the infiltration capacities of each. Field infiltration capacities ranged from 13.8 mm/min to 8.2 mm/min while road infiltration capacities ranged from 2.1 mm/min to 0.7 mm/min. Road cross sections reveal processes and estimated values of soil erosion. 2.99 m³ of soil was displaced from 374 m² of road surface and banks over a 15 day period. Discharge and suspended sediment load data collected during a storm event reveals paths of sediment transport. Overland flow from the same 374 m² dirt road surface was measured at 0.35 m³/min, with suspended sediment concentration of 1500 g/m³.

INTRODUCTION

The purpose of this study was to determine the most active processes of sediment production and transport within the Paopao basin, and to identify specifically those land use practices which effect these processes. The impetus for investigating this issue was provided by preliminary studies by London and Tucker (1992) and ongoing research by J. Hart, on the processes of sediment transport and deposition in Opunohu and Cook's bays. These two bays on Moorea's northern shore are similar in size and shape, and serve as outlets to drainage basins with similar areas, topographic relief, and precipitation characteristics (Stoddart 1992), but different land use practices. Cook's Bay, the easternmost of the two bays, receives drainage from the Paopao basin, an area of land which contains Moorea's largest town, Paopao, as well as 78.56 hectares of commercial pineapple plantations -- roughly 45 percent of the pineapple production on the island (Économie Rurale, 1992). A network of unpaved, agricultural access roads within this basin is one of the principal concerns of this study. Opunohu Bay drains the Opunohu basin, which is largely free of human settlement, and contains only 3.34 hectares of commercial pineapple agriculture (Économie Rurale, 1992). Simple visual examination of sediment plumes in both bays during storm events indicates that Cook's Bay is subject to greater sediment inflow than is Opunohu Bay. observation, coupled with the different land use practices within the two drainage basins, led London and Tucker (1992) to hypothesize that development, especially commercial pineapple agriculture, causes increased sedimentation.

This study tests the hypothesis that the rural access roads throughout the Paopao basin are a more significant contributor of sediment than are the pineapple fields themselves. Admittedly, the roads are simply a component of agricultural development as a whole, but there are several important reasons for distinguishing their effect on sedimentation from other agricultural practices. First, if corrective measures are ever to be taken to allay sedimentation in Cook's Bay, the exact sources of sediment, and paths of its transport must be determined. Second, methods which might be used to prevent or slow soil erosion and sediment

transport would be more easily implemented on agricultural access roads, than they would be on the comparatively vast pineapple fields. After determining the sediment production and transport processes at work within the basin, I will suggest several methods for retarding these processes, which would serve the dual purpose of keeping the soil within the basin for further use, and keeping it out of the bay, where it is not needed.

STUDY SITE

Sites were chosen based upon a preliminary evaluation of the land use practices most likely to cause erosion. Since overland flow is the most important agent which causes erosion and the associated transport of sediment (Horton 1945), it is logical to study areas subject to overland flow. Dunne and Leopold (1978) describe these as devoid of, or thinly vegetated, or rangelands and cultivated fields in regions with high rainfall intensities. Clearly, the pineapple plantations and their associated access roads throughout the basin are the most widespread land use type that fits this description. The pineapple on Moorea is grown in three year crop rotation cycles, with the fields often left bare for an indefinite amount of time after the final harvest (G. Teahiva, personal communication). Three plots of pineapple were chosen for this study to represent three different stages of the crop cycle. Plot 1 (fig. 1) is a field of mature, producing pineapple, with access roads around the perimeter, and through the Plots 2 and 3 (fig. 2) are fields of newly planted middle. pineapple, and bare soil, respectively. The access road through the middle of plot 2 was used for more detailed tests of the processes acting on the roads. All of these sites are located within valley of the eastern tributary of Paopao river.

METHODS

The three plots and their access roads were surveyed using a Top Con model GTB-35 surveying instrument. Reliable plan-view maps were the objective of the survey, so the perimeters of the fields, and the locations of the access roads were the most significant points.

Precipitation was measured and recorded daily beginning October 27 using five static rain gauges -- two were placed in plot 1, one each in plots 2 and 3, and one on the border between plots 2 and 3. Each of the gauges were placed in the open, with the apertures higher than the level of the surrounding plants to ensure that none of the precipitation was misdirected (Brassington 1988).

Infiltration rates were measured for all three types of fields, and for access roads, using the guidelines set forth by Dunne and Leopold (1978). A single-ring infiltrometer was set 10 cm into the ground, and water was ponded 5 cm deep inside the tube and maintained at a constant level with water from a graduated reservoir. The rate at which water was depleted from the reservoir indicates the rate at which water entered the soil. On some road surfaces, the hardness of the road prevented setting the infiltrometer more than 5 cm into the soil column. This allowed some of the water to seep out before it was designed to, and probably led to an overall elevation of the infiltration rates from

the roads.

The road surface and banks in plot 2 were characterized in cross-section initially on November 3. Two stakes were driven into the ground on either side of the road banks, and a line was stretched horizontally between them at a marked, arbitrary height. The distance was then measured between the line and the surface of the road or bank. This procedure was replicated for three transects along the road. On November 18, the process was repeated, and the difference between the two sets of measurements provides an approximate volume of soil displaced in the interim.

Measurements of overland flow from the road surface in plot 2 were taken during the storm event on November 2. Water flowing along the road surface was diverted first into a natural rill, then into a meter long trough, semi-cylindrical in shape, with a radius of 7.5 cm. The velocity of the water was measured one of two ways. When flow was high, hence extremely turbid, a piece of orange peel was timed over the one meter length, and its velocity multiplied by 0.75 to correct for increased velocity at the surface (Brassington 1988). When flow was low and clear, an amount of dye was injected into the current, and its velocity was measured as a faithful representation of actual velocity. The cross-sectional area of flow was determined by measuring the stage, and using the equation

$$\frac{\pi * R^{2} * 2.0 * \cos^{-1} * ((R-x)/R)}{360^{\circ}} - (R-x) * \sqrt{(2*R*x-x^{2})}$$

where x = stage (m), and R = radius (m). Discharge was determined by multiplying this area by the velocity (m/min). Precipitation was noted contemporaneously with velocity measurements. Three water samples were collected at regular intervals, and their contents were later filtered through papers to determine the amount of suspended sediment in the runoff.

RESULTS

Figure 3 illustrates the effect of maturity on the absorption characteristics of the soil. In figure 4, the infiltration rates from all the field tests are combined, and compared with the rates from the road tests. As the rates approach their saturated conductivities, the fields accept water at a rate more than one order of magnitude greater than the roads. These data can be further used to estimate the likelihood of overland flow. Dunne and Leopold (1978) claim that the infiltration rates obtained using a single-ring infiltrometer are probably 2 to 10 times higher than they would be under normal rainfall conditions. Dividing the infiltration rates as they approach saturated conductivity by 10, yields an approximate rate of precipitation necessary to achieve overland flow. For the fields, this estimate is 8.2 mm/min, and for the roads, 0.7 mm/min.

The road cross-section surveys yields diagrams which show the road surface on November 3, and November 18 (figs. 5,6,7). The scale along the abscissa has been condensed in order to highlight the differences along the ordinate. The approximate areas of soil displaced from transects 1, 2 and 3, are $0.023~\text{m}^2$, $0.051~\text{m}^2$, and

0.028 m², respectively. The mean of these three values, 0.034 m², can be multiplied by the length of the road surface, 88 m, to estimate the volume of soil displaced, 2.99 m3. During this 15 day period, there was a total of 10 mm of precipitation, 6 mm of which fell during one storm event.

Data obtained from the storm event on November 2 provides information relating the overland flow from the road, to precipitation intensity (fig. 8). As the intensity of the precipitation decreases, so does the runoff, with very little lag time between the two. Analysis of the filter papers reveals the concentration of suspended sediment within the runoff. After 10 minutes, the suspended sediment concentration was 1500 g/m3. This figure multiplied by the discharge at that time shows that 31.25 g/min of suspended sediment were in transport. After 15 minutes, the runoff contained 700 g/m³, or 5.36 g/min of sediment. After 25 minutes, there was still visible sediment within the water sample, but the methods used were not fine enough to discern its concentration. All runoff was produced from 374 $\rm m^2$ of road surface. This was the only major storm event during the study period, so replications of these data could not be obtained.

The data from the storm event can be used to establish annual estimates of suspended sediment discharge for the entire basin. The three plots studied had an average 8.5% road cover. The 78.56 hectares of cultivated plots in the Paopao basin can therefore be assumed to contain 66,300 m² of road surface. The 374 m² road surface in plot 2 produced runoff with roughly 183 g suspended sediment over a 20 minute period with 12 mm precipitation. Therefore, 66,300 m² road surface, with 2,822.4 mm average annual precipitation (Stoddart 1992), would yield 7,630 kg/year suspended

sediment.

DISCUSSION

The infiltration rates indicate that overland flow, therefore erosion, is much more likely to occur on the road surfaces than on the fields themselves. In fact, the estimated 8 mm/min of precipitation needed to produce overland flow on the fields is unlikely to occur. The relatively low infiltration rate of the mature pineapple field, compared with the newly planted and bare fields (fig. 4), might suggest a chance of erosion taking place on the mature field. However, the mature plants provide an almost complete cover of the soil, and their morphology serves to trap some of the precipitation on the plant itself, thereby providing a separate flow path for excess water into the soil column. The 0.7 mm/min estimated to produce overland flow on the roads is much more attainable. During the November 2 storm event, 1 mm/min was reached, and indeed overland flow did occur. Remember also that the methods used for determining infiltration rates on road surfaces were likely to result in higher rates than normal. Overland flow almost certainly occurs on road surfaces during lesser intensity than 0.7 mm/min. The data from storms of infiltration tests are supported by visual observation of many fields and roads throughout the valley. Almost all roads within the basin contain some rills, indicating the presence of overland flow and erosion. Only in one instance however were rills of any

kind observed in a field, and it was a field with hard packed soil, very uncharacteristic of fields in this area.

As the runoff travels downhill, it is confined to the road surface by banks on either side (figs. 5,6,7). The turbulence of the flow, and the energy used to overcome friction, do work on the surface, and erode soil from the rills. These rills commonly form on one or both sides of the road, and as soil from the banks sloughs down slope and into the current, it is swept downstream. An example of this sloughing is displayed on the left bank of transect 1 (fig. 5), and on the upper right bank of transect 3 (fig. 7). One part of the bank has lost soil over 15 days, while directly below it, soil has accumulated. This indicates a general downslope motion of soil. The net result of these processes is that soil is removed from the road surfaces and sloughed off the banks, and transported down the roadways, where some of it finds

its way to the streams, and eventually to Cook's Bay.

The simplest way to control runoff from the roads is to divert it into the fields, which have been shown to have infiltration capacities high enough to properly drain the excess water in most circumstances. There are several methods which would accomplish this. Most of the access roads in the basin traverse the slope, and are banked slightly contrary to the slope (fig. 9a), which leads to rill development and bank sloughing as described earlier. If the roads were to be banked slightly with the slope (fig. 9b), the runoff would flow onto the pineapple field and infiltrate into the soil. Since most of the roads are graded every 5 to 10 years (G. Teahiva, personal communication), this would be an easy procedure. The structural integrity of this practice would need to be studied before carrying it out. If this method proved impractical, road bars could be installed to divert the flow from the rill on one side, to the field on the downhill side. method would be more time and labor consumptive, but would perform the same function.

The issue of sediment production and transport in the Paopao basin needs to be further studied. Long term measurements of throughflow and groundwater storage, coupled with more overland flow data could help define a sediment budget for the basin (Dietrich et al. 1980). Such a budget would clearly describe all paths of sediment in the basin, and would help make more precise recommendations for remedies. For now, this study can serve as a small addition to the literature on tropical soils and land use, which Lo (1990) claims is inexcusably lacking.

ACKNOWLEDGMENTS

I thank Russ, Eric, and Katie for the use of their stopwatches, Bryn for numerous accompaniments to my site, Larry and Jason for their mathematical assistance, and all my other classmates for their support and encouragement of my endeavors. I thank Fred Booker for his persistent guidance and assistance, and all the faculty members for their cooperation. I thank John McKinnis for his support, Guy Teahiva for his permission to study the fields in his charge, and the Économie Rurale for their information.

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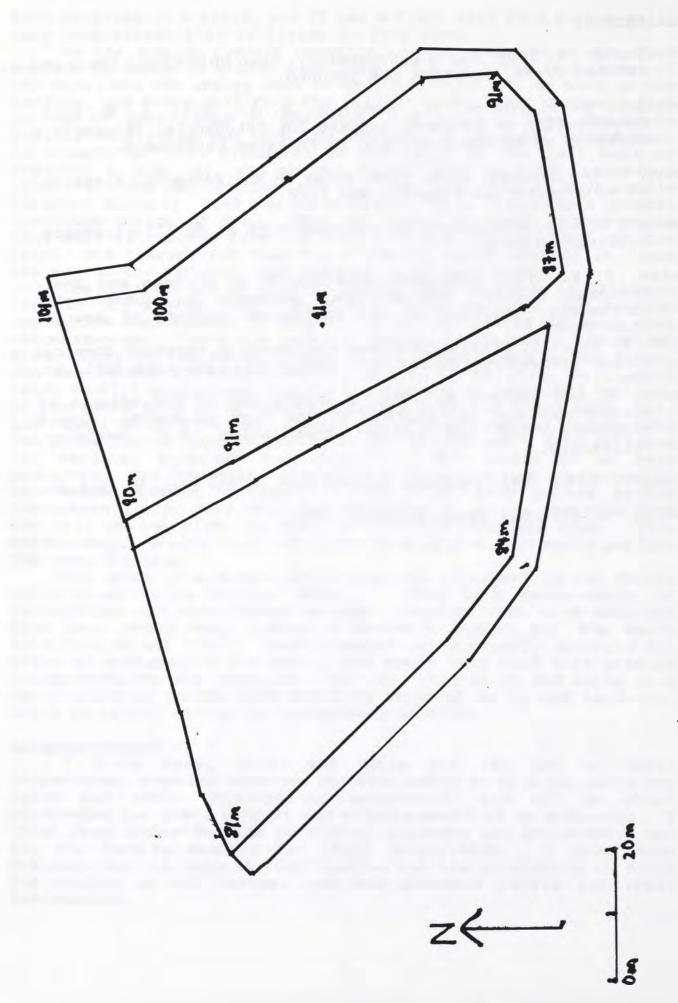


Figure 1 -- Plot 1 - mature field with road network

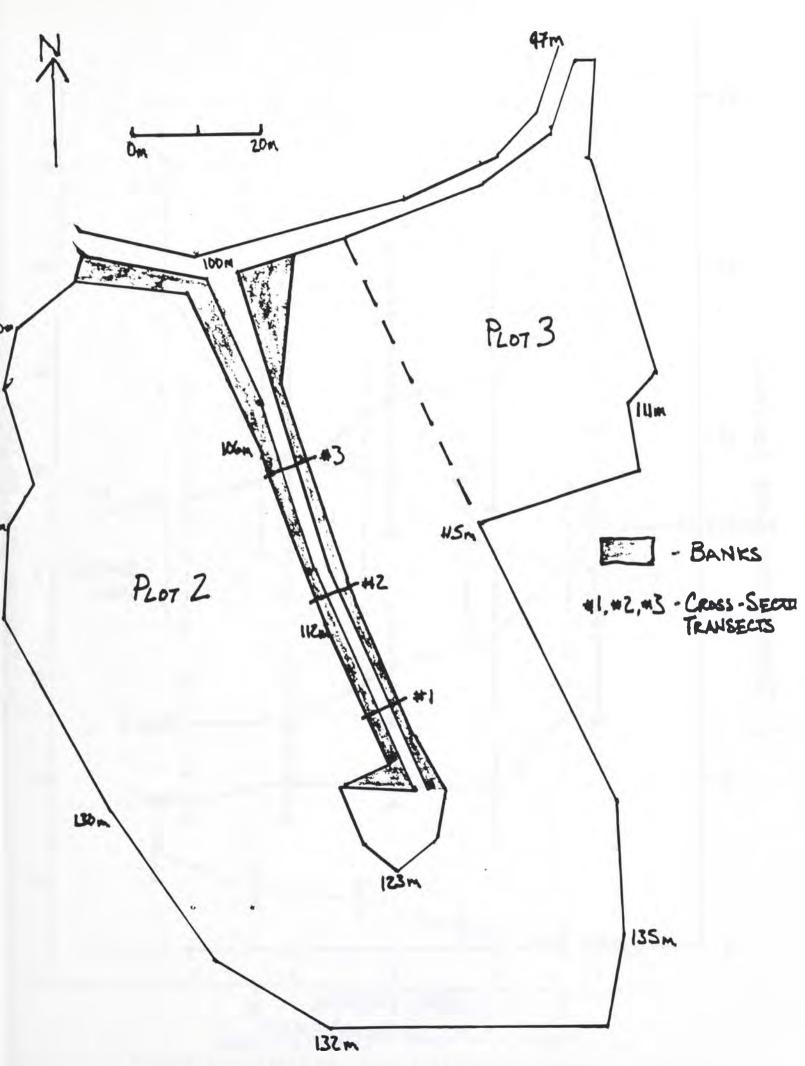


Figure 2 -- Plots 2 and 3 - young and bare fields with road naturals

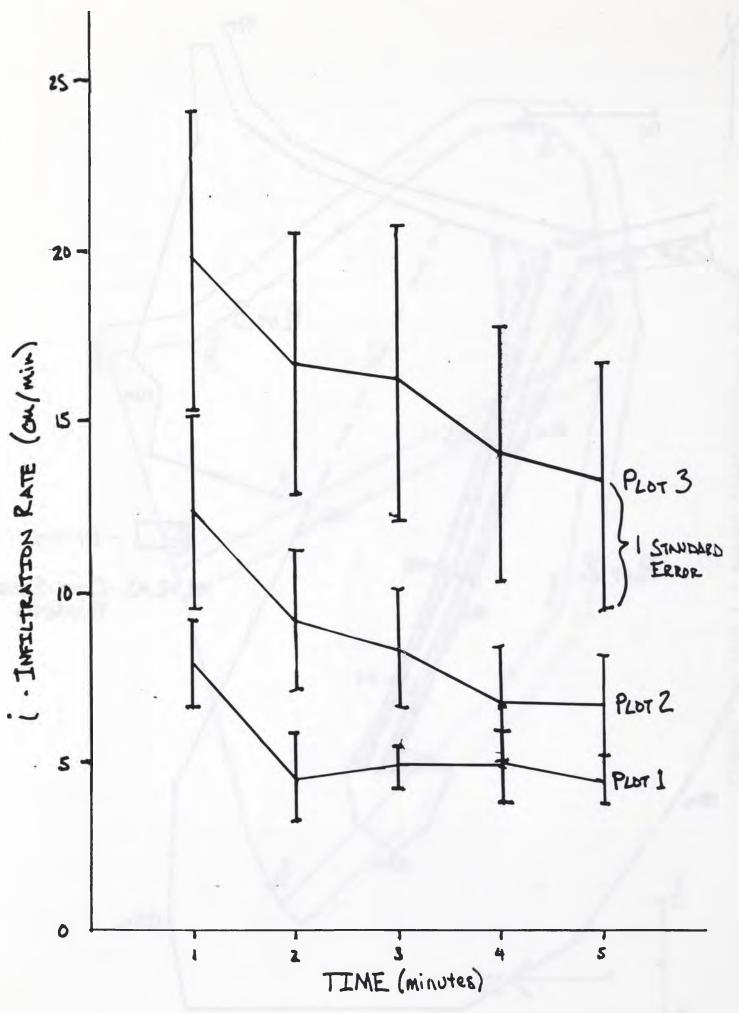


Figure 3 -- Field Infiltration Rates

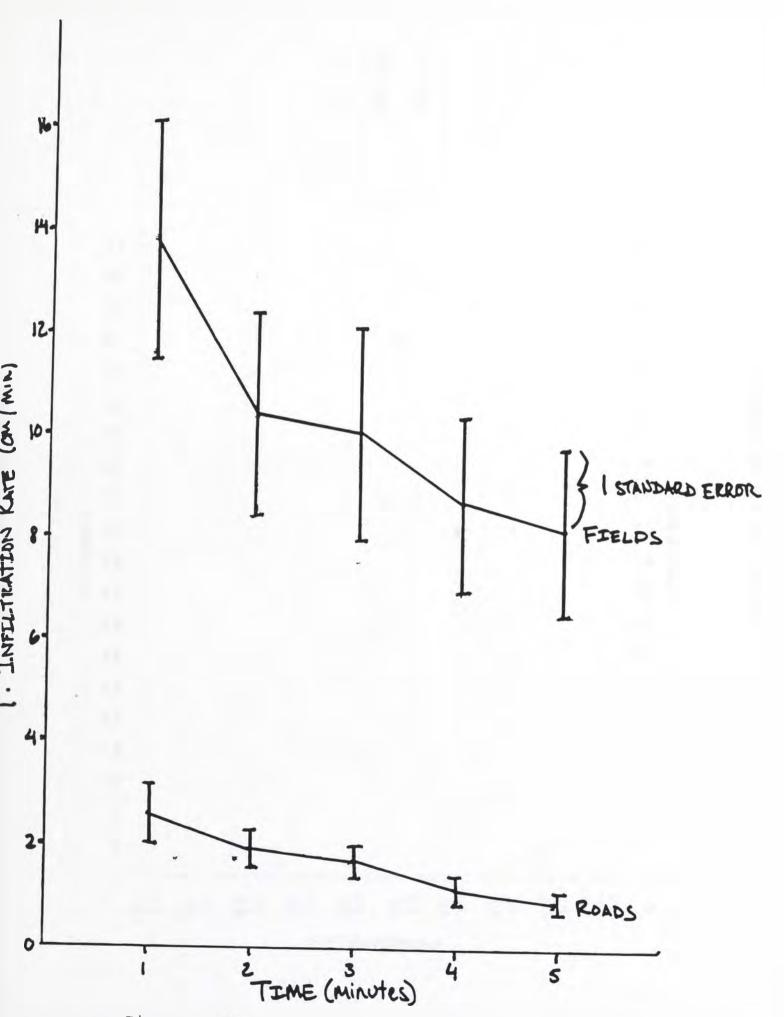
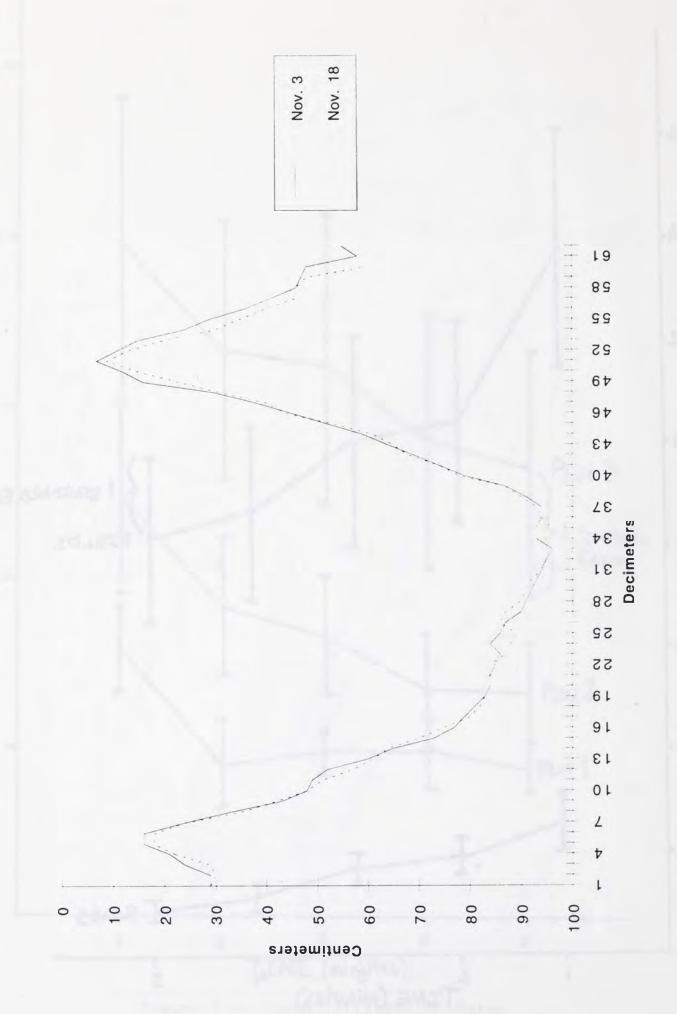
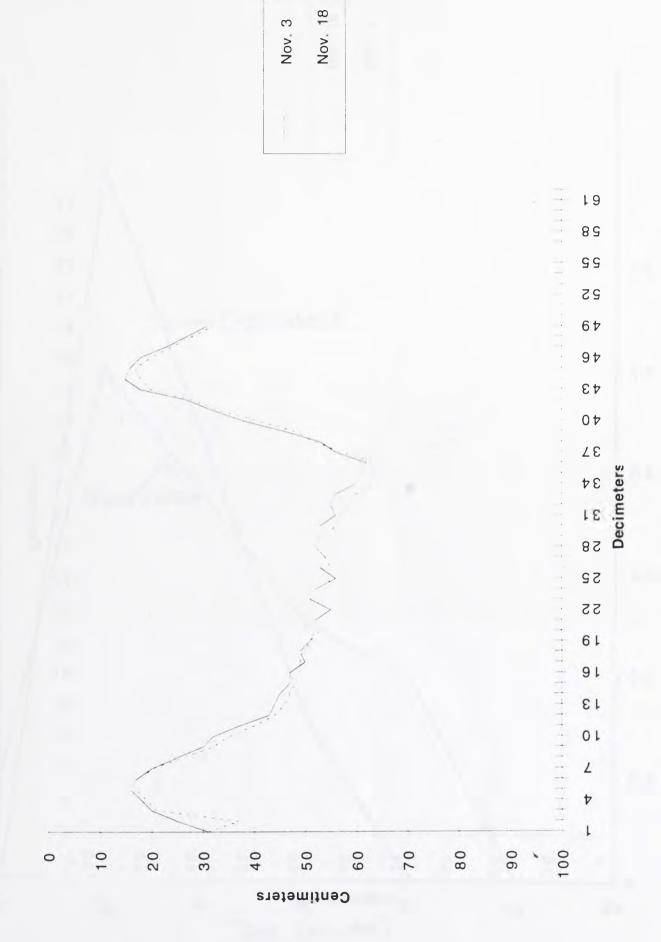
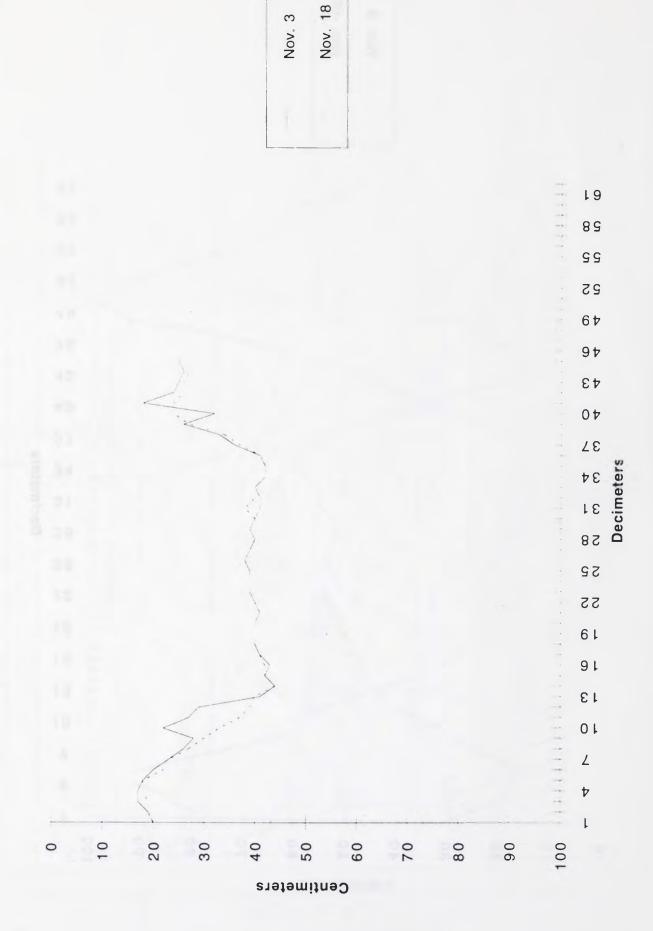


Figure 4 -- Field vs. Road Infiltration Rates







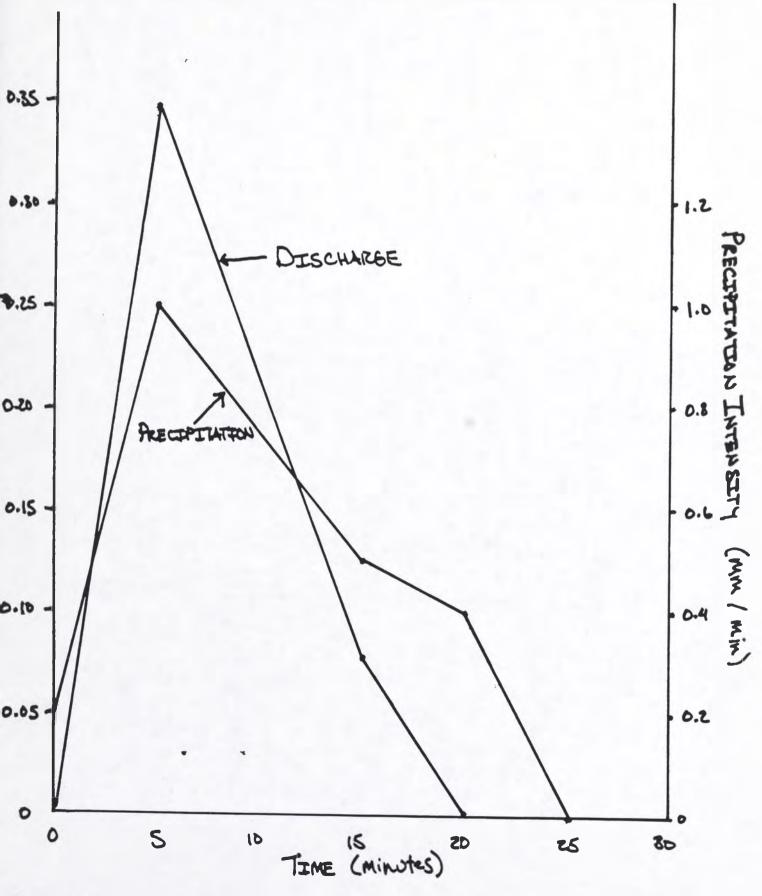
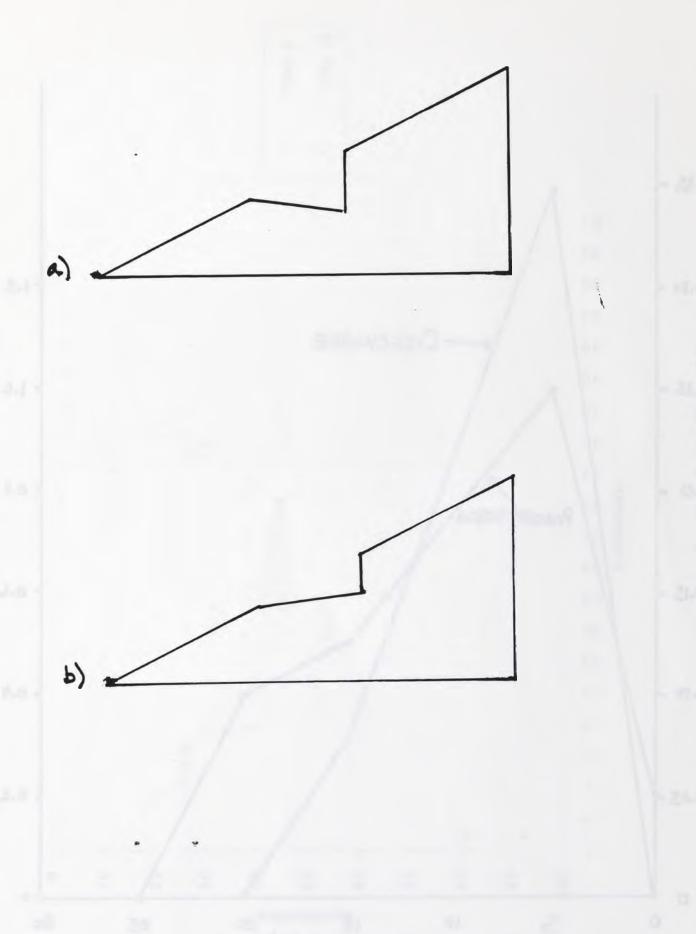
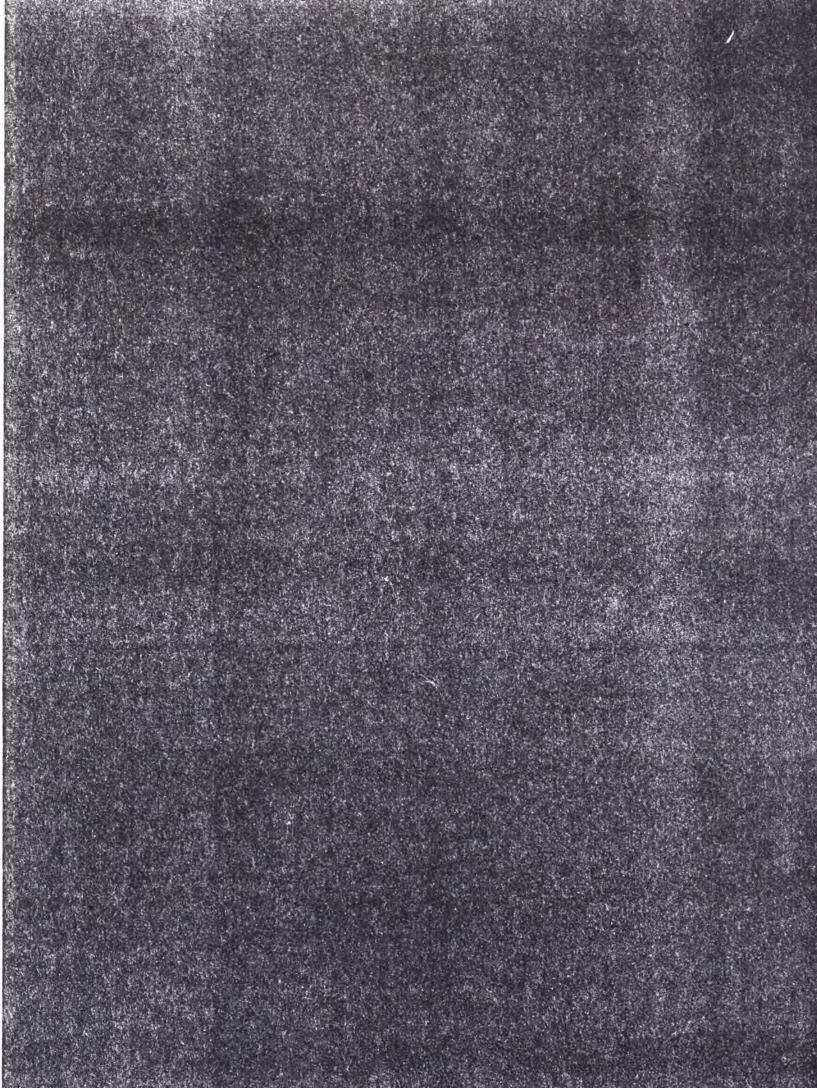


Figure 8 -- Discharge vs. Frecipitation Intensity - November 2



Figures 9a and 9b -- Road Grading Options



Family Plot Agriculture on Moorea Past. Present. and Future

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Abstract

This project examined the current state of family plot agriculture of eight gardens or fa'apus on the island of Moorea in French Polynesia. The Society Islands have undergone numerous changes since European contact in 1767. These changes include introductions of different food crops as well as a shift from a subsistence economy to one that is based on cash. The study tried to calculate these changes in terms of species diversity within each garden, commercial sales of different crops, and the amount of agrochemical inputs and irrigation required for each crop.

Research was conducted to record the differences in the amount of Polynesian introduced species versus those that were foreign introduced. The number and type of species cultivated in each garden was recorded. Estimations of crop areas and the number of trees grown were also made. The amount and type of crops sold on a commercial basis was noted in addition to the amount and type of agrochemicals used to produce these crops.

The study revealed the appearance of several trends. Although a few traditional aboriginal crops such as taro and banana are cultivated for commercial sale, a greater number of foreign introduced species are being grown on family plots. Quick growing vegetables that require agrochemical inputs and irrigation are an important commercial crop for many fa'apus. Not only have these trends indicated possible environmental problems, they have also shown that the desire for cash is leading to intensification of agriculture. The results of this project predicts that these trends will continue in the future as the population and immigration in the Windward Islands increases.

<u>Introduction</u>

Current theories provide evidence that ancient Polynesians who colonized isolated, uninhabited islands in the South Pacific, prepared for the life ahead of them by bringing their own plants and animals to their new home. These "intentional aboriginal introductions" provided sustenance and security in a place where there was often limited resources. (Whistler, 1991) The Society Islands in French Polynesia probably experienced the same colonization process as other Pacific islands. For many years after settlement, the Tahitians and Polynesians throughout Oceania altered the land until it was able to support the population at a subsistence level. (Ferdon, 1981 and Oliver, 1981) This

relatively simple lifestyle of the Tahitians changed forever after the first European explorer, Captain Samuel Wallis docked in the Bay of Venus of Tahiti on June 17, 1767. (Bovis, 1976) Since that date, foreigners from around the world continued to visit the islands. These travellers brought with them new doctrines, new products, and new species of flora and fauna to further influence the Tahitian people and their surroundings.

Needless to say, the past two centuries of foreign contact have created many changes throughout the Society Islands. Perhaps the most important has been the switch from a subsistence economy to one that is based on cash. This development of a market economy has had major implications for family plot agriculture. For example, a few Polynesian introduced species are now being cultivated for commercial purposes. More importantly, many introduced species, such as quick growing vegetables, are in demand.

The project to study family gardens or fa'apus was undertaken to assess current developments in agriculture on the island of Moorea. The results of this study will attempt to measure the changes that are occurring in Tahitian society today.

The first part of the project sought to determine the number and type of crops cultivated on today's fa'apu. Lists were compiled of foreign introduced versus polynesian introduced cultivated food species grown in each garden. In addition, the areas of each cultivated row crop were calculated. Estimates of tree species on the property were also recorded. General descriptions of the family plot were included in data collection.

The second part of the project tried to calculate the amount sold and the prices received for fa'apu produce. Was a higher percentage of crops grown for commercial purposes rather than for personal consumption? Information regarding type of produce sold, i.e. row crops vs. tree crops, or introduced species vs. Polynesian species was collected.

The third question addressed the amount and type of agrochemical inputs of each fa'apu. These inputs were classified as chemical fertilizers, herbicides, and pesticides. It was speculated that families who sell more introduced vegetable produce use more agrochemical inputs. From the data provided by the families, approximate yearly amounts of agrochemical inputs were determined.

Methods

The study of family plot agriculture examined eight different farms on the island of Moorea. The sites were chosen with the aid of people associated with the Gump Research Station on Cook's Bay. Personal introductions to families with *fa'apus* (gardens) facilitated site selection. (Table 1) reveals that the majority of farms studied were located in valleys.

Table 1: Locations and total number of farms studied on Moorea

Number of farms studied	Location
1	Teavaro Valley
2	Cook's Bay
2	Pao Pao Valley
2	Opunuhu Valley
<u>1</u>	Papetoai Valley
8	Total

Furthermore, (figure X) shows that most of the sites were on the northeast part of the island. In spite of these general similarities, each fa'apu had different climates and terrains which greatly affected crop type and cultivation techniques.

All visits were conducted from October 28, 1993 to November 17, 1993 during daylight hours. This time period coincided with the end of the "cold and dry" winter season and the beginning of the "warm and wet" summer season (Fages and Robineau, 1981).

Data was collected through interviews with the main cultivators of the gardens. Every interview consisted of a standard questionnaire that was used as a guide. Most conversations were conducted in French, sometimes with the assistance of various interpreters.

Estimates of land under cultivation were determined by pacing. These estimates were compared to data provided by the families. In addition, visual approximations were used to calculate the number of trees and other plants.

Results

Description

The first part of the project examined the number and kind of species cultivated in family plots. Species diversity was affected by several factors. The most important of these were the location and terrain of each fa'apu. For example, fa'apu sites ranged from valley to coast, from mountainous to flat, from wet to dry. A general description of these farms is provided by (table 2) which shows how crop diversity is limited by terrain.

Table 2: Type of land and principal crops cultivated in each fa'apu

Fa'apu#	and location	Type of land	Principal crops
Fa'apu 1	Cook's Bay	fenua mato	trees and pumpkins
		fenua vari/paruparu	taro
Fa'apu 2	Cook's Bay	fenua mato	trees
Fa'apu 3	Pao Pao	fenua vari/paruparu	taro
		fenua mea maro	vegetables
Fa'apu 4	Pao Pao	fenua mea maro	vegetables and taro
Fa'apu 5	Opunuhu Bay	fenua mea maro	vegetables and trees
Fa'apu 6	Opunuhu Bay	fenua vari/paruparu	vegetables and taro
Fa'apu 7	Papetoai	fenua mea maro	trees
		fenua mato	vegetables
Fa'apu 8	Teavaro	fenua mato	trees and pumpkins

Definitions of Tahitian terms for terrain (Oliver; 1981):

fenua - land

fenua mato: broken and with rocky outcrops (suitable for melons)

fenua vari, fenua paruparu: soft and muddy (suitable for taro)

fenua mea maro: dry (suitable for tarua, cassava, yams, vanilla, pineapple, etc)

fenua varivari: sandy, muddy, damp (suitable for coconut, breadfruit, mangoes)

Despite the difficulties of cultivation on rocky, mountainous or dry terrain, each family grew species within these restrictions in order to produce some food crops for commercial sale. On fa'apus 2 and 8, for instance, the owners burned the existing forest in order to cultivate fruit

trees and row crops on the slopes of the mountains. Although every family appeared to be in a constant struggle against unwanted tropical vegetation, they still had plans to extend cultivation of various food crops to the limits of their properties.

During the early 1800's, explorers tried to document the species of crops cultivated by the Tahitians. (Ferdon, 1981) Although a few of these Polynesian introduced species exist in today's gardens, many of them are no longer used as a source of food. Out of a list of 20 Polynesian introduced species that were cultivated at the time of European contact (table 3), only six are presently used for food in the eight *fa'apus* studied.

Table 3: Polynesian introduced species that were cultivated at the time of European "discovery" of the Society Islands with indications of species presently used for food today. (Whistler, 1991 and Petard, 1986)

Bold type indicates species cultivated on the fa'apus studied.

English	Latin	Tahitian
Banana	Musa paradisiaca	mei'a
Breadfruit	Artocarpus altilis	uru
Cordyline	Cordyline fruticosa	t i
Fig	Ficus tictoria	mati
Indian mulberry	Morinda citrifolia	nono
Kava	Piper methysticum	'ava
Malay apple	Syzgium malaccense	ahia
Melon	Cucumis melo	'atiu
Plantain	Musa troglodytarum	fei
Polynesian arrowroot	Tacca leontopetaloides	pia
Polynesian plum	Spondias dulcis	vi
Sugar cane	Saccharum officinarum	to
Sweet potato	Ipomoea batas	umara
Tahitian chestnut	Inocarpus fagifer	mape
Taro	Colocasia esculenta	taro
Taro (giant)	Alocasia macrorrhiza	ape
Yam (bitter)	Dioscorea bulbifera	hoi
Yam (common)	Dioscorea alata	ufi
Yam (five leaved)	Dioscorea pentaphylla	patara
Yam (spiny)	Dioscorea nummularia	parai

Of these six crops, banana and taro are significant cultivars on the eight gardens. Among these farms, banana is the primary tree crop (figure 2). It is planted along the edges of properties and near the houses. Once the stands of 4-7 banana trees become established, they usually require little or no attention. Taro is another important crop for five families (figure 3) who sell part of the produce on a regular basis. Bananas are also sold from five of the eight fa'apus.

Polynesian introduced species such as banana and taro are significant single crops in these family plots. The number and type of foreign introduced species, on the other hand, are more diverse than their aboriginal counterparts. For example, (figure 3) identifies foreign introduced species as predominant among the row crops. Out of the many plants that have been introduced to the Societies over the past 200 years of foreign contact (Barrau, 1961), 14 different tree crops and 16 different row crops were documented among the eight *fa'apus* (table 4).

Table 4: Introduced species currently grown on eight family plots

Tree crops		Row Crops	
English	<u>Latin</u>	English	<u>Latin</u>
Avocado	Persea americana	Bean	Phaseolus vulgaris
Carambola	Averrhoa carambola	Cabbage	Brassica oleracea
Citron	Citrus aurantiifolia	Chicory	Cichorum intybus
False pistachio	Eugenia cumini	Chinese greens	Brassica chinensis Brassica pekinensis Brassica juncea
Jackfruit	Artocarpus heterophyllus	Corn	Zea mays
Lychee	Litchi chinensis	Cucumber	Cucumis sativus
Mango	Mangerifera indica	Eggplant	Solanum melongena
Orange	Citrus aurantium	Lettuce	Lactuca sativa
Pamplemousse	Citrus grandis	Manioc	Manihot esuclenta
Pepper	Capsicum fruitescens	Parsley	Petroselinum hortense

Tree crops		Row crops	
Enalish	Latin	<u>English</u>	Latin
Rambutan	Nephelium Iappaceum	Pineapple	Ananas comosus
Soursop	Annona muricata	Pumpkin	Cucurbita pepo Cucurbita maxima
Star apple	Chrysophyllum cainito	Radish/Turnip	Rhaphanus sativus
Tamarind	Tamarindus indica	Tarua	Xanthosoma sagittifolium
		Tomato	Solanum melongena
		Vanilla	Vanilla planifolia

Foreign introduced crops are important sources of food and cash for each family. The diversity of these species is noticeable among the row crops. (Figure 4) indicates that manioc and pumpkin, two low-maintenance crops, are cultivated in large quantities. The figure also shows significant amounts of vegetables, i.e. beans, cabbage, chinese greens, cucumbers, lettuce and tomatoes, that are also cultivated.

Commercial

All families sell a portion of their produce to stores, hotels and friends, on a regular basis. Only three of the families, however, rely on these sales as their primary source of income. Three owners of fa'apus have other employment and cultivate crops for commercial sale as a side endeavor. Two families engage in other activities such as fishing and raising livestock for sale.

Crop distribution and amount of crops sold for commercial sale seem to be unrelated. Manioc, for example, is cultivated in family plots but is not sold and is sometimes never used. Pumpkins are also sold in lesser amounts (Figure 5). OUt of all the crops, bananas and vegetables are sold in the largest quantities and that generate the most income (figure 6). The distribution of sales can be seen from (figures 7 and 8). Banana trees can be found on almost every property, whereas vegetables crops depend on conscious efforts to clear the land and prevent unwanted vegetation. Taro is also a significant crop that is cultivated for sale with five out of eight plots selling a portion of its produce (figure 9). Banana Grops

have been cultivated for hundreds of years. Vegetables production, on the other hand, is a recent development among the gardens studied on Moorea. Of the six families who have sold vegetable produce, all of them have been growing these crops for under five years. (table 5).

Table 5: Number of years families have cultivated vegetable crops.

Fa'apu #	Number of years
Fa'apu 3	1
Fa'apu 4	2
Fa'apu 5	2
Fa'apu 6	4
Fa'apu 7	3

When asked why they have only recently begun growing vegetables for sale, owners replied that crops such as beans, lettuce, cucumbers and Chinese greens grow much faster than traditional crops such as taro and tarua. Families that grow vegetable crops continually earn more money because of these faster growth rates (Figure 10).

Continual production of the land does have its drawbacks. Nearly all of the fa'apus that cultivate vegetables (4 out of 5) must rest the land by laying it fallow for a month or more at a time. Unfortunately, this is not always possible if there is a limited amount of land available for cultivation. (Figure 11) shows that farms with smaller amounts of arable land, tend to intensify production by leaving less land fallow.

Agrochemical inputs

Vegetable cultivation is characterized by an increase in irrigation and agrochemical use. Five out of eight *fa'apus* use pumped water to grow vegetables. Each garden had raised sprinklers to water these crops.

Four out of eight fa'apus use agrochemicals on introduced vegetable crops. A total of three farms used fertilizer with names like Granulet, NPK Complet, and Urea Petrochem. The amount of fertilizer used per year ranged from 250 kg (9.8 kg per square meter) on fa'apu 4 to 300 kg (9.2 kg per square meter) on fa'apu 5 to 600 kg (.66 kg per square meter) on fa'apu 6. Although the data is limited to a small sample size, these figures seem to indicate that the less land under cultivation, a greater amount of fertilizer is used.

Three farms use at least one brand of pesticide. They consist of Folinmat 50, Attack, Carbendazime, Vitazeb80WP, and Huile d'Ete. The amount of pesticide used per year ranged from 1 to 6 liters. Concentrations were difficult to calculate because each brand was very different. Fa'apu 5 has 2765 m under cultivation and uses 2 liters per year. Fa'apu 6 has 396 m and uses 7 kg of pesticide per year. Fa'apu 7 has 1584 m under cultivation and uses 1 liter.

Only two farms use herbicides called *Sting* and *Gramosal*. They are used in lesser amounts; *fa'apu* 7 uses 1 liter per year, and *fa'apu* 5 uses 2.5 liters.

Discussions with cultivators revealed that they are conscious of the dangers of extensive agrochemical use. Not only are these inputs very expensive, they also create problems further down the line. One woman explained that bugs develop resistance to the pesticides if too much is used. Another person said that too much chemical fertilizers wore out the soil. Despite the problems associated with agrochemicals, families usually have no choice but to use a small amount in order to protect the relatively fragile vegetable crops.

It sould be noted that none of the families use agrochemicals or irrigation on their Polynesian crops or tree crops. Planting methods of tree crops and starchy plants are the same as when ancient Polynesians lived on the land. The only change from traditional techniques occurs on fa'apu 2. Its owner fertilizes while disposing waste by planting banana trees in holes that have been prepared by leaving garbage in them for three months.

Discussion

Historical Background

Polynesian colonizers of the Society Islands brought with them many food plants that would help them to survive in an isolated environment with limited resources. Researchers have tried to provide a complete picture of these existing plants before European contact. A few of these food crops included taro, breadfruit, banana, plantain, yam, sweet potato, Malay apple, Tahitian chestnut, Polynesian arrowroot, and cordyline, or ti... (Whistler, 1991, Ferdon, 1981, Petard, 1986 and Oliver, 1981) This isolated island environment changed in the middle of the 18th century,

when European explorers travelled around the world to lay claim to all land that was undiscovered. Tahiti and her islands were no exception. Foreign influence had a profound impact on Tahitian agriculture as well as on the Tahitian economy.

Tahitian agriculture was greatly affected because foreigners brought new species of plants for cultivation. Many of these introduced species provided diverse additional food resources and were easier to cultivate. Polynesian arrowroot, for instance, was replaced by cassava or manioc because it was easier to grow and to prepare (Oliver, 1981). Tarua, an aroid similar to taro, could be cultivated on dry soil and was less susceptible to diseases (Ferdon, 1981). Other vegetables such as lettuce, Chinese greens, tomatoes, cucumbers, and cabbage became popular among Chinese truck gardeners (Fages and Robineau, 1973).

The changes in agriculture mirrored the changes in the Tahitian economy. French rule and contact with the outside world accelerated the establishment of a market economy that was based on cash transactions. This transformation within Tahitian society was documented by anthropologists during the 1950's (Barrau, 1961 and Oliver, 1981) Tahitians adjusted to this new society by growing Polynesian and introduced crops for sale. Especially during the 1950's, market gardening increased along with fruit cultivation (notably pineapples, bananas and oranges) and with traditional subsistence crops (taro, tarua, and plantains) (Fages and Robineau, 1973). Although production of subsistence crops increased, former staples of taro, breadfruit and tarua were replaced by more convenient starches such as bread and rice. These traditional foods were relegated to Sunday meals and special occasions (Barrau, 1961).

Today, Tahitian society is completely linked to the outside world through a cash economy. Current prices in French Polynesia are extremely high due to inflation. The influence of this market economy is reflected in the changes involving family plot agriculture today.

Implications of present study

It appears that the population's demand for fresh produce has encouraged the production of many introduced crops as well as the production of some Polynesian introduced crops (Doumenge et al, 1988). Although significant amounts of taro and banana are cultivated, there is a

higher diversity of introduced species in many family plots. Today's crops, notably the vegetable crops, are grown mostly for commercial reasons rather than for cultivation for personal consumption. This is evident by the recent shift to cultivating quick growing vegetables on four out of the eight gardens studied (table 5). A hypothesis could also be expressed to explain why the other four gardens do not cultivate vegetables. Fa'apus 1, 2, and 8 are located on hill slopes that are very rocky and difficult to clear and water. This terrain may prevent vegetable cultivation. Fa'apu 3, on the other hand, is located on a new property that has not yet been fully developed. Possibly, the owner will start selling produce as soon as the house is finished. This demand for fresh produce will probably increase along with the population rate.

In spite of terrain limitations as described in (table 2), families continue to clear the land in order to cultivate more crops. On the mountain slopes of fa'apus 2 and 8, for instance, the removal of existing vegetation by using slash and burn techniques may lead to soil erosion. This has already occurred in Tahiti in the 1950's when Chinese truck gardeners intensified agriculture on hills (Fages and Robineau, 1973). In valleys such as Opunuhu, Pao Pao and Papetoai, extending cultivation will affect forest ecosystems and erosion into streams.

Traditional agricultural techniques are still utilized for Polynesian crops but are generally not used for introduced vegetable crops. Agrochemical inputs, on the other hand, has increased among introduced species. Although the amounts for each *fa'apu* appear relatively small, continued use of chemical pesticides, herbicides and fertilizers may have profound effects in the future as insects become immune, soil becomes infertile, and the island environment is polluted.

Increased irrigation of introduced crops will also have a large effect on the water supply. Five farms utilize independent pumps to water their vegetables. At a conference to assess alternative agricultural enterprises for the Caribbean and Pacific Basins, Professor William Stall recommended that drip irrigation be used for vegetable production because overhead sprinklers are inefficient (Stall, 1988). If every fa'apu that cultivates vegetables use this method for irrigation, limited water supplies on Moorea will be wasted.

The increase of introduced species cultivation may have huge impacts on the island's water, soil, and product quality. Inputs of agrochemicals and irrigation systems may fnegatively affect the environment. It appears that these trends will continue as the demand for fresh produce increases.

Project limitations

This project encountered many problems in its execution. One difficulty was that sites were chosen through personal introduction. Therefore, gardens were not randomly selected among different places on the island. Another problem was interacting with the French bureaucracy. Since most organizations could not provide any information without a lengthy application period, ownership records were unavailable. Fa'apus could not be selected from a range of small, medium and large plot sizes. Areas of the family plots themselves were difficult to calculate because of terrain limitations and because there was little or no documentation of ownership. Finally, the language barriers between French, Tahitian and English were difficult and sometimes impossible to overcome. Future researchers should use an interpreter or be fluent in French and/or Tahitian.

Data may also be inaccurate because the project was conducted during planting season from October to December (Oliver, 1981). Information concerning crop type and areas of land under cultivation may be radically different during other times of the year.

Recommendations for the future

In order to complete this study with more accuracy, a larger sample size is needed. It would be helpful if farms in different valleys are examined to compare regional differences. Improved mapping techniques would help to standardize plot sizes. In addition, land ownership records could provide exact information of family boundaries.

Conclusion

population (166,753) of French Polynesia lived on Tahiti or Moorea. The annual growth rate of 3.2 percent has led to predictions that by the year 2000, French Polynesia will have at least 220,000 people (Doumenge et al, 1988). This population increase may have an important impact on family plot agriculture. Already, intensification of production has occurred with the use of agrochemicals and irrigation for introduced crops. Many families have increased the amount of land under cultivation and have plans to extend this land.

Since the 1960's the French government has encouraged agricultural production in order to offset the high prices of food imports (Fages and Robineau, 1973). Many development experts have also recommended this economic path. As a result of these development plans, individual crop sales will increase as the demand for fresh produce is fulfilled by local farmers. If conscious efforts are made to preserve soil fertility through fallowing and crop rotation, it will be possible to maintain a balanced agricultural system (Barrau, 1961). Unfortunately, some development "experts" also recommend the use of agrochemical inputs on traditional aroid crops in order to increase production (Reboul, 1984).

If current trends continue, the future of family plot agriculture is bleak. Agricultural production on Moorea needs to be closely examined and monitored in future research projects in order to fully assess the effects of population growth and introduced species cultivation.

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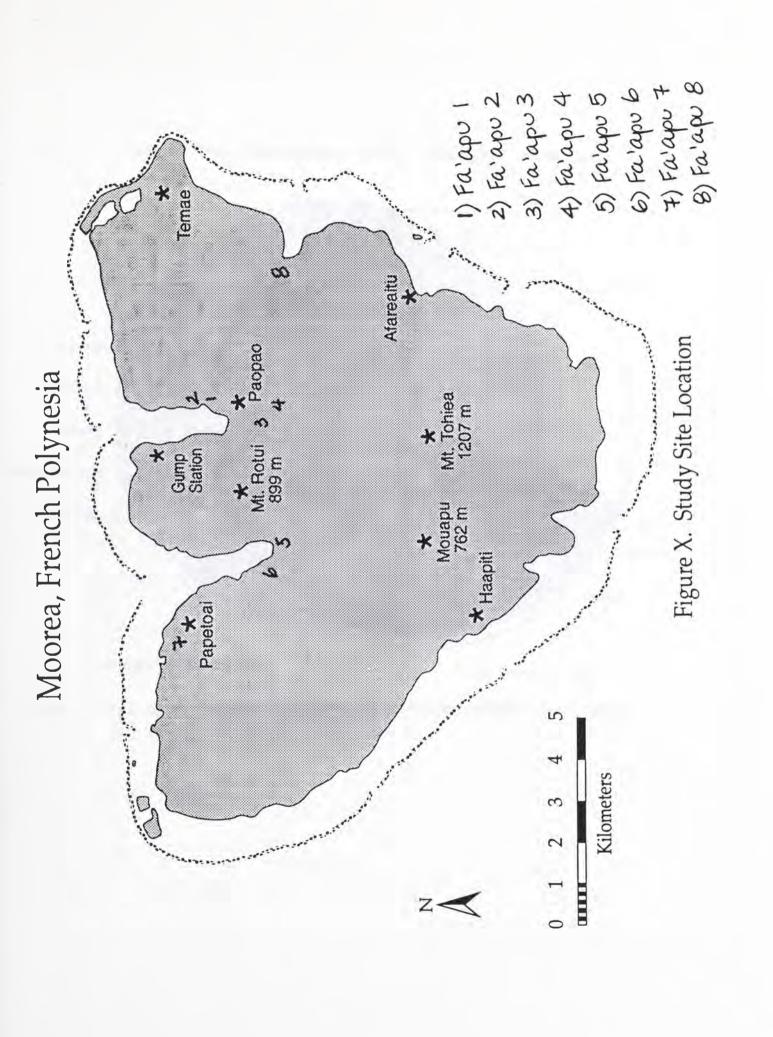
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Data from "Polynesian species distribution"

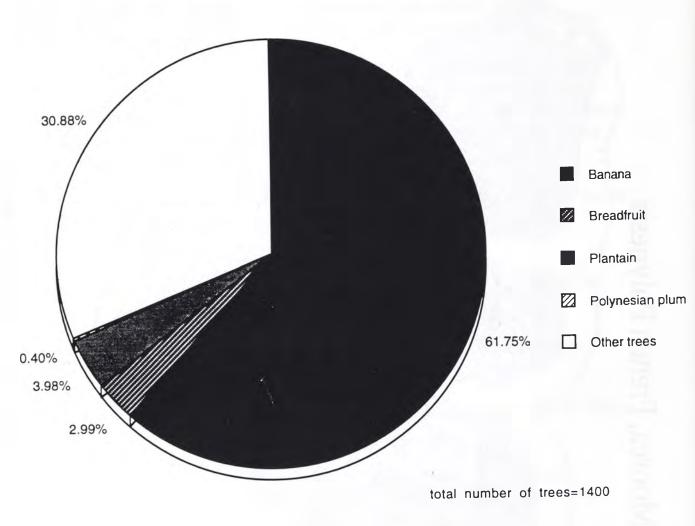
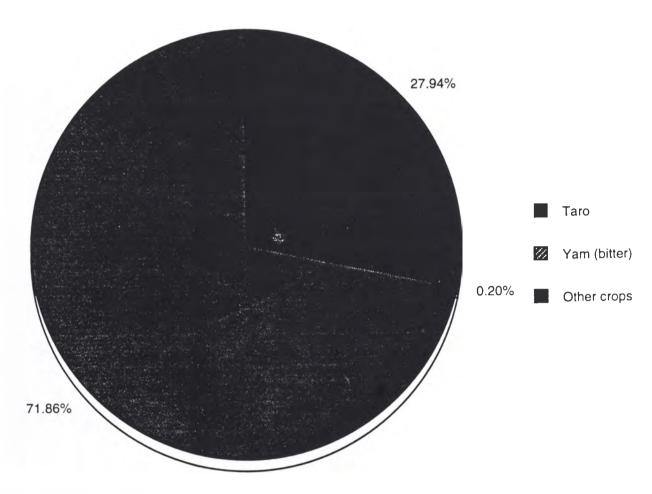


Figure 2: Polynesian introduced species distribution for tree crops on fa'apus

Data from "Polynesian species distribution"



total amount of land=2 hectares

Figure 3: Polynesian introduced species distribution for row crops on fa'apus

Data from "row crop distribution"

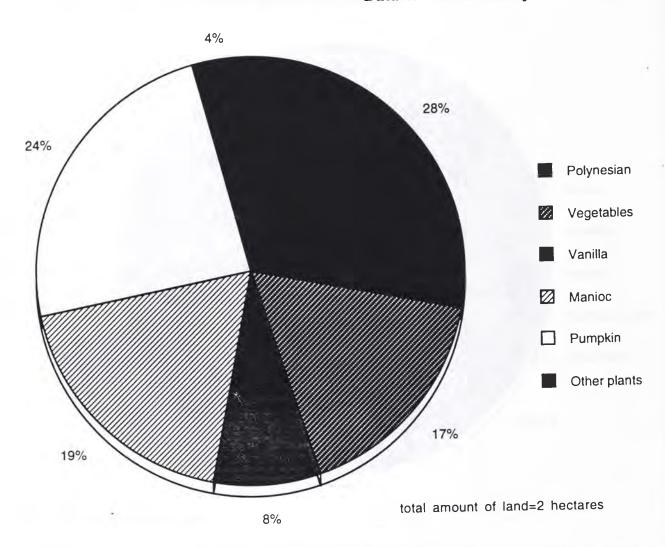
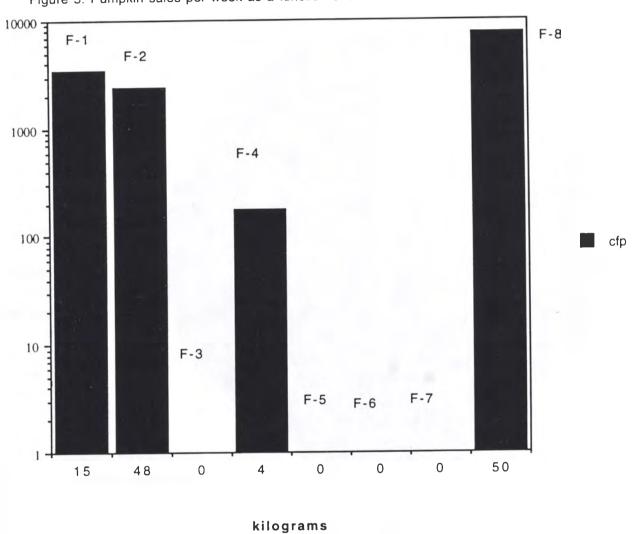


Figure 4: Foreign introduced species distribution for row crops on falapus

Data from "pumpkin sales per week"

Figure 5: Pumpkin sales per week as a function of amount earned and amount sold



Data from "distribution of crops sold"

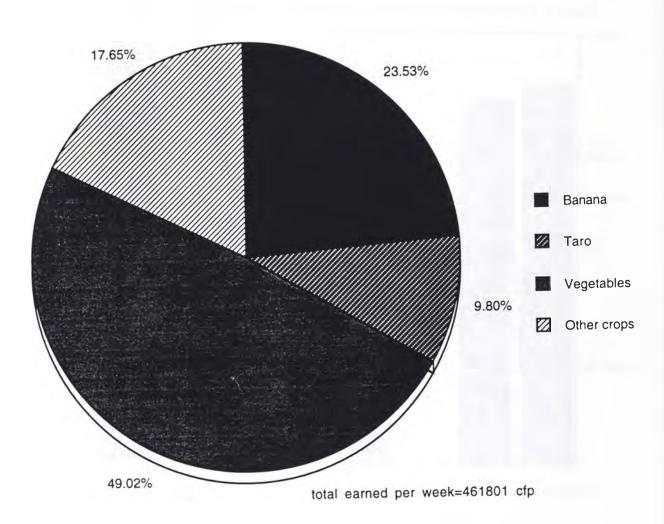
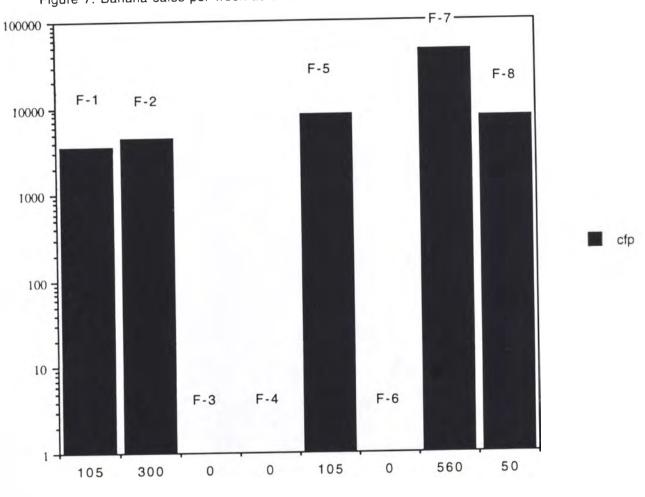


Figure 6: Distribution of crops sold each week by fa'apus

Data from "banana sales per week"

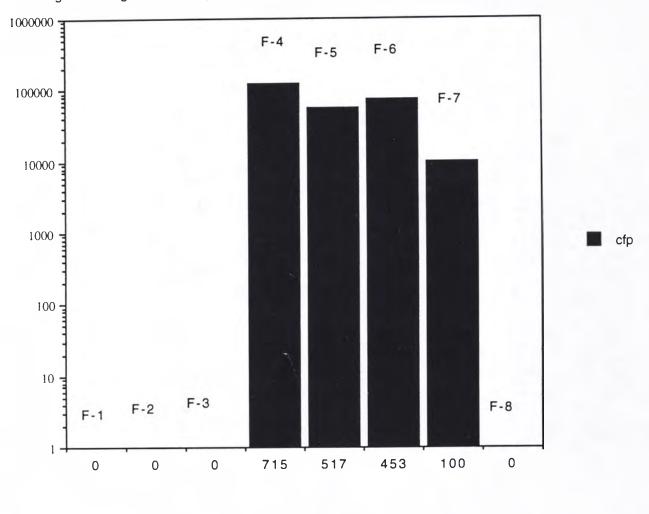
Figure 7: Banana sales per week as a function of amount earned and amount sold



kilograms

Data from "vegies sales per week"

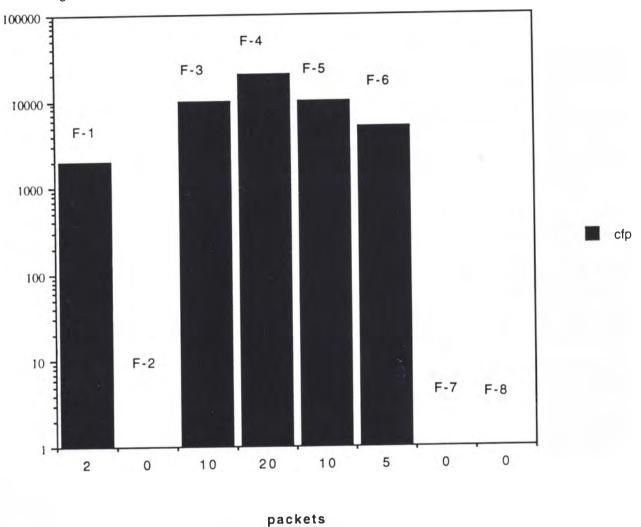
Figure 8: Vegetable sales per week as a function of amount earned and amount sold



kilograms

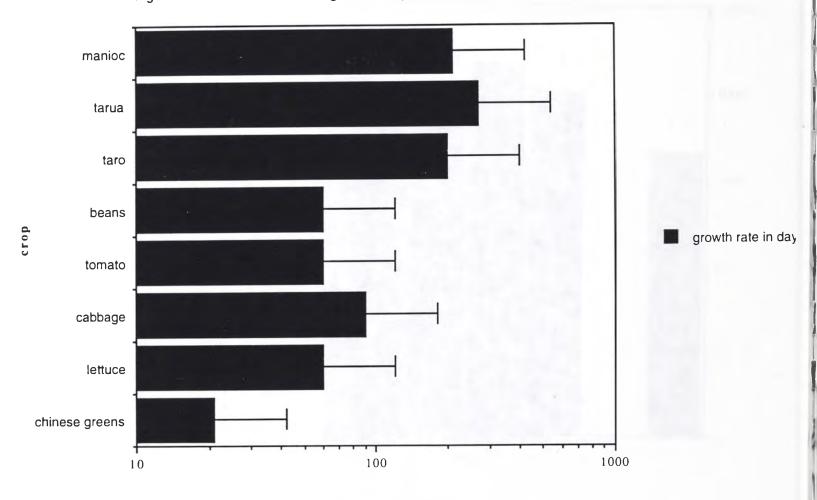
Data from "taro sales per week"

Figure 9: Taro sales per week as a function of amount earned and amount sold



Data from "growth rate"

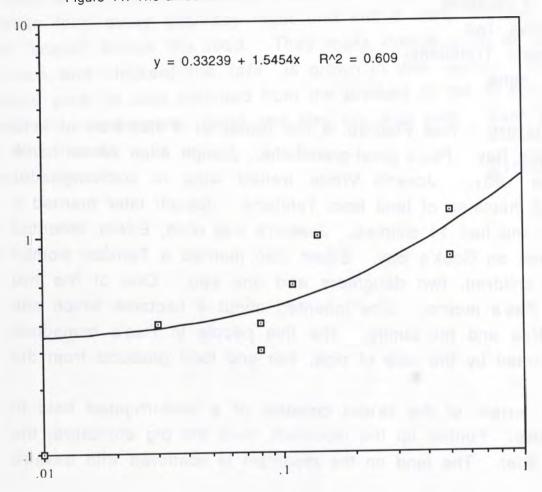
Figure 10: Growth rates of vegetable crops versus traditional crops



growth rate in days

Data from "intensification of agriculture"

Figure 11: The amount of land laid fallow in relation to plot size



fallow land in hect

fallow land in hectares

Fa'apu #1

Location: Cook's Bay Family name: **Puairau**

Amount of land: 4 hectares Number of families: two

Predominate crops: Traditional

Agro-chemicals: none

Irrigation: none

Description: <u>History</u> - Paa Puairau is the owner of 4 hectares of land situated on Cook's Bay. Paa's great-grandfather, Joseph Allen White, came from Boston in 1901. Joseph White traded wine in exchange for approximately 15 hectares of land from Tahitians. Joseph later married a Tahitian woman and had 14 children. Joseph's first child, Edwin, inherited these 15 hectares on Cook's Bay. Edwin also married a Tahitian woman and had three children, two daughters and one son. One of the two daughters was Paa's mother. She inherited about 4 hectares which she passed on to Paa and his family. The five people in Paa's immediate family are supported by the sale of pigs, fish and food products from the land.

<u>Terrain</u> - The terrain of the fa'apu consists of a well-irrigated field in front of the house. Further up the mountain, near the pig enclosure, the soil is rich yet drier. The land on the mountain is scattered with basaltic rocks.

Planting methods - The Puairau's plant taro using traditional methods with a baton, a large wooden digging stick, about 5 1/2 feet long. The baton is pounded into moist ground to form a hole about 10 inches deep. After the soil at the bottom of the hole is packed down by hand, the stem attached to the top of the root of the taro plant is placed in the hole. Manioc is planted by cutting part of the main stem and sticking it into the ground. The family does not use any chemicals to cultivate their plants. Type of crops - The Puairau family cultivate mostly traditional crops.

front of the house, there is a wet taro patch interspersed with banana trees. In back of the house, about 40 meters up the road, is the rest of the family's land. Around the pig enclosure, the family grows manioc, papaya,

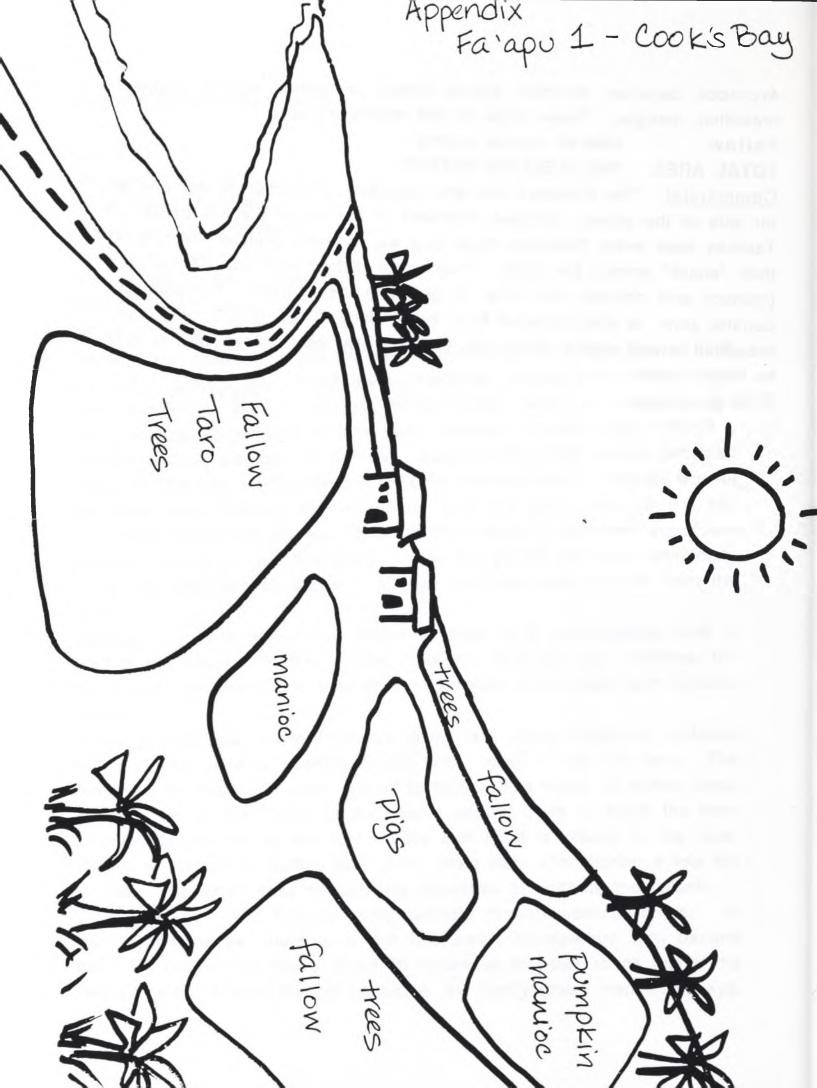
avocados, bananas, pumpkin, citrons (limes), pistachios, vanilla, peppers, breadfruit, mangos. These crops do not require irrigation.

Fallow 4986.67 square meters **TOTAL AREA** 7963.06 SQUARE METERS

Commercial - The Puairau's fruit and vegetable production is not enough for sale at the stores. Instead, members of the family prepare traditional Tahitian food every Saturday night and sell it early Sunday morning at their "snack" across the road. They make dishes such as *fafa poulet*, (spinach and chicken) the *fafa* is grown in their garden. Pumpkin and banana *poe* is also prepared from the produce of the *fa'apu*. Steamed breadfruit, sweet potato, tarua and taro are also sold. Each dish is sold for 500 francs.

Total per week:

21500 cfp



Fa'apu #2

Location: Cook's Bay Family name: White

Amount of land: 8 hectares Number of families: five Type of crops: Traditional

Agro-chemicals: none

Irrigation: none

Description: <u>History</u> - Joseph White is the current owner of 8 hectares of land on Cook's Bay. Joseph's great-grandfather was also Joseph Allen White. Joseph Allen White's son, Edwin inherited the 15 hectares. Of Edwin's three children, Edwin's son, Joseph was given most of the land, 8 hectares. Although Joseph has been growing and selling produce for about 20 years, he was also a taxi driver for about eight years. He has since retired and now his main occupation is running the "petit snack" on the main road. Joseph White has already divided his land among his seven children, five daughters and two sons. Joseph's oldest son, Edwin has gained 4 hectares of this family plot.

<u>Terrain</u> - The land higher up the mountain is extremely rocky and difficult to grow (row) crops. The area is also quite dry, so dry land taro or tarua is grown. This plot is used to grow fruit trees and crops that require little or no maintenance. The land has also been used for a number of years, so it must be left fallow.

<u>Planting methods</u> - Joseph leaves the garbage of the family in the holes that will grow banana plants for about three months. This method of recycling and fertilization reduces waste and creates healthier banana trees. Joseph also kills "male" papaya trees, the trees that do not bear fruit in order to encourage the development of fruit on "female" trees. The White family does not use any chemicals to cultivate plants. The land also must rest for about 4-5 years, especially during the time when row crops of vegetables are grown. The family also rotates traditional crops in this order: tarua, manioc, sweet potato, then manioc, tarua, manioc, sweet potato etc. M. White has controlled forest regrowth on the mountainous

landscape with fire twice in the past twenty years. Burning the unwanted vegetation also rejuvenates the soil.

<u>Type of crops</u> - Joseph White's land has undergone many changes. About 35 years ago, his parents used the 15 hectares to cultivate coconut trees and vanilla, and to raise pigs and cows. When Joseph inherited his land, he tried to grow pineapple, the newest cash crop. He found that this was a problem because it required large amounts of expensive agrochemical inputs.

Although the land has been divided among his children, Joseph still maintains most of the 8 hectares. He cultivates fruit trees ranging from papaya, mango, avocado, citrons, oranges, pamplemousse, banana, corosal, pomme etoile, breadfruit, uru taratoni, passion fruit.

Fallow

1359.44 square meters

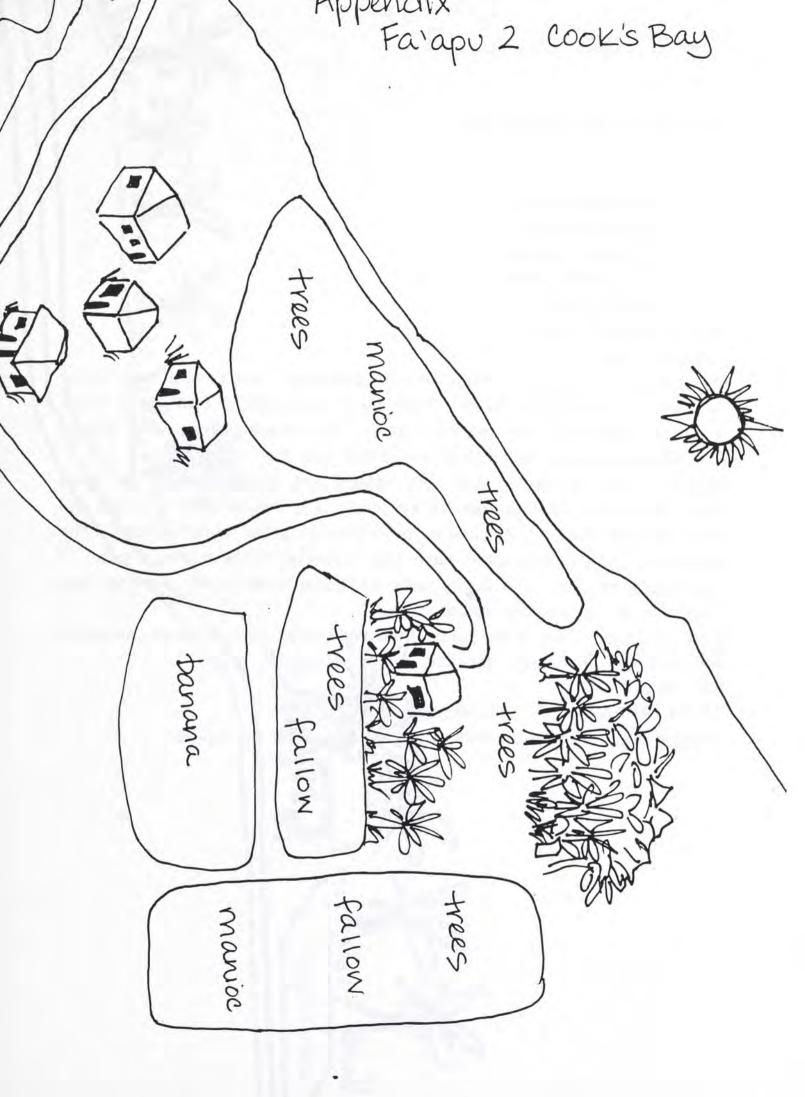
TOTAL AREA 96

9684.50 SQUARE METERS

<u>Commercial</u> - Joseph sells all of his produce at his little snack on the main road.

Total per week:

89400 cfp



Fa'apu #3

Location: Pao Pao Valley Family name: Unknown Amount of land: 1 hectare

Number of families: five

Type of crops: Mixed Agro-chemicals: none

Irrigation: yes

Description: <u>History</u> - This family cultivates crops with four other families on a large taro patch. They are in theprocessof finishing a house a quarter mile away from the taro patch. The owners have a small garden that will be extended after they are settled into their new home.

Terrain - The taro fields are well-irrigated and located behind the trees near the stream on Pao Pao Valley road. The house itself is about 1/4 mile up the road. The house is currently under construction. The surrounding garden and plants have been cultivated for less than a year.

<u>Planting methods</u> - The family uses traditional methods for planting taro. They also do not use any agrochemicals.

<u>Type of crops</u> - The crops range from vegetables such as corn, tomatoes and cabbage, to manioc, bananas, citrons, breadfruit, etc.

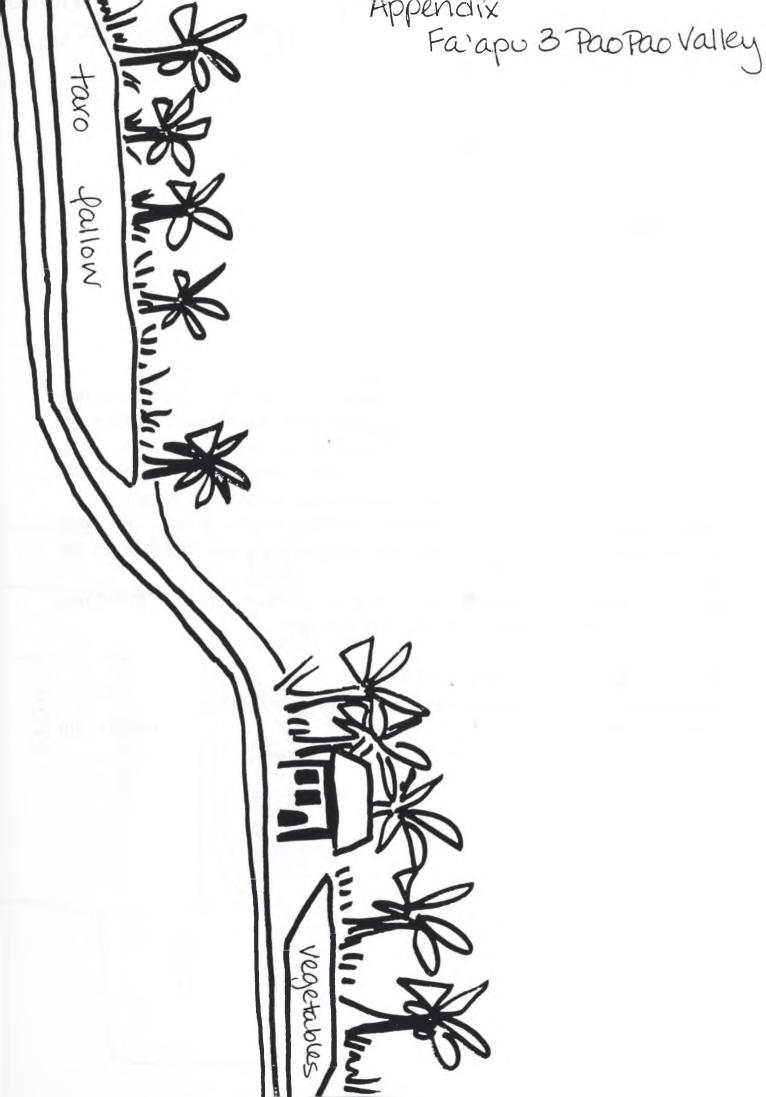
Fallow

0

TOTAL AREA

5240.99 SQUARE METERS

<u>Commercial</u> - The family sells taro once a week at the stores.



Fa'apu #4

Location: Pao Pao Valley
Family name: **Tuahiua**Amount of land: 1 hectare
Number of families: one

Type of crops: Mixed Agro-chemicals: yes

Irrigation: yes

Description: <u>History</u> - George and his wife work the land near his house and across the road. He inherited the land from his parents. Before he began cultivation for an occupation, he used to do construction work.

<u>Terrain</u> - M. Tuahiua has a large garden next to his house. He also has additional land down the road from his house and across the stream.

<u>Planting methods</u> - He uses traditional methods for taro growth. He does not use slash and burn. He does use agrochemicals and irrigation on his garden.

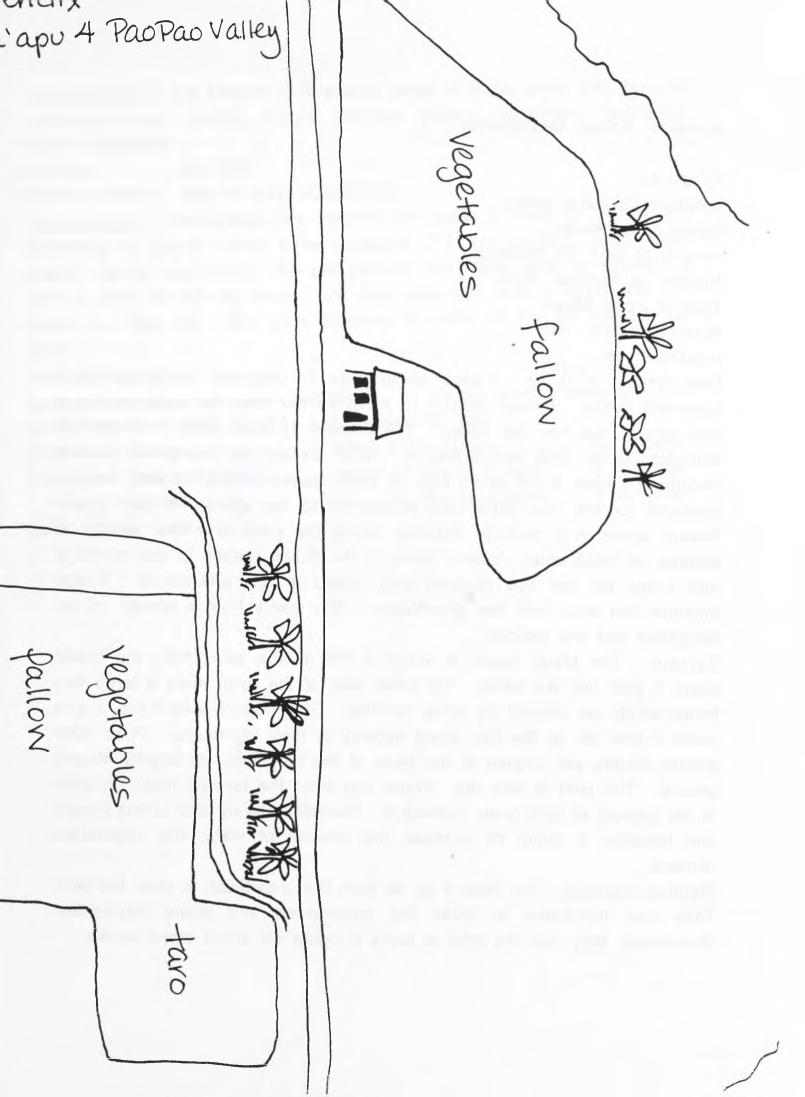
<u>Type of crops</u> - Pineapple, fei, banana, chinese greens, tomatoes, cucumbers, pumpkin, lettuce, chicory, manioc, taro. . .

Fallow 887.38

TOTAL AREA 2766.25 SQUARE METERS*

Commercial - George Tuahiua sells vegetables once a week:

total per week 140701 cfp



Fa'apu #5

Location: Opunuhu Valley

Family name: Maau

Amount of land: 21 hectares

Number of families: eight

Type of crops: Mixed Agro-chemicals: yes

Irrigation: yes

Description: <u>History</u> - Loana Maau lives in Opunuhu Valley with her extended family. It was difficult to measure her land because each plot was spread out into the valley. The amount of land under cultivation is estimated to be 4000 square meters. When Gerard and Loana are finished clearing the land, it will be as high as 6000 square meters. Loana and her husband, Gerard, hold other jobs in addition to the upkeep of their fa'apu. Gerard works in a bank in Papeete during the week and only returns to Moorea on week-ends. Loana works at the Gump Station in the mornings and cares for her two children and fa'apu in the afternoons. Loana inherited her land from her grandfather. She came from a family of six daughters and one brother.

Terrain - The Maau fa'apu is about a 100 meters away from the house along a path into the valley. On either side of the path, there a large taro fields which are shared by other families. The Maau's also have a taro patch to the left of the trail about halfway to their big fa'apu. Their 4000 square meters are located at the base of the mountain, on slightly sloping ground. The land is very dry. Water has been the family's main limitation to the amount of land under cultivation. Recently, Gerard and Loana bought and installed a pump to increase the amount of water the vegetables demand.

<u>Planting methods</u> - The Maau's do not burn the underbrush to clear the land. They use machetes to clear the underbrush and some herbicides. Sometimes, they rest the land to leave it fallow for about three weeks.

Type of crops - The Maau's have a wide range of crops tarua, taro, banana, lettuce, chicory, vanilla, beans, chinese greens, cucumber, tomatoes, radish, breadfruit, . . .

fallow 836.048

3007.37 SQUARE METERS TOTAL LAND

Commercial - Loana sells her produce two times a week to friends and according to orders. She sells tomatoes (7-8 per packet), pota, green beans, lettuce, cucumbers (4-5 per packet), etc. She sells 20 packets of each a week at 200 cfp each. She also sells taro once a week- 4-6 in a bunch for 1000 cfp. She sells bananas in packs of 7-8 for 200 cfp per pack.

total per week

74000 cfp

Agro-chemicals - Fertilizer: Complet 1 sac every 2 months

active ingredient: NPK 12.12.17 + 2 Papeete 68, 098

Herbicide: Sting Pesticide: Folinmat 50 size: 5 litre bottle 1-2 years

dose: 15 mm to 2 litres 1 per year

Attack

15 mm to 2 litres 1 per year

size: 1 litre bottles



Fa'apu #6

Location: Opunuhu Valley Family name: Yu Seng

Amount of land: 1 hectare Number of families: four

Type of crops: Non-traditional

Agro-chemicals: yes

Irrigation: yes

Description: <u>History</u> - Jacques Yu Seng and the family of his wife have leased their land with several other families for about thirty years. Jacques' father-in-law, M. Kongwell, used to pay rent for the land. Today, the family does not have to pay rent on the land. Jacques and his wife were given their plot of land in exchange for keeping the land clear and cultivated. The landlord can receive free vegetables, but he does not take very much of the families' produce. For the past four years, Jacques has grown quick-growing vegetables for profit.

<u>Terrain</u> - The family's land is flat and well-irrigated. There are few rocks and the soil is rich and productive.

<u>Planting methods</u> - Jacques does not need to rest the land. It is still rich enough to keep growing crops for the next two years. They do irrigate the land with standing sprinklers.

<u>Type of crops</u> - Jacques grows taro, pota, cabbage, tomatoes, eggplant, lettuce. He has one papaya tree.

fallow 110.13

TOTAL AREA 1012.2 SQUARE METERS

<u>Commercial</u> - Jacques sells large numbers of vegetables each week to stores and hotels.

Total per week:

77250 cfp

<u>Agro-chemicals</u> - Fertilizer: Urea 1 sac per month (50 kg)

active ingredient: Petrochem Nitrogen 46%

Pesticide: Carbendazime 50%PM

dose: 6 grams per 10 litres

Vitazeb80WP

15 to 20 grams/litre

active ingredient: manganese ethylenebisdithiocarbamate 80%

weight: about one kilogram each? amount used: 1 bag per 3-4 months

Fa'apu 6 Opunuhu Valley C.greens Calobage house

Fa'apu #7

Location: Papetoai Valley Family name: **Germain**

Amount of land: 3000 square meters

Number of families: 2 Type of crops: Mixed Agro-chemicals: yes

Irrigation: yes

Description: <u>History</u> - Leonard. Germain lives in Papetoai Valley surrounded by members of his extended family. Although he is part French, he only speaks Tahitian. He received his land from his parents. and has been working on it ever since. Before he started growing vegetables for sale, he held different jobs that were finished at three in the afternoon. He would return home to work on his fa'apu until sunset. Three years ago, he started growing vegetables for sale at stores and hotels. Currently, about five people live on his land.

Terrain - M. Germain's farm is nestled deep in Papetoai Valley off of a dirt road. Most of his crops are situated near his house either just across the road or around his three houses. He grows vegetables across the stream about 200 m from his house. The land around the house is flat with some hills. Most of the tree crops are across the road in a dense, forest like area that was nearly impossible to enter. The large vegetable garden was orderly and cleared of rocks at the base of a cliff.

<u>Planting methods</u> - M Germain realizes the problems of extensive agrochemical use. He tried to grow lettuce for sale but stopped because of the need to use lots of chemical pesticides. He also had to expend a lot of energy to maintain the plants. There is no need to use fertilizers because the soil is rich enough to grow plants without them. He cleared the land but did not burn the cover.

<u>Tvpe of crops</u> - This fa'apu has a wide range of plants: lots of fruti trees, corosal, coconut, citron, pepper, hbreadfruit, papaya, beans, tarua, flowers, fei, . . .

fallow

280.62 square meters

Commercial - Leonard sells vegetables once a week:

total per week

58550 cfp

Agro-chemicals - Fertilizer: none

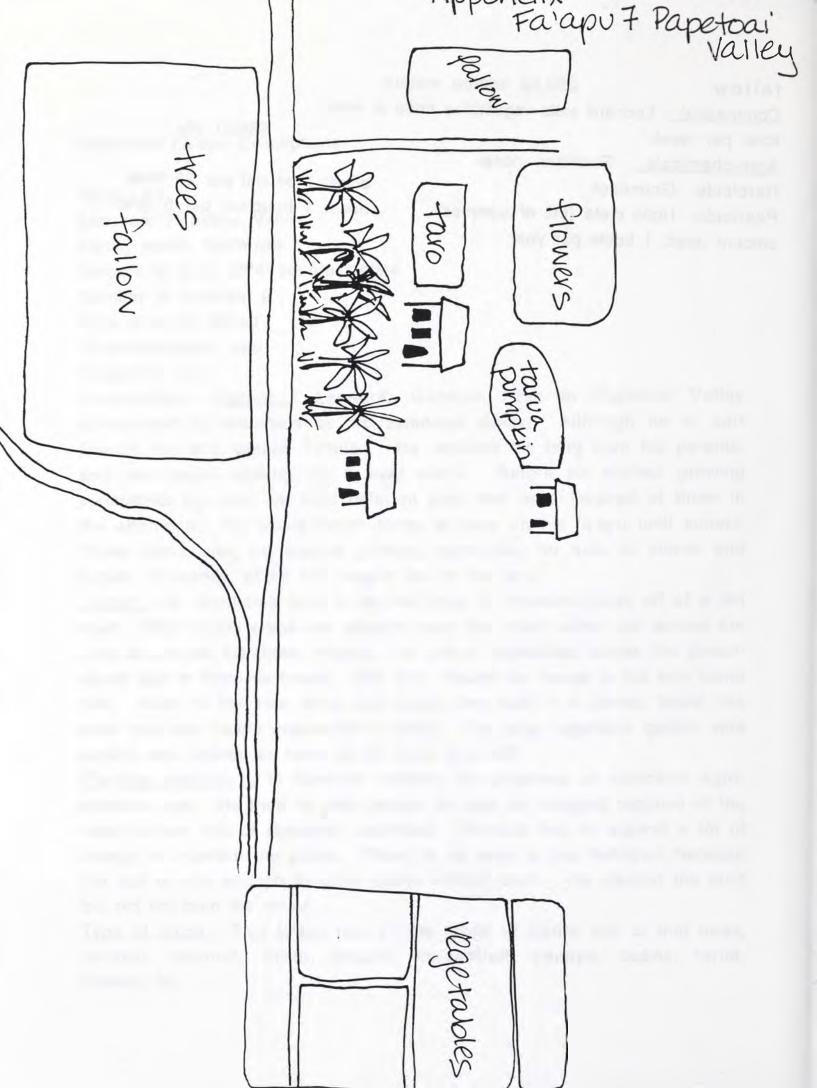
Herbicide: Gramosol

dose: 1 boucal per 20 litres

Pesticide: Huile d'ete (Oil of summer)

dose: 1 bouchon per 5 litres

amount used: 1 bottle per year



Appendix: Fa'apu Descriptions

Fa'apu #8

Location: Teavaro Valley

Family name: Hunter

Amount of land: 2 hectares Number of families: zero

Type of crops: Mixed Agro-chemicals: none

Irrigation: none

Description: <u>History</u> - Fred inherited his land from his grandmother who was a Tahitian associated with royalty. His grandfather, on the other hand, was a pirate. Although he has a lot of land under cultivation, he still works at two jobs. During the week, he lays tile in Papeete and in the evenings, he is the night manager at the Club Bali Hai.

<u>Terrain</u> - At the foot of the valley, the land is relatively flat and well irrigated. Fred's parcel is near a stream and is shaded by a huge banyan tree and other mango trees. His main parcel of land is much higher up the mountain about a ten minute hike up a steep dirt road. This land is on a mountain face that has been cleared of trees. It is very rocky and difficult to maneuver.

<u>Planting methods</u> - Fred burned the mountain face in order to kill the forest trees. He also cut the base of the trees to kill them. His gardening is a constant battle to prevent these trees from recolonizing the mountain. M. Hunter also kills male papaya trees.

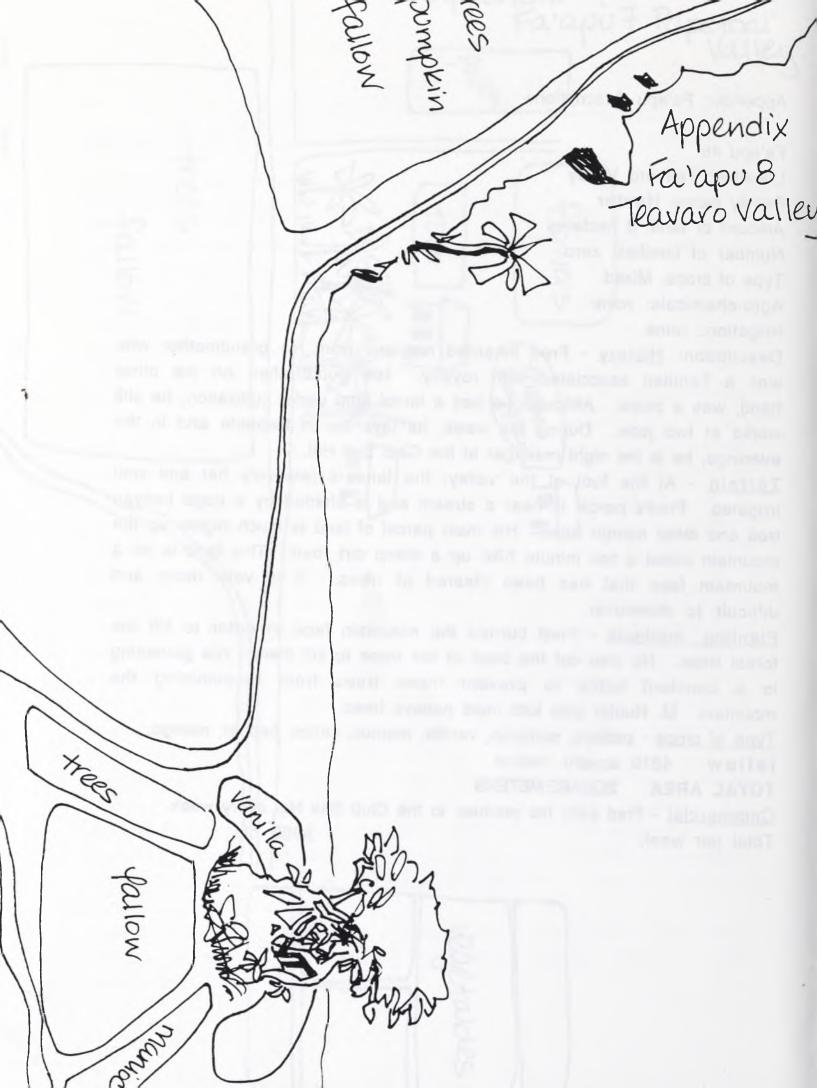
Type of crops - papaya, pumpkin, vanilla, manioc, citron, pepper, mango. . .

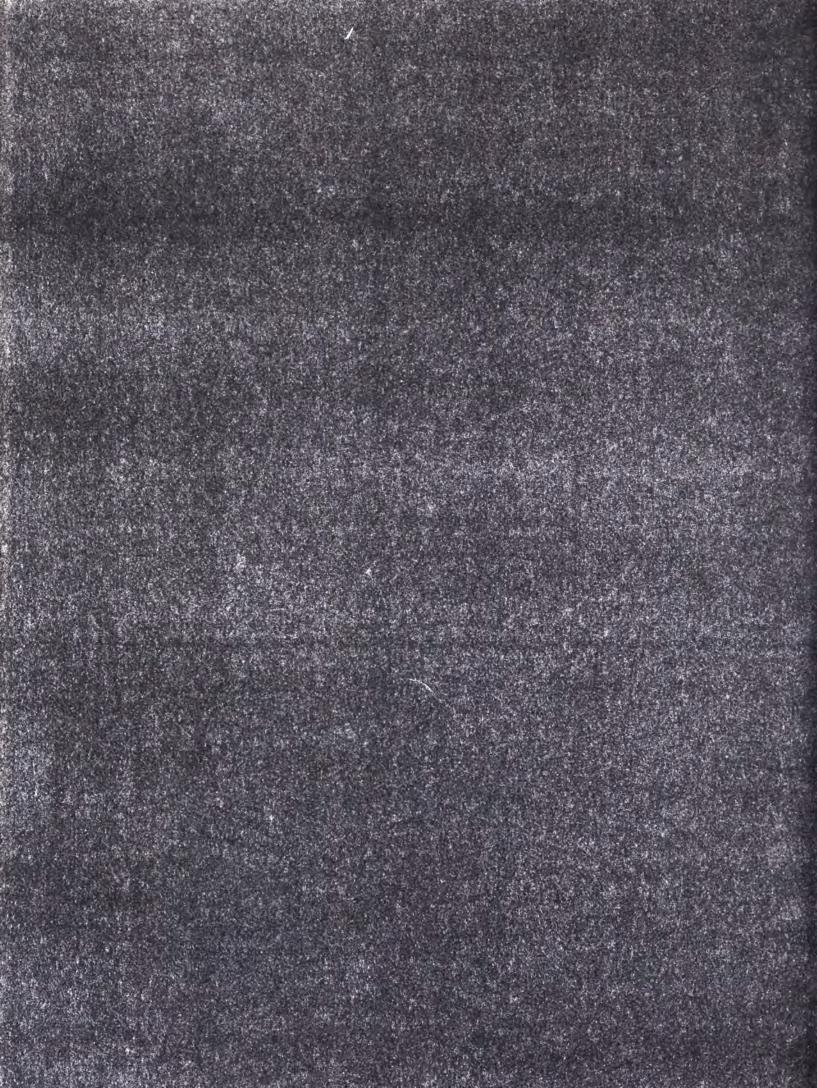
fallow 4810 square meters

TOTAL AREA SQUARE METERS

<u>Commercial</u> - Fred sells his produce to the Club Bali Hai every week.

Total per week: 8900 cfp





A survey of the dominant sessile macroorganisms and the damselfish, Stegastes nigricans, on the tropical island of Moorea, French Polynesia, in some areas possibly impacted by humans

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Abstract. Moorea is a developing tropical island frequented by tourists. On similar islands, algae is overgrowing the coral reefs. It is likely that the same trend is occurring in Moorea. This project determined that Turbinaria ornata, Halimeda sp, Dictyota bartayresii, and the red filamentous algae harvested by the damselfish, Stegastes nigricans, are abundant on Moorea's fringing reefs, whereas only the relatively resistant coral. Porites is abundant. It appears as though Porites predominates over algae in the areas that have a relatively low human impact. There is also a nearly significant negative correlation between the percent cover of Porites and the percent cover of Turbinaria, Dictyota, and red filamentous algae, separately. Stegastes nigricans is present at all sites except on the northwest shelf of Cooks Bay. There is no correlation between the percent cover of *Porites* and the number of damselfish at the sites studied. There is, however, a significant correlation between the number of damselfish and the percent cover of red filamentous algae, cultivated by the territorial fish. There is a nearly significant positive correlation and a nearly significant negative correlation between the number of damselfish and the percent cover of Turbinaria and the percent cover of *Dictyota*, respectively.

INTRODUCTION

In a pristine and healthy coral reef ecosystem, colorful, live corals typically occupy greater than 80 percent of the available bottom space (Lapointe, 1989). As more reefs are exposed to human impacts, however, coral cover seems to be declining and algae cover increasing. Nutrient pollution, over fishing, and sedimentation could be promoting this trend (Lapointe, 1989 and Jackson, 1991). In the long term, such a trend would cause drastic changes in the community structure of coral reefs, eliminating the existing natural relationships and causing the possible extinction of some of the many species that the diverse and complex coral reef ecosystems support.

Moorea, a member of the Society Islands archipelago, has a growing tourist industry and a increasing population. The resulting development of the island may cause increased human impacts on its reef ecosystems, leading one to suspect that algae overgrowing the reefs could be a potential problem. This trend has been noted and some research has been done (Done, Dayton, Dayton, and Steger, 1991 and Gleason, M.G. unpublished), but no extensive quantification of the types and amounts of coral and algae present in some impacted areas of Moorea have been published. The intent of this project is to assess what sessile macroorganisms dominate the benthic substratum, how much and what kind of uninhabited substratum occurs, and how many of the territorial damselfish, *Stegastes nigricans*, reside at each of five different sites on

Moorea. The five sites were chosen such that reef ecosystems experiencing varying impacts are represented. Survey data were examined for possible inverse correlations between percent cover of the dominant coral, *Porites*, and different dominant algae. Any possible correlation between the number of Stegastes nigricans and the percent cover of Porites was investigated, as well as any correlations between the number of damselfish and the percent covers of the dominant algae.

METHODS AND MATERIALS

Study Site. Moorea is a member of the Windward islands in the Society Archipelago. Moorea lies at 17deg.30' South latitude and 149deg.50' West longitude and is 25km to the North-west of Tahiti (Galzin and Pointer, 1985). It is surrounded by a barrier reef, forming a lagoon that is 500 to 1500 meters wide (Galzin and Pointer, 1985). There are two large bays on the northern edge of the triangular island, Cooks Bay and Opunohu Bay where the waters are typically turbid and rich in nutrients released by land-water runoffs (Ricard, 1981) (figure 1). The five sites sampled consisted of two sites in each bay and one site in the Vaipahu lagoon which lies in between the bays (figure 2).

Cooks Bay is more developed than Opunohu Bay, with hotels and rural/urban developments lining its shore. The Pao Pao river that pours into the head of the bay, drains a basin that is the principle pineapple growing area on the island and also supports a small community. Thus, the two sites in Cooks Bay are assumed to be the most heavily impacted by sediment and nutrient inputs. One site is along the northeast shore of the bay, just north of the Cooks Bay Hotel. The other is along the northwest shore, straight out from the Gump Field Station and south of a culvert used for discharging by the Moorea Juice Factory (figure 2).

Opunohu Bay does not have any hotels, but there are a few homes lining it's perimeter. The Opunohu river is lined with pastures and fields planted with citrus and coconuts in the lower reaches, however these practices do not require tilling and therefore sediment and nutrient runoff are not likely to be large scale inputs into the bay. The valley is owned and run by the Territorial Authority and managed by the Rural Economy Bureau, with the intent of preventing urbanization (Galzin and Pointer, 1985). Therefore, the two sites in Opunohu Bay are assumed to be less effected by sediment and nutrient inputs. One site is along the northeast shore of the bay, offshore from a culvert and just south of a private residence near the shore. The other site is along the northwest shore, also offshore from a culvert, with private residences across the road from the shore (figure 2). All four sites in the bays begin where the fringing reef drops off and continue in towards the shore for twenty meters.

Vaipahu lies between the bays. A north to south transect of Vaipahu reveals three zones, the fringing reef, an artificial channel for boat travel, and the barrier reef (Galzin and Pointer, 1985). The study site is in the fringing reef zone, beginning about fifty meters south of the channel and continuing towards the shore for twenty meters, and about 400 meters offshore from the Moorea Lagoon Hotel (figure 2). Unlike the bays, the barrier reef and lagoon are flushed by oligotrophic ocean waters and therefore it is unlikely that sediment and nutrients are major impacting forces (Ricard, 1982). Therefore, this site is assumed to be the least impacted of all the sites.

Procedure. Sampling of sessile organisms was accomplished using a line transect method. Every 0.5m along a 20m chain transect, the dominant sessile benthic organism or uninhabited substrate directly under that link of the chain was recorded. At each site, the line transect method was replicated three times by placing the transects approximately four meters apart and parallel to each other. The organisms were identified to the best of the ability of the observer. Algae was identified to species if possible, however coral was only identified to genus. Other organisms were sometimes only identified to phylum, however these were not encountered frequently enough to be used in the analysis.

The damselfish, *Stegastes nigricans*, were sampled by converting the above 20m transects into 20x2m² band transects, divided into 2x2m² quadrants. In each quadrant, the damselfish were tallied according to three size classes, small (<10cm), medium (between 10 and 20 cm's), and large (>20cm). Sampling was accomplished by waiting for the damselfish to reappear after the initial disturbance of the observer (usually 30-60 sec.) and a maximum search time was set at 3 minutes to avoid bias. Because no tagging was involved, it is possible that some damselfish were counted more than once, however, since they are territorial, they could be separated from one another by visually assessing which fish occupied which algae mat and thus it is also unlikely that one individual would move from one quadrant to the next.

Statistical Analysis. From the line transect data, it was determined which species of algae, coral, and which uninhabited substrates were relatively abundant (≥ 2% of total points sampled). Oneway Anovas, with multiple treatments, having three replicates per site, were performed on the line transect data to determine whether or not there were statistically significant differences in the amounts of dominant algae, coral, and uninhabited substrates (Sokal and Rohlf, 1987). The number of treatments in each Anova varied, depending on the number of sites at which the subject was present

Correlations (Sokal and Rohlf, 1987) between percent covers were performed on the algae and coral species that showed significant

differences in abundance. This determines whether or not a relationship possibly exists such that, where there is more algae, there is less coral and vice versa.

A one-way Anova with four treatments and three replicates each was performed on the band transect data, to determine whether there was a significant difference in the numbers of damselfish at the four sites where they were present. Correlations between the number of damselfish and the percent covers of *Porites*, *Turbinaria*, *Halimeda*, *Dictyota*, and red filamentous algae were also performed (Sokal and Rohlf, 1987).

RESULTS

The most frequently occurring algae are Halimeda sp, Dictyota bartayresii, Turbinaria ornata, and the red filamentous algae harvested by the damselfish (table 1). The analysis of variance tests performed on the dominant algae show significant differences in their amounts at the sites where they are present (table 2). The percent cover of *Turbinaria* is highest at the northeast Opunohu site, intermediate at both the northwest Opunohu and the northeast Cooks sites, low at the Vaipahu site, and zero at the northwest Cooks site (figure 3). Red filamentous alga has a very high percent cover in the northeast Opunohu site, an intermediate value at the northwest Opunohu and northeast Cooks sites, and low values at the northwest Cooks and Vaipahu sites (figure 3). Halimeda cover is highest at the northwest Opunohu site, lowest at the Vaipahu site, and intermediate at the other sites (figure 3). Dictyota cover is highest at the northwest Cooks site, intermediate at the northeast Opunohu site, low at the Vaipahu and northwest Opunohu sites, and zero at the northeast Cooks site (figure 3).

The most abundant corals are live and dead *Porites* (table 1). The Anovas performed on these data showed a statistically significant difference in the amount of live *Porites*, but not in the amount of dead *Porites* at the different sites(table 3). The percent cover of *Porites* is highest at Vaipahu, with northwest Opunohu close behind. The two Cooks sites show intermediate cover, and the northeast Opunohu site has a very low percent cover of live *Porites* (figure 4).

The uninhabited substrates present at the sites are sand, pavement, and coral rubble (table 1). The Anovas performed on the sand and pavement data show a significant difference at the various sites, but the one performed on the rubble data shows no significant difference (table 4). There is a lot of sand at the northwest Cooks and Vaipahu sites and very little at the rest (figure 5). The percent cover of pavement is high in northeast Cooks, but fairly low everywhere else (figure 5).

There is a nearly statistically significant negative correlation between the percent cover of *Turbinaria* and live *Porites*, between the

percent cover of *Dictyota* and live *Porites*, and between the percent cover of red filamentous algae and live *Porites* (figures 6, 7, and 8). These relationships are most obvious at the northeast Opunohu site, when comparing the very low cover of live *Porites* to the high covers of all three algae species (figures 3 and 4). It is also apparent at Vaipahu, where *Turbinaria*, *Dictyota*, and red filamentous algae covers are very low, but the live *Porites* cover is the highest (figures 3 and 4). The correlation between *Halimeda* and live *Porites* is not at all significant (n=15, r=0.07, r_{crit}=0.51).

The Anova for the damselfish data shows no significant difference in the numbers of damselfish at the different sites where they reside (table 5). There is no significant correlation between the percent cover of live *Porites* and numbers of damselfish (n=15, r=-0.05, $r_{crit}=0.51$). There is a significant positive correlation between the number of damselfish and the percent cover of red filamentous algae, and a nearly significant positive correlation between the number of damselfish and the percent cover of *Turbinaria* (figures 9 and 10). A nearly significant negative correlation was found between the number of damselfish and the percent cover of *Dictyota* (figure 11). No significant correlation was found between the number of damselfish and the percent cover of *Halimeda* (n=15, r=0.15, $r_{crit}=0.51$).

DISCUSSION

The abundance of four types of algae on Moorea's reefs as compared to the abundance of only a single coral species is indicative of a potential take over of coral reefs by algae. The highest percent cover of *Porites* and the lowest percent cover of all the abundant algae species is at Vaipahu, which is the site least likely to be impacted by nutrient pollution and sedimentation. This leads one to believe the original assumption that at this site, human impacts are minimal.

However, northeast Opunohu, a site which is assumed to be less impacted than any Cooks bay site, demonstrates the reverse relationship with high algae cover and low coral cover. Why this relationship exists at this site and not at a more impacted site is not clear and could very well be simply due to the geomorphologic makeup or water circulation patterns of that portion of reef. Large differences in the turbidity of the water at the Opunohu sites were observed on a few occasions and may be a result of predominant wind patterns. That site was shallow relative to the others and therefore may encourage algal growth because of higher light intensity. The high coral cover and relatively low Turbinaria, *Dictyota*, and red filamentous algae cover at the northwest Opunohu site indicates a healthy reef.

In Cooks Bay, not much algae or coral covers the bottom, especially at the northwest site in front of the Gump Field Station, which is in fact mostly sand and *Dictyota*. It would be interesting to determine the origin and makeup of the sand, which is quite possibly derived in part from terrestrial sediment. The sand here appears to be finer and composed of less coral fragments than the sand at all the other sites studied. The northeast site in Cooks Bay is predominantly pavement and could be a result of the observed boat traffic through the reef to the Cooks Bay Hotel. Nonetheless, coral cover here is significantly less than that of Vaipahu and northwest Opunohu, which appear to be the least impacted sites.

From the nearly significant negative correlations assessed, it appears as though *Turbinaria*, *Dictyota*, and red filamentous algae may be competing for space with *Porites*, whereas *Halimeda* may not be interfering with coral cover. Even though each correlation was only nearly statistically significant, the potential for the existence of such relationships provides the groundwork for another potential project. In this case it is possible that data from more sites around the island would provide insight into the actual significance of such a relationship.

The above relationships could be better explained if the actual nutrient and sediment inputs were monitored and sources pinpointed. Even along the same sides of each bay, the coral reef environment varies greatly (Gleason, M.G. pers. corr.), therefore differences in these sites could possibly result simply from the fact that the sites themselves are different and not because of varying human impacts. The time span of this study prevented the pursuit of this, however, further studies would be interesting and helpful. Also, an accurate account of the predominant wind and water current patterns in both bays would allow for better speculations about the observations. Because the sites of each transect were carefully benchmarked to permanent structures (see appendix), it is possible for future studies to be conducted at the exact same sites.

The results of the damselfish correlations reveal some expected and some surprising possible relationships. Because territories of *Stegastes nigricans* are comprised of red filamentous algae, it is not surprising to find a significant correlation between their abundances. Also not surprising is the insignificance of the correlation between abundances of damselfish and live *Porites*. It has been previously noted that *Porites* are not significantly more common inside damselfish territories than outside, as are other coral species (Done, Dayton, Dayton, Steger, 1991 and Gleason, M.G. pers corr).

However, the nearly significant positive correlation between damselfish and *Turbinaria* is surprising and leads me to suspect that the active defense of territories against herbivorous urchins and fish by damselfish (Williams, 1979, Gleason, M.G. pers corr, and pers obs) may

somehow benefit *Turbinaria*. I suspect that *Turbinaria* may dominate the edges of damselfish territories where herbivores are not likely to linger and therefore may benefit from the damselfishes' expenditures in defense of their algal mats. This could be an exciting point of interest for future studies.

The nearly significant negative correlation between abundances of damselfish and *Dictyota* is interesting in light of the above positive correlation with a different species of alga. *Dictyota* is abundant at the northwest Cooks site where sand is the dominant substratum and no damselfish were found. Damselfish territories are predominantly on standing skeletons of dead *Acropora* assemblages and among lobes of living *Porites* (Done, Dayton, Dayton, Steger, 1991) where the surface is heterogeneous and there are places for them to hide. These observations lead me to suspect that the negative correlation could be a result of both organisms' utilization of different habitats. However, experiments with transplanting *Dictyota* and relocating damselfish would enable the quantification of the suspected relationship.

It is questionable whether or not damselfish are encouraging or discouraging the increase in algae and the decrease in coral in reef ecosystems. There is some evidence that recruitment, growth rates, and survivorship of the coral species *Pocillopora* and *Acropora* are higher inside damselfish territories than outside (Done, Dayton, Dayton, Steger, 1991, and Gleason, M.G. pers corr). The behavior of damselfish defending algal mats against herbivorous urchins and fish, and against the coral eating *Acanthaster planci* has also been documented and shown to benefit coral (Colgan and Glynn, 1988, and Williams, 1979) However, there is some evidence that damselfish interfere with the growth of corals mainly through encouraging algal overgrowth (Risk and Sammarco, 1982). Also, the results of this study show a possible positive relationship between damselfish and some species of algae. Therefore, it has yet to be determined if damselfish contribute to or inhibit the trend of increasing algal growth on tropical coral reefs.

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Table 1. The most abundant species and substrates encountered (≥2% of total points sampled.

		X% of total
	рс	ints sampled
ALGAE	red fil.	14
	Turbinaria	10
	Dictyota	10
	Halimeda	11
CORAL	Porites, live	12
	Porites, dead	2
SUBSTRATE	sand	17
	rubble	4
	pavement	11

Table 2. Summary of Anova results for the dominant algae.

A.) Turbinaria	a			7 9 10	
Source of Varia	ition				
	SS	df	MS	F	P-value
Between Group	176.25	3	58.75	9.4	0.00532449
Within Groups	50	8	6.25		
					F crit
Total	226.25	11			4.06618028
B.) Red Filam	entous				1 13
Source of Varia	tion				
	SS	df	MS	F	P-value
Between Group	125.066667	4	31.2666667	4.78571429	0.02038077
Within Groups	65.3333333	10	6.53333333		
					F crit
Total	190.4	14			3.47804985
C.) Halimeda					
Source of Varia	tion				
	SS	df	MS	F	P-value
Between Group	74.2666667	4	18.5666667	4.09558824	0.03211617
Within Groups	45.3333333	10	4.53333333		
					F crit
Total	119.6	14			3.47804985
D.) Dictyota					
Source of Varia	tion				
	SS	df	MS	F	P-value
Between Group	82.6666667	3	27.555556	4.08230453	0.04955169
Within Groups	54	8	6.75		
					F crit
Total	136.666667	11			4.06618028

Table 3. Summary of Anova results for the live and dead coral, *Porites*.

A.)Live Porite	S				
Source of Varia	tion				
1	SS	df	MS	F	P-value
Between Group	140.933333	4	35.2333333	7.04666667	0.00577662
Within Groups	50	10	5		
					F crit
Total	190.933333	14			3.47804985
B.) Dead Porit	es				
Source of Varia	tion				
	SS	df	MS	F	P-value
Between Group	6	2	3	0.81818182	0.48505831
Within Groups	22	6	3.66666667		
1				•	F crit
Total	28	8			5.14324938

Table 4. Summary of Anova results for the dominant unihabited substrates.

	_				
A.) Sand					
Source of Varia	tion				
	SS	df	MS	F	P-value
Between Group	630.4	4	157.6	18.46875	0.00013018
Within Groups	85.3333333	10	8.53333333		
Ī					F crit
Total	715.733333	14			3.47804985
B.) Pavement					
Source of Varia			100		Durchin
1	SS	df	MS	F	P-value
Between Group	342.266667	4	85.5666667	9.03873239	0.00234738
Within Groups	94.6666667	10	9.46666667		
					F crit
Total	436.933333	14			3.47804985
C.) Rubble					
Source of Varia	tion				
	SS	df	MS	F	P-value
Between Group	11.6666667	3	3.8888889	1.72839506	0.23821726
Within Groups	18	8	2.25		
					F crit
Total	29.6666667	11			4.06618028

Table 5. Summary of Anova results for the number of damselfish.

Source of Variation					
	SS	df	MS	F	P-value
Between Group	1404	3	468	2.17169374	0.16927604
Within Groups	1724	8	215.5		
					F crit
Total	3128	11			4.06618028

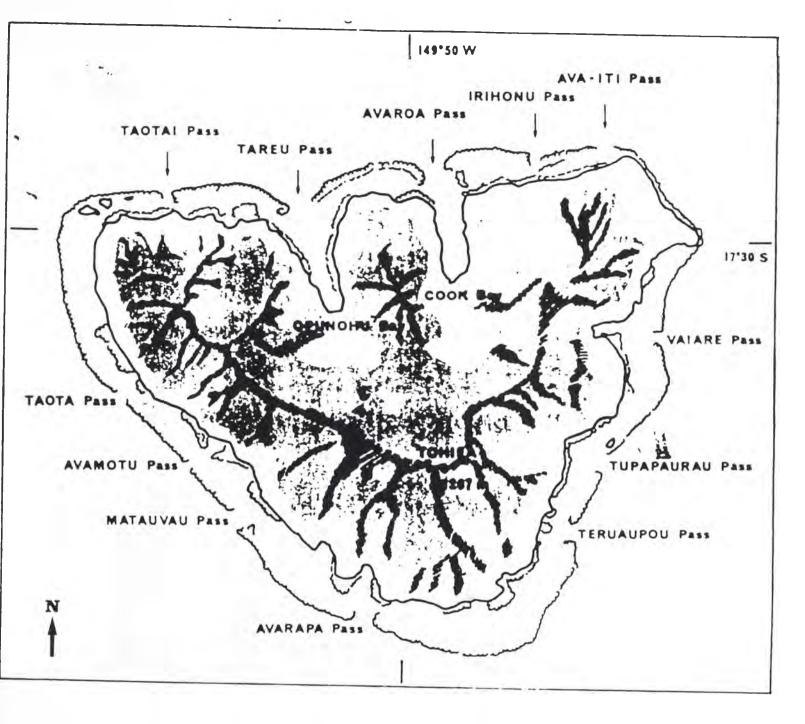


Figure 1. The island studied was Moorea, a member of the Society Islands, in French Polynesia.

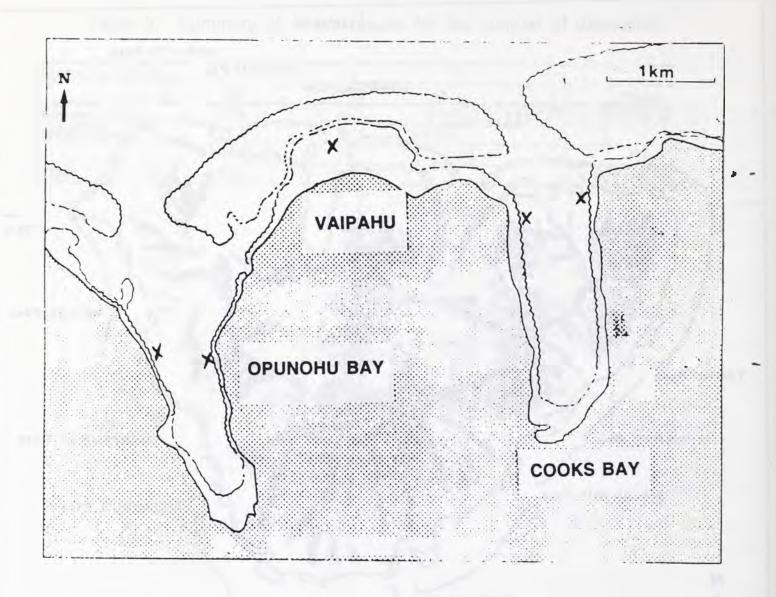


Figure 2. There were five study sites, two in the fringing reefs on opposite shores in each bay, and one in the the fringing reef of the Vaipahu lagoon.

Relative Percent Covers of the Dominant Algae at the five different sites

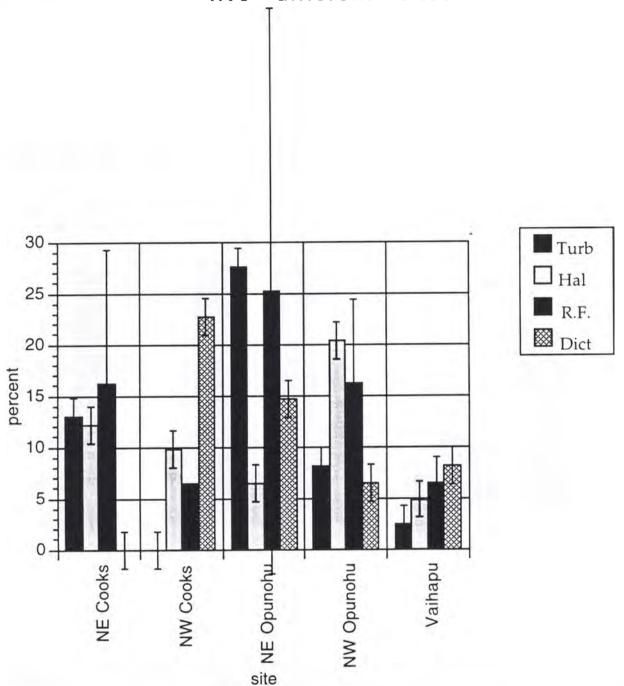


Figure. 3. The dominant algae show significant differences in their percent covers at the sites where they are present.

Live Porites Average Percent Cover of at the five different sites 25 Por. 20 15 percent 10 5 Vaipahu NW Opunohu NE Cooks NW Cooks NE Opunolta site

Figure 4. The dominant live coral, *Porites*, shows significant differences in its percent cover at the five sites.

Average Percent Covers of Sand and Pavement at the five sites

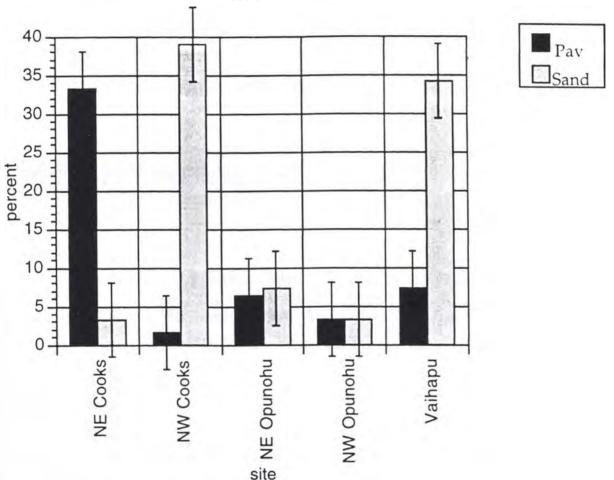


Figure 5. The percent covers of both sand and pavement are significantly different at the various sites.

Scatter Plot of Percentages of Live Porites and Turbinaria

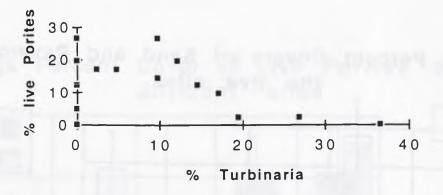


Figure 6. The negative correlation between percentages of live *Porites* and *Turbinaria* is nearly statistically significant (n=15, r=-0.47, r_{crit}=0.51).

Scatter Plot of Percentes of Live Porites and Dictyota

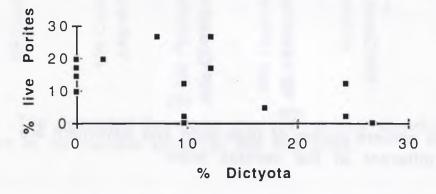


Figure 7. The negative correlation between percentages of live *Porites* and *Dictyota* is nearlty statistically significant (n=15, r=-0.48, r_{crit}=0.51).

Scatter Plot of the Percentages of Live Porites and Red Filamentous Algae

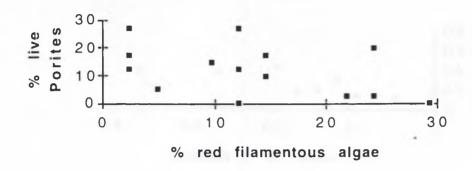


Figure 8. The negative correlation between percentages of live Porites and red filamentous algae is nearly statistically significant (n=15, r=-0.34, r_{crit} =0.51).

Scatter Plot of Percent Red Filamentous Algae and Number of Damselfish

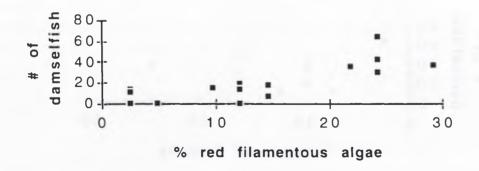


Figure 9. The positive correlation between percent cover of red filamentous algae and number of damselfish is significant $(n=15, r=0.80, r_{crit}=0.51)$.

Scatter Plot of Percent Turbinaria and Number of Damselfish

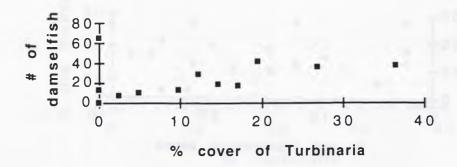
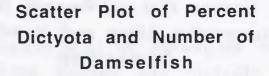


Figure 10. The positive correlation between percent cover of Turbinaria and number of damselfish is nearly statistically significant (n=15, r=0.45, r_{crit} =0.51).



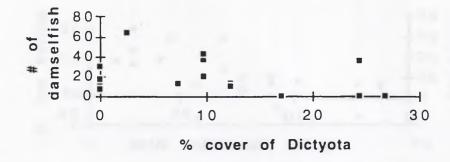


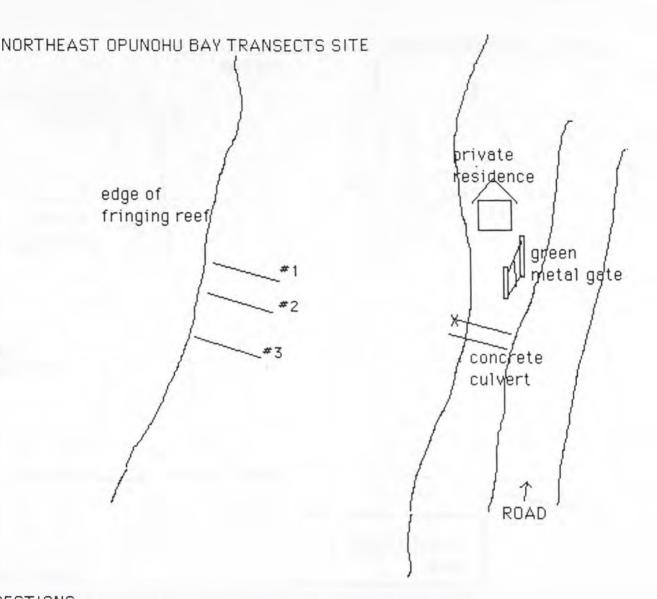
Figure 11. The negative correlation between percent cover of *Dictyota* and number of damselfish is nearly statistically significant (n=15, r=-0.33, r_{crit}=0.51).

APPENDIX

DIRECTIONS

- 1. Benchmark #1 corresponds to transect #1, and is 5m south of the concrete culvert. Transect #1 is 43deg. NE from benchmark #1.
- 2. Benchmark #2 corresponds to transect #2, and is 16m south of the concrete culvert. Transect #2 is 35deg. NE from benchmark #2.
- 3. Benchmark #3 corresponds to transect #3, and is 9m southeast of benchmark #2. Transect #3 is 38deg. NE from benchmark #3.

NOTES: Volleyball and soccer fields are just north of site, on other side of road.



DIRECTIONS

- 1. All transects are benchmarked to the north wall of the culvert.
- 2. Transect #1 has a bearing of 278deg. from benchmark, and a NW bearing along the transect of 270deg.
- 3. Transect #2 has a bearing of 250deg. from benchmark and a NW bearing along th transect of 250deg. as well.
- 4. Transec #3 has a bearing of 225deg, from the benchmark and a NW bearing along the tansect of 260deg. (Trans#3 is approx 20m south of culvert)

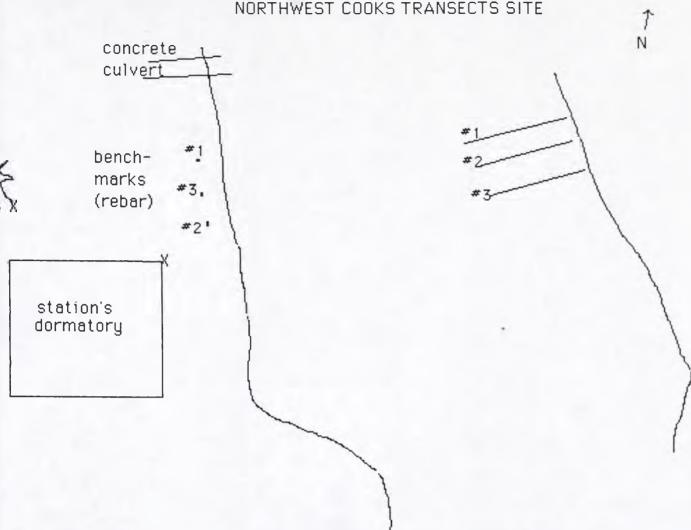
NOTES: The culvert is about 0.3km south of 16km road marker, and 2m south of a green metal fence.

Hotel

DIRECTIONS

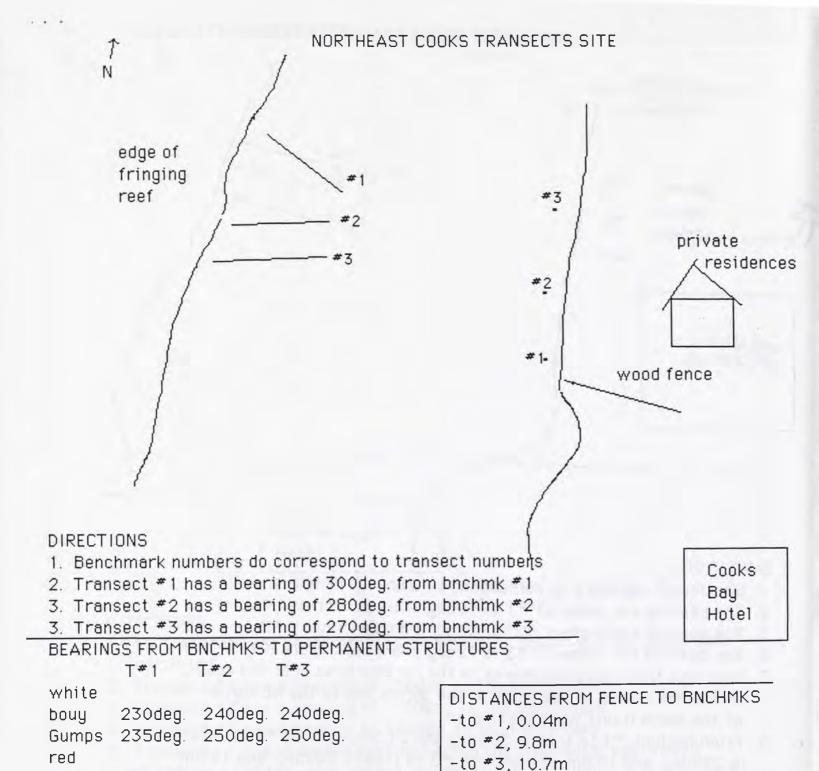
- 1. All transects are benchmarked to the white channel marker from their north end.
- 2. Transect #1 has a bearing of 160deg, to the benchmark
- 3. Transect #2 has a bearing of 170deg, to the benchmark
- 4. Transect #3 has a bearing of 180deg, to the benchmark
- 5. Transects 1,2, and 3 have bearings along the transects, southward of 160deg., 150deg., and 155deg. respectively

NOTES: Transects are about 50m south of marker, and 400m north of Moorea Lagoon Hotel.



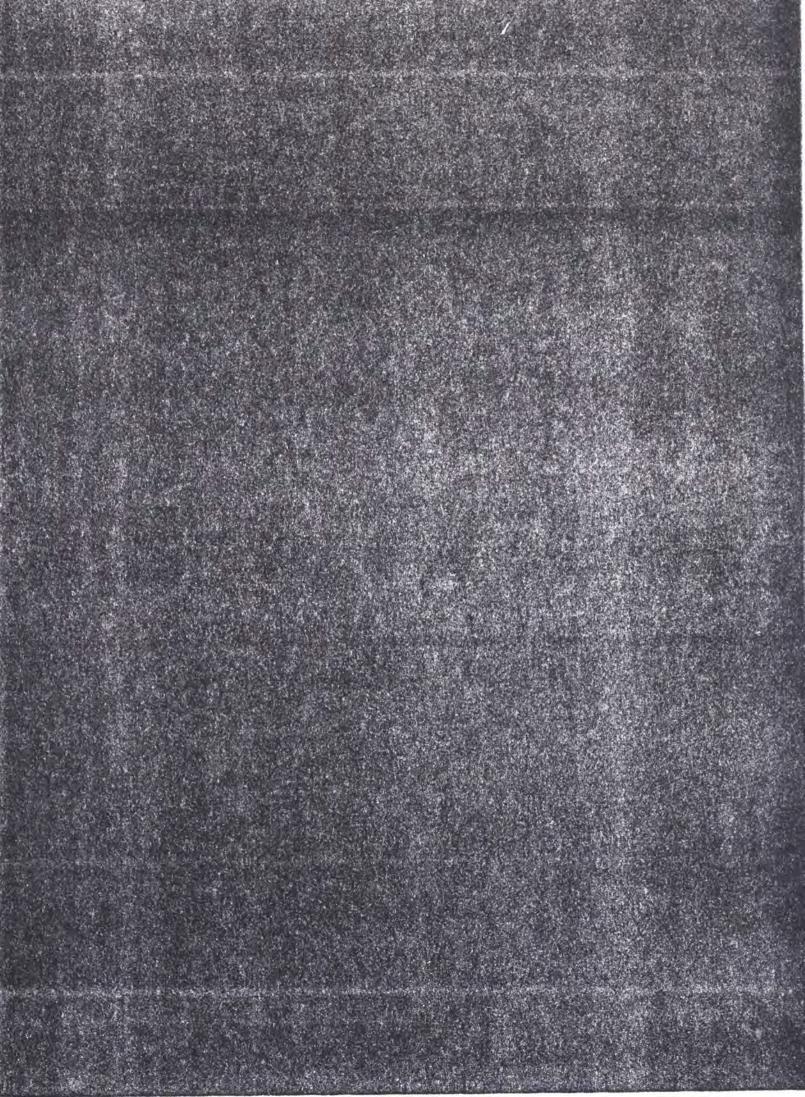
DIRECTIONS

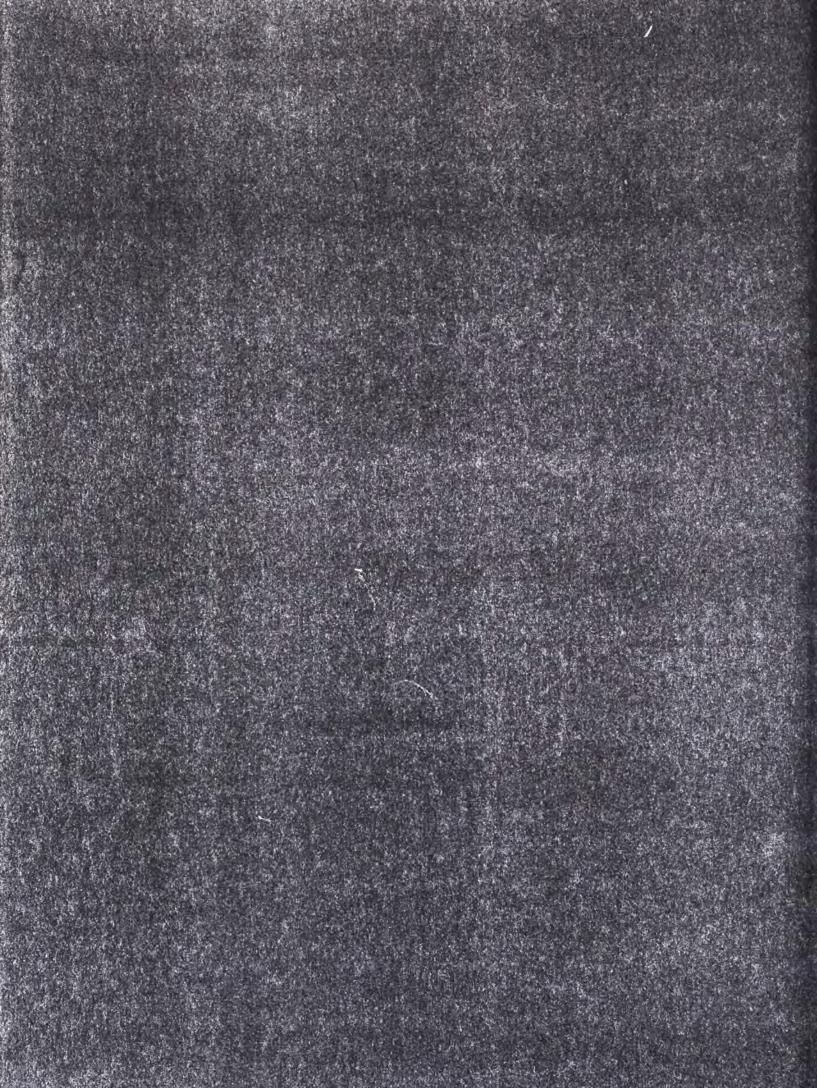
- 1. Benchmark numbers do correspond to transect numbers.
- 2. The bearing for transect #1 is 70deg. from benchmark #1.
- 3. The bearing for tansect #2 is 68deg. from benchmark #2.
- 4. The bearing for transect #3 is 75deg. from benchmark #3.
- 5. Bearings from the benchmarks to the coconut tree near the road at the NW corner of the patio of the dorms and to the NE corner of the dorm itself were taken also.
- 6. From bnchmk #1 to tree is 225deg and 21.5m, bnchmk #2 to tree is 259deg. and 18.6m, and bnchmk #3 to tree is 243deg. and 19.5m.
- 7. From bnchmk #1 to dorm is 191deg. and 20.6m, bnchmk #2 to dorm is 200deg. and 14.4m, and bnchmk #3 to dorm is 204deg. and 16.5m.



350deg. 345deg. 345deg.

bouy





A POPULATION SURVEY: ECHINODERMS OF THE COOK'S AND OPUNOHU
BAYS OF MOOREA, FRENCH POLYNESIA

Russell Owen Iwanchuk

2735 Hillegass Ave., Berkeley, CA 94705-1256 Integrative Biology 158, Fall 1993 Abstract. Populations of four regular echinoid species (Phylum Echinodermata) were investigated in shallow shelf habitats at five sites on the northern shore of Moorea, French Polynesia (Latitude 17°30'S, Longitude 149°50'W). My intent was to determine whether there were any differences in echinoid density between the two bays present on this part of the island. Four of the sites were in the two bays on the northern shore, Opunohu and Cook's Bays, and one site was in the lagoon between the bays. The bay sites were placed such that the two sites in each bay were on opposing sides of the bay. All transects were established between the dates of October 22, 1993 and November 16, 1993.

Echinoids of the species *Echinometra mathaei* were the most abundant, and occurred with significantly highest density (per 40m² transect) at the northwestern Opunohu Bay site. Additionally, a significantly higher density of echinoderms was found in the NW Opunohu site than in any other. These differences in population density suggest a difference in habitat between some sites. In two data sets (*E. mathaei* and all echinoderms) the west side of each bay had a greater density than did the east side. This difference in density suggests a "parallel" system of bay water circulation.

INTRODUCTION

Of the class Echinoidea, composed of sea urchins, heart urchins, and sand dollars, sea urchins are referred to as regular echinoids (Maglitsch, 1972). Members of the class Echinoidea are important in the trophic systems of many marine littoral communities.

Glynn, et al. (1975), and Sammarco (1980) wrote that sea urchin grazing can affect aspects of marine plant populations, which can, in turn, affect marine animal populations.

In addition, the study of reef echinoderms is important since a change in their number can greatly affect community structure of reefs (Hughes, et al. 1987).

I observed regular echinoids in most, if not all, shallow-water habitats in Moorea's lagoon and bay regions. Of Opunohu and Cook's Bays, Cook's Bay has more human development around it. I thought it a possibility that the development's effect on urchin habitats might affect urchin population density.

The echinoid *Echinometra mathaei* is found in urchin-excavated holes, not much bigger than the echinoid's body and spines, in marine coral (maximum spine to spine diameter observed: ~10cm). They contribute to bioerosion—the ingestion of hard substratum (Lawrence & Sammarco, 1982). They feed primarily on algae (both live growing on the substrate and detrital washed into their burrows), but sponges, polyzoans, foraminiferans, molluscs, crustaceans, corals, and seagrasses have also been found in gut contents (De Ridder & Lawrence, 1982).

The echinoid *Diadema savignyi* is found during the day underneath coral heads adjacent to sandy substrate, when available, and grouped on the sand when no coral heads are available (maximum spine to spine diameter observed: ~30cm). This echinoid also contributes to bioerosion (Lawrence & Sammarco, 1982). During the night, they come out from under the coral heads to feed. Based on gut content analysis, this echinoid eats many organisms found on the bottom (De Ridder & Lawrence, 1982), including algae (Sammarco 1980).

The echinoid *Echinostrephus aciculatus* is a smaller (maximum spine to spine diameter observed: ~4cm) found in burrows that it seems to have rasped out as it grew, since the aperture of the burrow is too small for the animal to exit. This echinoid, too, contributes to bioerosion (Lawrence & Sammarco, 1982).

The echinoid *Echinothrix diadema* is found underneath coral heads and inside "caves" found within them (maximum spine to spine diameter observed: ~20cm). Based on gut content analysis, these echinoids eat algae and encrusting organisms (De Ridder & Lawrence, 1982).

Other echinoderms found in transects though not counted as separate species in this study were the echinoid *Tripneustes gratille*, the holothuroids *Holothuroidea dificilis* and *Bohadschia argus*, and the asteroid *Culcita novaeguineae*.

METHODS

Study system

The field study was conducted at five sites on the northern shore of Moorea, French Polynesia. Moorea is roughly triangular in shape, with each side approximately 12km in length. The bays are approximately 3km apart. It has an area of 13,237 hectares (Parks & Flenley, 1990).

The NW Opunohu Bay site was the deepest site, ranging in depth from about 1.5-3m. It also seemed to be the site that got the most wave action. There were massive coral heads here, and in places, there appeared to be some dead. The presence of massive coral heads made this site quite rugose: there were many "valleys" between heads. *E. mathaei* individuals could be seen burrowed into virtually every piece of coral rubble or coral head.

The NE Opunohu Bay site was fairly shallow, ranging in depth from about 0.3-2m. It was fairly calm here and seemed to get more of a freshwater input than did other sites, evidenced by the visible interface between the fresh- and saltwater. The site had smaller pieces of coral rubble, all covered by algae—mostly the coralline *Turbinaria* sp. Few urchins were apparent to the casual observer here due to the heavy algal cover. In

counting urchins here, I attempted to explore every possible urchin habitat, to avoid neglecting one due to algal cover. Damselfish were quite abundant.

The NW Cook's Bay site was off the property of the Richard B. Gump Biological Research Station. The depth here ranged from about 1-2m. The bottom was mostly loose sand and some silt, with scattered coral rubble and few live corals. The lack of live corals here could be a result of the observed silt, as corals respond adversely to a high sediment load (Rogers, 1990). *E. mathaei* could be observed burrowed into many of the pieces of rubble, and *D. savignyi* could be seen in aggregations underneath large pieces of coral rubble.

The NE Cook's Bay site was near the Baie de Cook Hotel. The depth here ranged from about 0.4-2m. The bottom consisted of coral rubble on a pavement substrate. Many surfaces were algae covered, but there were many *E. mathaei* seen and few *D. savignyi*.

The Vaipahu site was directly in front of the Moorea Lagon Resort. The depth was a fairly constant 2m or so. There were numerous massive coral heads present, mostly live. This site had the most impressive assemblage of echinoderms out of all the sites. *E. mathaei* were visible in bored holes in coral heads, *D. savignyi* and *E. diadema* were visible beneath coral heads.

Methods

At each study site except Vaipahu, three 20m transects were established on the shallow (0.5-3m) coral shelf around the perimeter of each bay. At Vaipahu, three 20m transects were established in the shallow (~3m) lagoon between the bays. At each study site, the transects were approximately parallel to each other and perpendicular to shore. They were no more than 4m apart at any site. They began at the drop off of the shallow shelf and continued shoreward (for 20m).

Along each 20m transect, 2m by 1m rectangular quadrats were established at 1m intervals, such that the 1m side was along the transect. This allowed a continuous 20m by 2m band transect to be sampled. Counts were made by species of all echinoderms found within each of the 20 quadrats per transect and immediately written down on a water-proof slate. The counts were accomplished by surface snorkeling accompanied by free diving where necessary.

Assumptions for ANOVA were not met (homogeneity of variances—see Table 2 for F_{max} values); therefore, the non-parametric Kruskal-Wallis test (Sokal & Rohlf, 1981) was used to determine whether mean urchin counts for each species differed significantly between sites. The Kruskal-Wallis test was also used with the counts of the remaining echinoderms found but not listed above, which were grouped together for the purpose of this study.

RESULTS

The Kruskal-Wallis test showed most echinoderm data sets to have mean counts of animals (Table 1) significantly differing between the five sites. All data sets were significant at the P < 0.05 level (one can confidently reject the null hypothesis of the means being equal), with the exception of the other echinoderms data (Table 2).

E. mathaei density (individuals per 40m²) was significantly greatest at the NW Opunohu site and significantly least at the NE Cook's site (Figure 1). Individuals were found at all five sites. *D. savignyi* density (individuals per 40m²) was significantly greatest at the Vaipahu site, while it could not be significantly determined which site had the least density (Figure 2). No individuals were found at the NE Opunohu site (Figure 2). *E. aciculatus* density (individuals per 40m²) was significantly greatest at the Vaipahu site and significantly second greatest at the NE Cook's site (Figure 3). No individuals were found at other sites (Figure 3). The significantly greatest density of *E. diadema*

occurred at Vaipahu (Figure 4). No individuals were found at any other site (Figure 4). Other echinoderms were found at all sites except NW Opunohu (Figure 5). It could not be significantly determined which site had the greatest densities (individuals per 40m²) of other echinoderms (Figure 5). The greatest echinoderm density (counting all species) occurred at the NW Opunohu site (Figure 6).

DISCUSSION

The data fall into some interesting patterns if one studies the figures. The *E. mathaei* data indicate higher densities in transects in Opunohu Bay than in Cook's Bay (Figure 1). This could very well be the result of more development in Cook's Bay, which leads to higher sediment and/or pollution levels, which could lead to decreased urchin densities, perhaps by limiting a food source, such as algae (De Ridder & Lawrence, 1982). It is also a possibility that the sites sampled are not accurate reflections of the whole of the bays, and the higher density is a regional effect. Another possible reason for the difference in densities is a difference in available habitat space or a difference in the community structure of the habitat. If the Opunohu Bay had more available habitat, i.e., coral appropriate to the burrowing behavior of this urchin, then one would expect densities to be higher. Additionally, if predation were lower in one site, one would expect higher densities there.

Figure 1 also shows that *E. mathaei* densities are greater on the NW side of each bay than on the NE side. This suggests some difference in the habitats between the sides of both bays. A reason for this could be differing nutrient availability to each side, possibly resulting from an effect of current within each Bay. If this be the case, the data suggest that the current circulation in each bay is "parallel", that is, that they both circulate either clockwise or counter-clockwise.

D. savignyi densities were smaller in Opunohu Bay than in Cook's Bay, while they were greatest in the lagoon between bays (Figure 2). Again, this is likely the result of the bays having differing habitats, whether it be a result of differing substrate or community structure. This urchin also has a greater density on the NW side of each bay than on the NE side, possibly for the same reasons as mentioned above.

E. aciculatus was absent at three of five sites (Figure 3) and E. diadema was absent at four of the five sites (Figure 4). Again, this could be due to a lack of available habitats in those three sites or the presence of a particular predator affecting either of these urchins and not E. mathaei or D. savignyi. It is possible that a physiological constraint plays a role, as the Vaipahu site is likely to have a higher salinity than any of the bay sites.

The densities of echinoderms found in the bays were greatest at the NW sites (Figure 6), again suggesting that the bays have some habitat difference between sides of the bays, perhaps for the reasons mentioned above.

There are a few studies that could be pursued to further explore the populations of echinoderms, and specifically, echinoids in Moorea. It would be interesting to study an echinoid species' survivorship and behavior in sites in which they were not naturally found by this study. An example is a transplant experiment of *E. diadema* into any of the sites other than Vaipahu. It would help determine whether they are actually restricted to Vaipahu, perhaps by physiological constraints, predation, lack of food, or some other factor. If they thrive in other sites, it could be that there is a dispersal barrier between sites and island biogeography would come into play.

Another such study would be to investigate if water circulation is indeed what causes the difference in *E. mathaei* densities from the west to the east sides of both bays. One could start by mapping currents in the bays, to get a general idea of the circulation.

An controlled experiment could then be carried out in which urchins have as many factors of their natural habitat as possible, including substrate, predators, and food sources—different habitats reflecting the differences between sides of the bay would be necessary. One could then keep constant the water flow and nutrient input between the two experimental conditions. If it is possible to control enough of the variables, which seems difficult, one might conclude that the circulation of the bays is responsible for density differences.

ACKNOWLEDGMENTS

I thank K. Bickel, J. Goldman, S. Smith, and B. Sakagawa for their invaluable help in collecting data for this project, and J. "Mike" Daniels and M. Power for their help in compass-sighting the sites from land. Thanks also to M. Power, F. Booker, and T. Krantz for their help in guiding the design of the project and to M. Power again for editing the first draft. The Richard B. Gump South Pacific Biological Research Station of the University of California at Berkeley provided research facilities and materials.

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TABLES

TABLE 1. Mean urchin counts per 40m^2 transect \pm 1 SE

Genus		Site			
species	NW Opunohu	NE Opunohu	NW Cook's	NE Cook's	Vaipahu
E. mathaei	$3().33 \pm 22.00$	22.00 ± 2.08	53.00 ± 19.01	15.00 ± 4.73	50.00 ± 3.51
D. savignyi	0.33 ± 0.33	()	6.00 ± 2.08	1.33 ± 0.88	24.33 ± 7.26
E. aciculatus	()	()	()	0.67 ± 0.33	3.67 ± 1.76
E. diadema	0	()	()	0	9.33 ± 0.33
other	()	0.33 ± 1.33	$1.()() \pm ().00$	1.33 ± 0.88	0.33 ± 0.33
all	130.67 ± 21.98	22.33 ± 2.33	60.00 ± 50.60	18.33 ± 3.84	87.67 ± 9.49

TABLE 2. Results of F_{max} test for homogeneity of variances ($F_{max} = 0.05[5.2] = 202$) and

Kruskal-Wallis	non-parametric tes	$t(\chi^20.05 4)$	= 9.49).
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	· · · · · · · · · · · · · · · · · · ·			
Genus species	$s^2_{\text{max}} / s^2_{\text{min}}$	Р	H/D	Р
E. mathaei	111.7()	< ().()5	10.13	< ().()5
D. savignyi	div by ()	> ().()5	12.15	< 0.05
E. aciculatus	div by ()	> ().()5	11.64	< ().()5
E. diadema	div by ()	> ().()5	13.85	< ().()5
other	div by ()	> ().()5	6.22	> ().()5
all	8.89	< ().()5	10.30	< 0.05

FIGURES

FIGURE 1. Mean count per 40m² transect of individuals of *E. mathaei* counted at the five sites (+1 SE).

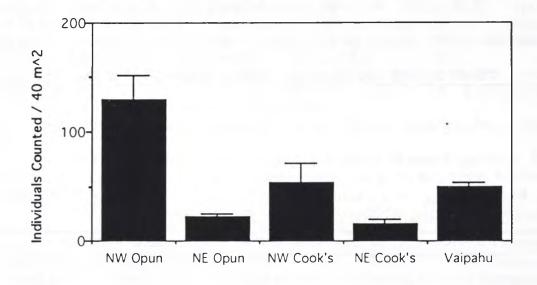


FIGURE 2. Mean count per 40m^2 transect of individuals of D, savignyi counted at the five sites (+1 SE).

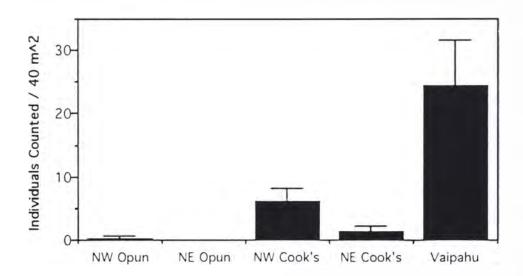


FIGURE 3. Mean count per 40m^2 transect of individuals of *E. aciculatus* counted at the five sites (+1 SE).

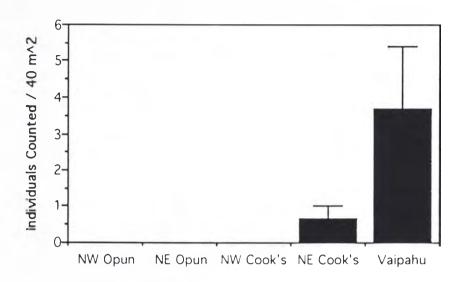


FIGURE 4. Mean count per 40m^2 transect of individuals of *E. diadema* counted at the five sites (+1 SE).

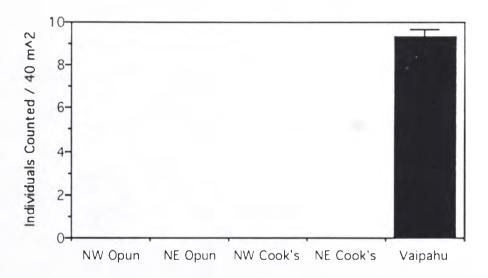


FIGURE 5. Mean count per 40m^2 transect of individuals of other species counted at the five sites (+1 SE).

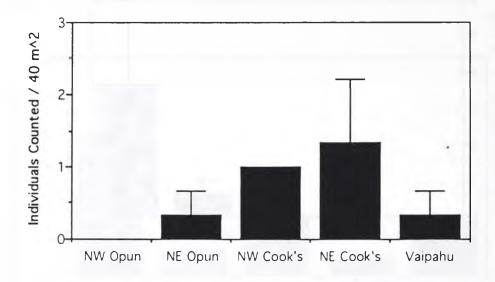
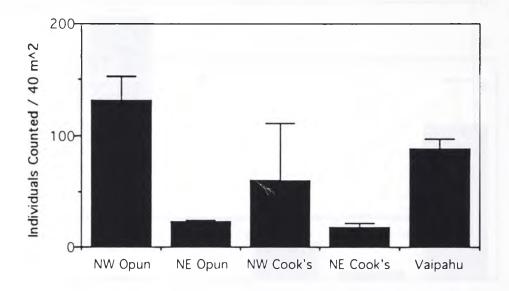
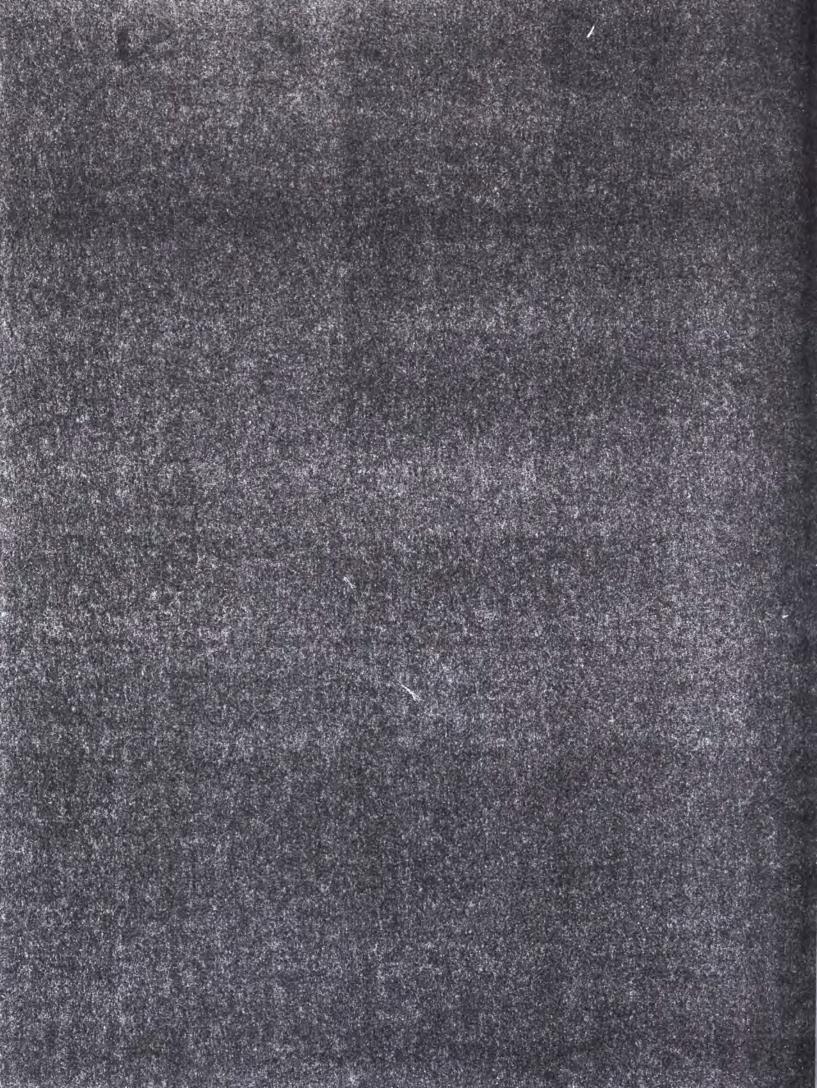


FIGURE 6. Mean count per 40m^2 transect of individuals of all echinoderms counted at the five sites (+1 SE).





The Effects of Sedimentation on the Fungiid Coral, Fungia scutaria

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ABSTRACT

Around the island of Moorea, French Polynesia (149° W. longitude, 17° S. latitude), Fungia scutaria experience stress due to sedimentation. The size of the particles in the sediment and the sediment load on the corals are both important factors which determine the amount of stress experienced by the individuals. In addition, the turbidity of the water influences the amount of stress experienced by these organisms. Intermediate particle size (500 microns - 4 millimeters) is the most detrimental to these organisms, followed by large particles (>4 millimeters), then small particles (< 500 microns). When these intermediate sized particles become lodged between the hard, radiating striations of the coral, they cannot be removed by the organism and cause death in the immediate area. This factor is more important in determining fungiid mortality than are predators.

INTRODUCTION

Upon observing the *F. scutaria* on the fringing reef around the island of Moorea, the question arises as to what limits the distribution of this species. Clearly these corals rely on photosynthesis, and therefore any factor which limits this will also limit these corals. Sedimentation is such a phenomenon (Rogers, 1990), and the increasing development of coastal lands creates large sediment loads on the fringing reef community. The effect of sedimentation, arising from hotel activity, land development, and also deposition by rivers upon emptying into the bay, is the central question investigated during this study. It is proposed that the make-up, particularly the size fractions, of the sediment will determine the degree to which the organisms will be affected by it. Different size particles will have varying effects on the fungiids, and it is the aim of this study to determine the size at which particles are most injurious to fungiids and the sizes which may be acceptable for fungiid growth.

STUDY SITES

In order to evaluate each of the three sources of sedimentation described, it was necessary to set up a site at three different location, one of each type, plus a site controlled for sedimentation. One site was placed near the point of outflow of effluent into Cook's Bay from the Baie de Cook Hotel (Figure 1), as the discharging of effluent not only contributes to suspended sediment but also stirs up sediment from the bottom of the bay. A second site was maintained adjacent to the Gump Research Station (Figure 2), which experiences increased sedimentation due to the altered topography of the land and the prevailing currents in the bay, not to mention the activities of humans at the station. A third site was placed near the mouth of the Opunohu River (Figure 3), close enough so that it would be influenced by the river's sediment load yet far enough so that a depth within the observed range for naturally occurring fungiids could be maintained. The fourth site, the control, was located in the northwest region of Opunohu Bay (Figure 4), because this area is representative of a typical fungiid community where sedimentation levels do not exclude these corals.

METHODS AND MATERIALS

The study was done during November, 1993, which is the beginning of the rainy season for French Polynesia. At each site, three transects were set up approximately five meters apart. Along each transect, three individual *F. scutaria* were placed at a depth consistent with the observed depth of fungiids around the two bays under examination (i.e., between 1 meter and 8 meters deep) (Table 1) in a north/south orientation. Where

possible, the study organism were placed within an existing fungiid community; that is, all sites except the Opunohu River site, where none could be found. These fungiids were arbitrarily selected, based upon an observed high level of living areas, from south of the Northwest Opunohu site, and were between 76 and 120 millimeters in diameter. All were handled in the same manner, which consisted of placing the corals in a collection bag, then into a tank for transport back to the lab, where they were placed into a holding tank for one day. They were then transported to a study site in a tank, which took between thirty and seventy-five minutes. Before putting the corals in place, a sketch was made of each individual representing the area of the coral which was originally living and healthy. Photographs were also taken of each individual for comparison with the sketches. The three fungiids for each transect were arranged in the following manner: 1) the northernmost, caged (with a strawberry basket) to control for predation; 2) the central coral, left uncaged; and 3) the southernmost, covered with a cage which had two sides removed to control for the effects of the cage (Figure 5).

Every few days (between three and five), observations were made as to the degree of mortality of the corals, any predation or other organismal interactions occurring, and any other environmental factors which appeared relevant. On these days, Secchi disk readings were taken (according to the procedure taken from Wetzel, 1975) to determine the relative turbidity of the water in which the corals were placed. A standard reading was taken each day in the middle of Cook's Bay in order to place the readings on a uniform scale so that comparisons could be made.

Temperature readings were also taken periodically to determine if the water was within an acceptable range for corals.

At the Baie de Cook Hotel site, water samples were taken during the course of an effluent discharge cycle at a depth of 0.5 meters and analyzed using kordon® Aquatru™ water test kits for ammonia, nitrate, and nitrite concentrations to determine if an increase in these occurs at these times. Each sample was analyzed after sitting in a capped plastic bottle for ten hours. Samples were also taken from the other sites and analyzed for comparison with one another.

A count of naturally occurring fungiids was taken around each of the two bays (Figure 6) by setting up transects perpendicular to the shore at each kilometer marker beginning with pk number 6 and running continuously to pk number 22. The transects began at the distance from the shore where the first fungiids were encountered, and ran for a length of ten meters. An area was marked off 10 meters out from the line perpendicularly on either side, giving a total area of 200 square meters to be searched. A total of 20 minutes was spent counting all visible fungiids, without overturning any debris or organisms. This count was done in order to assess the validity of the study sites as viable locations for normal growth of fungiids, and also to determine what the depth range was for naturally occurring fungiids (Table 1).

Sediment samples were obtained from the bottom of the bay at each study site so as to represent the typical suspended sediment during a disturbance event. They were stored in capped plastic jars for 12 days and returned to Berkeley, where they were wet sieved (according to the procedure taken from Folk, 1974) using sieve numbers 5 (4 millimeters), 18 (1 millimeter), 35 (500 microns), 60 (250 microns), 120 (125 microns), and 230 (63 microns). They were then grouped into three size classes for analysis: 1) small (< 500 microns), 2) medium (500 microns - 4

millimeters), and 3) large (>4 millimeters). These size classes were determined by measuring the distance between striations of eighteen fungiids, two individuals from each of the transects used to map the fungiid density around the bays where individuals were found. The measurements were taken at the smallest and largest distances between striations along three arbitrarily determined sets of striations on each individual, and the fifty-four values for the smallest and for the largest were then averaged (Table 2). The particle sizes were then chosen by selecting the sieve whose size was the closest to the average, yet outside of the range. Percent make-up of the sediment for these three classes was then determined for each sample.

At the end of the study, the corals were removed, sketches were made in the same manner as before, and photographs were again taken so that percent mortality of each individual could be determined. To do this, the shape of each fungiid was approximated to a circle, and total area was calculated. From the original sketches, the dead areas were measured and areas calculated by approximating shapes of the dead areas to regular geometric shapes or combinations of shapes. This area was then subtracted from the circular area to obtain the total living area of the individual at the outset of the experiment. From the final sketches, the same method was used to obtain a value for the total living area after the study, and the difference between the two was taken to be the mortality induced by the experiment. In order to obtain an estimate of a normal rate of mortality, measurements were taken of individuals not included in the study at each site (except the Opunohu River site), both before and after the experiment. Three fungiids were chosen arbitrarily at each site for this purpose.

RESULTS

At each site, sediment was deposited on the corals, and in fact accumulated to a certain degree. However, these accumulations were dynamic, changing shape constantly as a result of currents and organismal disturbances. Observations of these sites of accumulation did not correspond with the sites of mortality observed.

The Secchi disk readings of the water turbidity (Table 3) showed the highest clarity at the control site of Northwest Opunohu Bay, which averaged 81 percent of the standard. At the Baie de Cook Hotel site, the readings averaged 70 percent of the standard depth. At the Gump Station site the average water clarity was 61 percent of the standard. The readings at the Opunohu River site give a value of 28 percent of the standard; however, the depth at this site did not always allow for a true reading because the Secchi disk reached the bottom before disappearing on certain occasions and therefore the readings could only be taken to be greater than that depth in those cases. Hence, the average value of 28 percent is a low-end estimate of the actual turbidity at this site. The temperature of the water at each site remained within 3° Centigrade of that at the other sites, and within the optimal range of 25°-29° Centigrade for corals (Vaughn, 1919).

Upon analysis of the water samples obtained from each site, nearly all samples were below the detectable limits of the tests (i.e., 0.0 milligrams per liter for ammonia, 35 milligrams per liter for nitrate, and 0.15 milligrams per liter for nitrite). The exceptions were the two samples taken immediately following effluent discharge at the Baie de Cook Hotel. These samples gave readings of 0.2 - 0.4 milligrams per liter of ammonia, and were below detectable limits for nitrate and nitrite (Table 4).

The analysis of the sediment breakdown into the three size classes showed that the Gump Station site had the highest amount of the intermediate sized particles as a percentage, at 89 percent. The second highest percentage of this size class was at the Baie de Cook Hotel site, which had 84 percent of the sediment within this range. The test site with the lowest percentage of this size class in its make-up was the Opunohu River site, where it made up 78 percent of the sediment. The control site of Northwest Opunohu contained 75 percent intermediate sized particles in its sediment (Table 5).

The greatest mortality (i.e., the difference between the original amount of living area and the amount of living area at the conclusion of the experiment) (Table 6) was experienced at the Gump Station site, with 42 percent of the originally living coral dying by the conclusion of the study. The next greatest was at the Baie de Cook Hotel site, at 36 percent mortality. The lowest mortality of the three treatments was 23 percent, experienced by those individuals at the Opunohu River site. The control site corals underwent 14 percent mortality, and the untreated corals gave a calculated value of 4 percent, although visual observations did not indicate that an appreciable amount of mortality had occurred.

DISCUSSION

The fact that certain amounts of sediment accumulated on each individual appears to be insignificant in the determination of mortality because these were constantly moving, covering and uncovering different areas. Short term accumulation seems to be less important than long term turbidity with regards to mortality (Marszalek, 1981), as suggested by the

finding that the more turbid a site was, the greater the mortality experienced there (Figure 7), while sites of accumulation did not necessarily correspond to sites of mortality. It is important to note that the organisms at the control site also experienced an appreciable degree of mortality, which gives a value for the mortality induced by the handling and transporting of the corals. The fact that measurement and calculation gave a positive value of mortality for fungiids which were not exposed to this handling and transportation suggests that this value gives the error inherent in the method used for determination of mortality. Hence, it is likely that the calculated figures for mortality are approximately 18 percent higher (14 percent due to handling and transportation plus 4 percent due to error) than the actual mortality induced by the treatments

Anything which shades a photosynthesis-dependent organism for a prolonged period of time will have the same detrimental effect that turbidity has, such as algal overgrowth. The increased nitrogen levels (and, likely, other nutrients) at the Baie de Cook Hotel site create a perfect environment for red filamentous algae, which was found overgrowing the cages used in the experiment at this site. This was constantly removed in order to keep this site consistent with the other sites, where this did not occur. The increase in nitrogen levels appears to have no other effect on the study here.

The analysis of the size make-up of the sediment shows that mortality is the greatest when the size is such that the particles can become lodged between the hard striations of the organism (Figure 8), thus making them impossible for the individual to remove. Similar results have been reported (Smith, 1984), supporting these findings. This effect may be due to the fact that these particles serve to permanently block out light,

affecting the ability of the organism to photosynthesize, or it may be that the organism expends so much energy trying to remove the particle that it dies in the effort. Another possibility is that the individual sacrifices this region, allotting little if any resources to it because it is not cost-effective.

Upon comparing the data obtained on mortality for the whole of the organisms at each site to a breakdown of the data based on the three types of treatment at each site, no significant differences were seen. This indicates that predation was of little consequence to the outcome of the study. It also indicates that the cage itself did not alter significantly the effects of any of the treatments (Table 7).

In the analysis of the water samples, only levels of nitrogen could be evaluated due to the lack of means by which to quantify other nutrients. Also, only one set of samples could be analyzed due to a lack of materials for repeated sampling sets. More equipment and supplies would serve to increase the data and knowledge in this area.

Because of the short time period over which the study was conducted, caution should be exercised when trying to generalize about the results. It may be that over a longer time frame the organism may be able to adjust to its environment, and that the rate of acclimatization to each treatment is the only factor exposed by this study. Likewise, there may be some genetic basis for the results obtained, whereby a certain sub-species or strain may be better able to withstand the stresses induced here. If this is the case, it is possible that over generations the organism will evolve devices or changes in morphology which will enable it to cope with the problems induced by sedimentation quite well, to the point where it is not a problem. This question can only be answered by repeated, long term studies.

The fact that so few individuals were included in the study introduces problems related to small sample sizes. In this case, anomalous data can go unrecognized, and deviations are introduced into the data. A larger scale experiment is needed to address these issues.

The findings of this study are nonetheless alarming. If future experiments support the findings reported here, then the fate of these and other organisms lying within the same region may be viripation. In order to slow this process, land use practices must be reevaluated and people must be instructed in ways to more intelligently interact with our environment. By doing this the best use of the Earth and its resources can be determined not in terms of the interests of humans alone but in terms of the interests of all living things.

ACKNOWLEDGMENTS

I would like to thank Dr. Mary Power for her help in defining the scope of my study; Dr. Roy Caldwell for his help in choosing a suitable organism for examination; Fred Booker and Tim Krantz for their advice and technical support throughout the course of the experiment; the Antenne Museum for literature and maps; Lisa Wells for the use of her laboratory; and Michelle Goman for her assistance in analyzing the sediment samples. Most importantly, my sincere thanks and appreciation go to Lisa M. Angeloni, Larry Bernstone, and Stacey Leanne Smith for their continual aid and support, without which this experiment would never have been possible.

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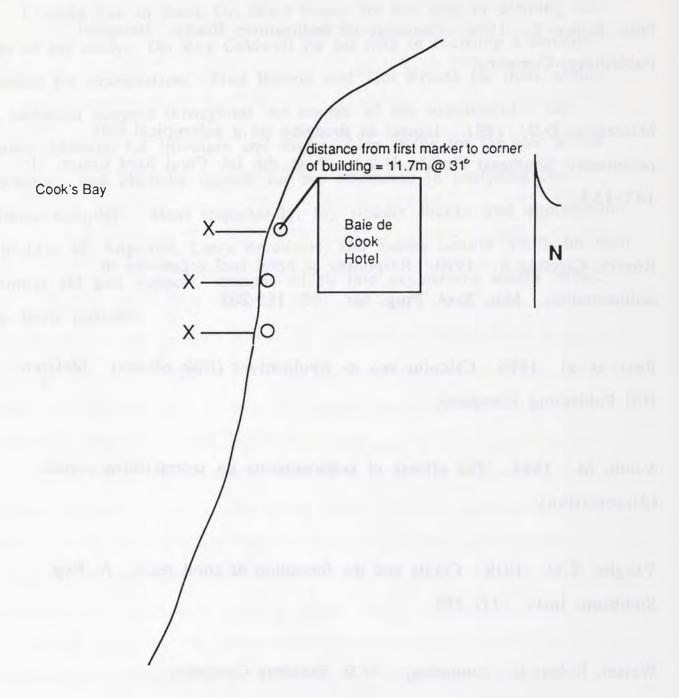
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Figure 1. Baie de Cook Hotel



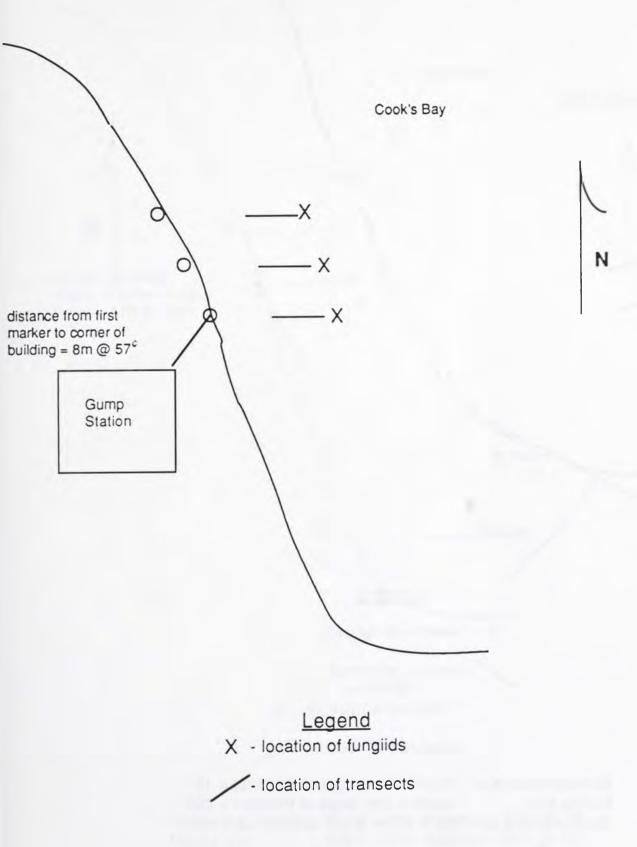
Leaend

X - location of fungiids

- location of transects

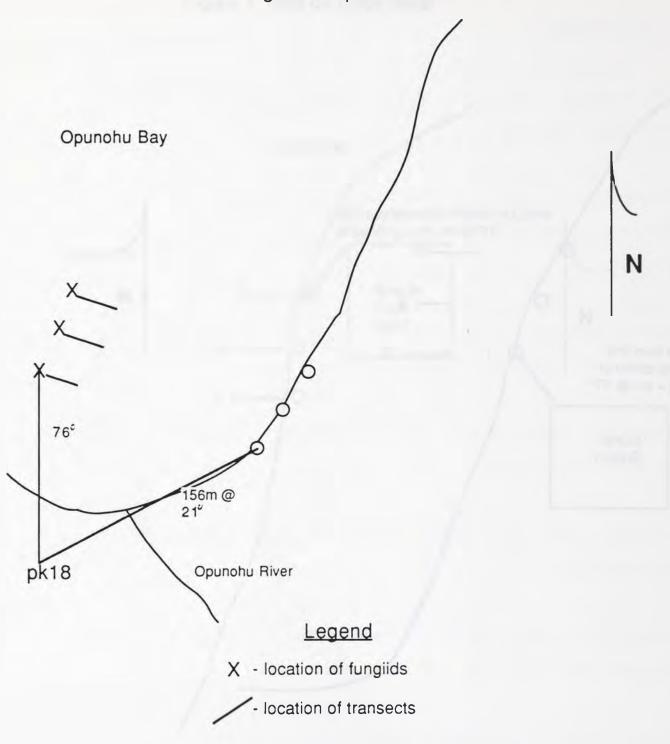
Northernmost site: depth = 3m; distance = 6.9m @ 188° Middle site: depth = 4m; distance = 7.6m @ 185° Southernmost site: depth = 5m; distance = 8.0m @ 189°

Figure 2. Gump Station



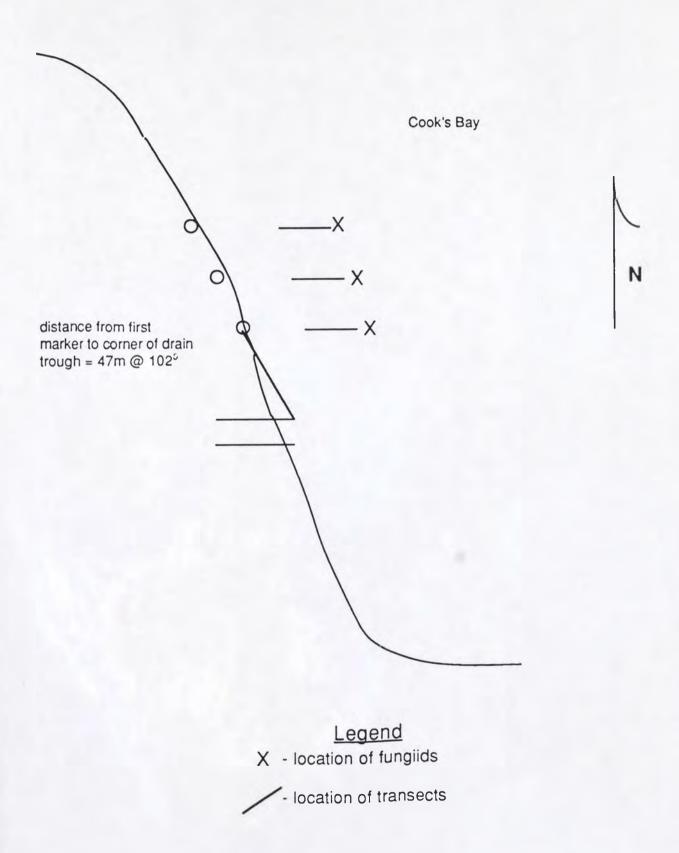
Northernmost site: depth = 4m; distance = 28m @ 11° Middle site : depth = 3m; distance = 29m @ 6° Southernmost site: depth = 3m; distance = 31m @ 9°

Figure 3. Opunohu River



Northernmost site: depth = 3m; angle of transect = 154° Middle site: depth = 3m; angle of transect = 162° Southernmost site: depth = 3m; angle of transect = 160°

Figure 4. Northwest Opunohu



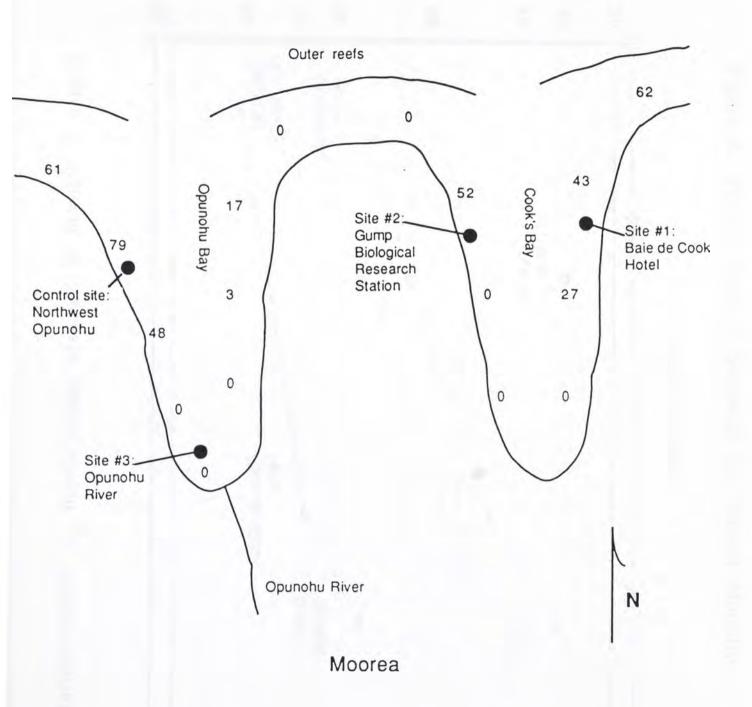
Northernmost site: depth = 4m; distance = 38m @ 36° Middle site: depth = 5m; distance = 36m @ 32° Southernmost site: depth = 3m; distance = 41m @ 30°

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OF FINCHS AT CITES SET UD FIGURE S



Figure 6. Distribution of *Fungia scutaria* in Cook's and Opunohu Bays, Moorea, French Polynesia.



Numbers indicate count of fungiids given by searching an area of 10 meters by 20 meters for 20 minutes without overturning any debris. The searches were conducted at 1 kilometer intervals at the pk markers set along the circum-island road and were begun at the distance from the shore where the first fungiid was found along the transect leading perpindicularly from the shore at the marker.

% Standard Seoch Depth (m)

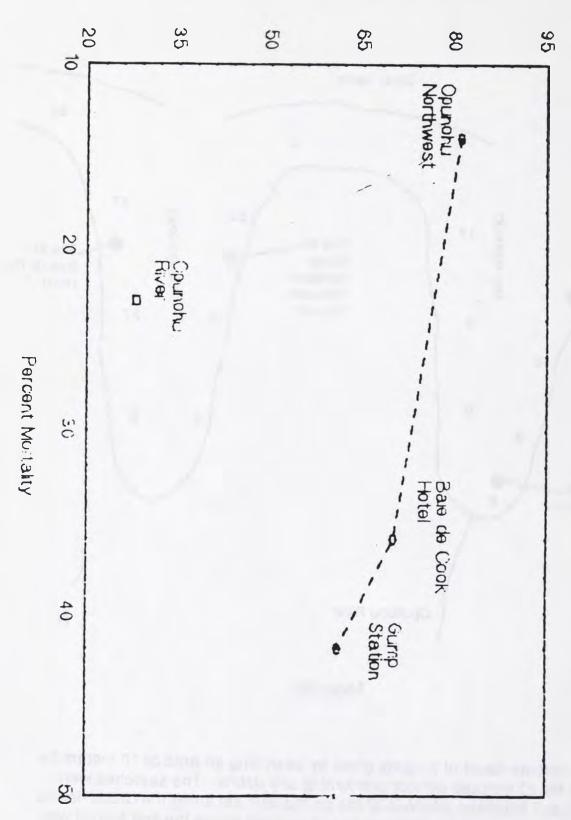


Figure 7. Percent of Standard Secchi Depth vs. Percent Mortality.

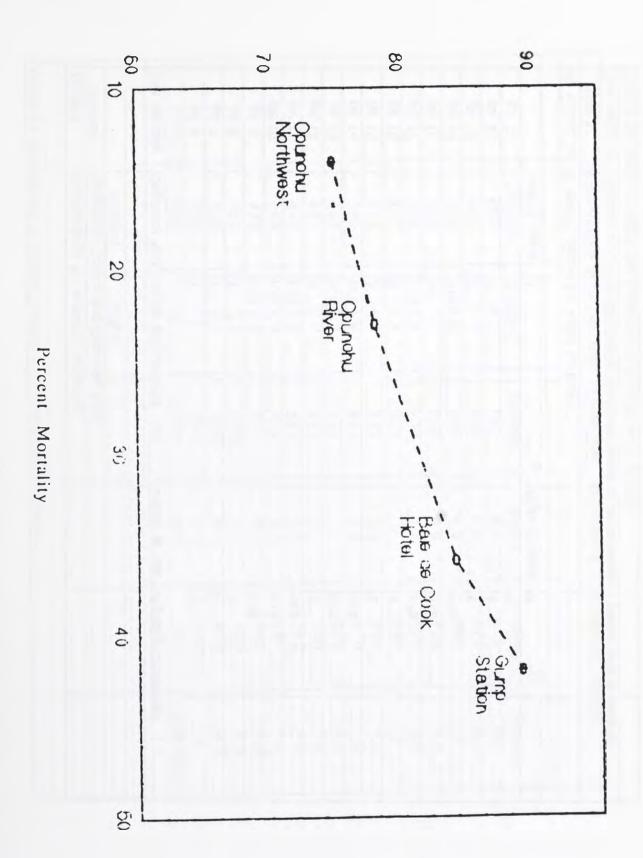


Figure 8. Percent Sand in Sediment vs. Percent Mortality.

	funglids in Cook's and Opunohu bays	bays.
Site number	Depth of first funglid encountered	red Depth of last funglid encountered
pk 7	-	S
	-	ω
pk o	n/a	n/a
	מ מי	n/a
	n/a	n/a
	2	ω
	n/a	n/a
pk 14	n/a	n/a
pk 15	3	5
pk 16	2	4
pk 17	n/a	n/a
pk 18	n/a	n/a
pk 19	n/a	n/a
pk 20	2	6
pk 21	2	8
pk 22	2	5
	lowest value: 1	highest value: 8
All values are	in meters below the water surface	ace.
The range for	for naturally occurring fungilds is	
	The state of the s	OC DOMOCOLL LINGS

				0.35	27.4	s.d.
				4.2	484	average
				largest	smallest	
4.4	455	4.5	486	4.2	487	18
4.5	487	4.3	478	4.1	456	17
4	432	3.8	463	4	506	16
3.7	478	4.1	496	4.3	533	15
4.9	503	4.2	476	3.6	452	14
4.3	493	4.4	511	3.8	476	13
4.2	481	4.4	502	4.3	496	12
4.6	512	4.5	463	3.9	446	1
4.5	503	4.1	487	3.7	477	10
4.1	522	4	498	3.7	467	9
4.2	470	4.2	467	4.6	560	8
4.1	490	ယ	542	4.5	513	7
4	495	5	532	3.4	467	6
3.8	468	3.7	437	3.8	454	5
4.1	498	3.6	522	4.3	423	4
4	463	4.5	506	4.5	498	ω
4.2	478	4.8	476	4.2	476	2
3.8	456	4.1	487	4.3	457	-
largest	smallest	largest	smallest	largest	smallest	
	ω		2			

sk read	ings taken at	SIDDY SILES DE	W 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
	Baie de Cook	Gump Station	Opunohu River	NW Opunohu
5	n 10/			85%
10.6	0/. I C			0000
8.1	70%			
6.9		86%		102%
9.8	78%			
9.1			33%	
11.9		45%		70%
8.6	91%			
7.5	53%		32%	
7.8		78%	0	73%
7.9	85%			
8.1			37%	
9	69%	81%	6 24%	
	63%	68%	6 18%	
12.4	70%	72%	35%	
12.4	1000	13.30%	6 9.20%	14.10%
	Standard Standard 10.6 8.1 6.9 9.8 11.9 8.6 7.5 7.8 7.9	sk readings taken at 10.6 S1% 8.1 70% 9.8 78% 9.1 11.9 8.6 91% 7.8 7.8 7.9 85% 8.1	sk readings taken at study sites bet and study sites bet state and study sites bet state and sta	readings taken at study sites between 03N0 Baie de Cook Gump Station Opunohu 0.6 51% 0.6 51% 0.8 78% 0.9 86% 0.9 45% 0.19 91% 0.5 53% 0.7.5 53% 0.7.8 73% 0.8 73% 0.8 78% 0.9 85%

Table 4.	Nitrogen Test Results of Water Samples Taken at Study	esuits of Water	Samples Take	n at Stud
	Sites Between 15NOV93 and 16NOV93	15NOV93 and	16NOV93.	
Site	Time	Ammonia	Nitrate	Nitrite
detectable limits of test		0.0 mg/L	<35 mg/L	< 0.15 mg/L
Gump Station	10:10pm	^	^	^
	11:10pm	0.2-0.4	٨	^
	12:10am	^	٨	^
	1:10am	^	٨	^
	2:10am	^	^	^
	3:10am	^	^	^
	4:10am	0.2-0.4	٨	^
	5:10am	^	^	^
	6:10am	^	^	٨
Cook's	10:10pm	^	^	^
	11:10pm	^	٨	^
	12:10am	^	٨	^
	1:10am	^	٨	^
	2:10am	^	٨	^
	3:10am	^	٨	^
	4:10am	^	٨	^
	5:10am	^	٨	^
	6:10am	^	^	٨
				-1

Table 4. (continued)				
Site	Time	Ammonia	Nitrate	Nitrite
detectable limits of test		0.0 mg/L	<35 mg/L	< 0.15 mg/L
Opunohu River	10:10pm	٨	^	^
	11:10pm	٨	^	^
	12:10am	^	^	٨
	1:10am	^	^	٨
	2:10am	^	^	^
	3:10am	^	^	٨
	4:10am	۸	^	^
	5:10am	^	^	٨
	6:10am	^	٨	^
NW Opunohu	10:10pm	^	^	^
	11:10pm	^	^	^
	12:10am	^	^	^
	1:10am	^	^	^
	2:10am	^	^	٨
	3:10am	^	^	^
	4:10am	^	^	^
	5:10am	^	٨	^
	6:10am	^	^	٨
Indicates that the sample was below detectable limits	e limits.			

Figure 5.a. Size fractions of sediment from Gump Station.

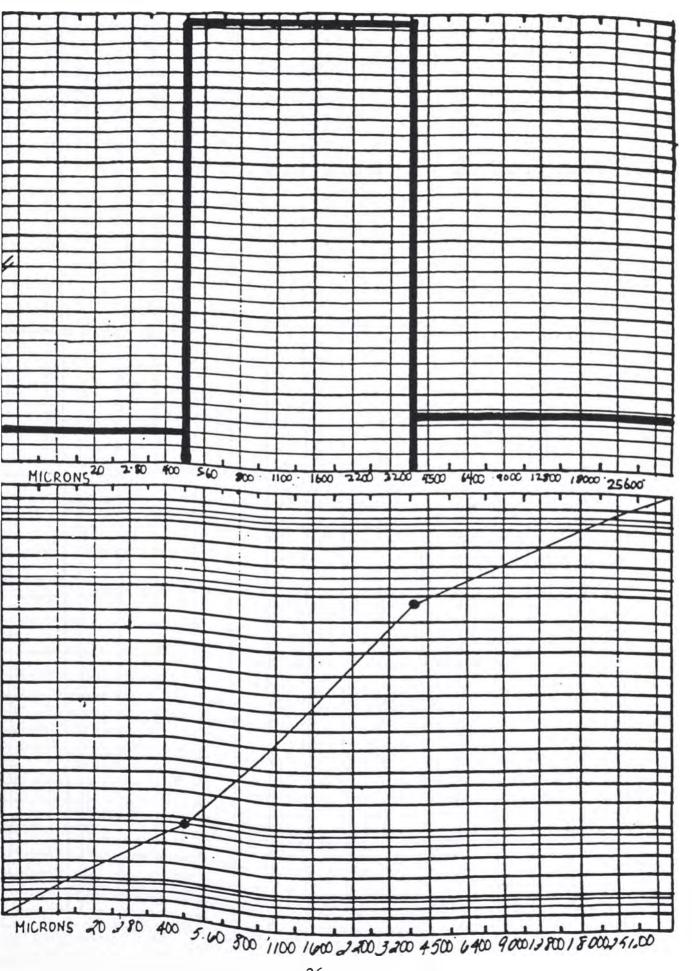


Figure 5.b. Size fractions of sediment from Cook's Bay.

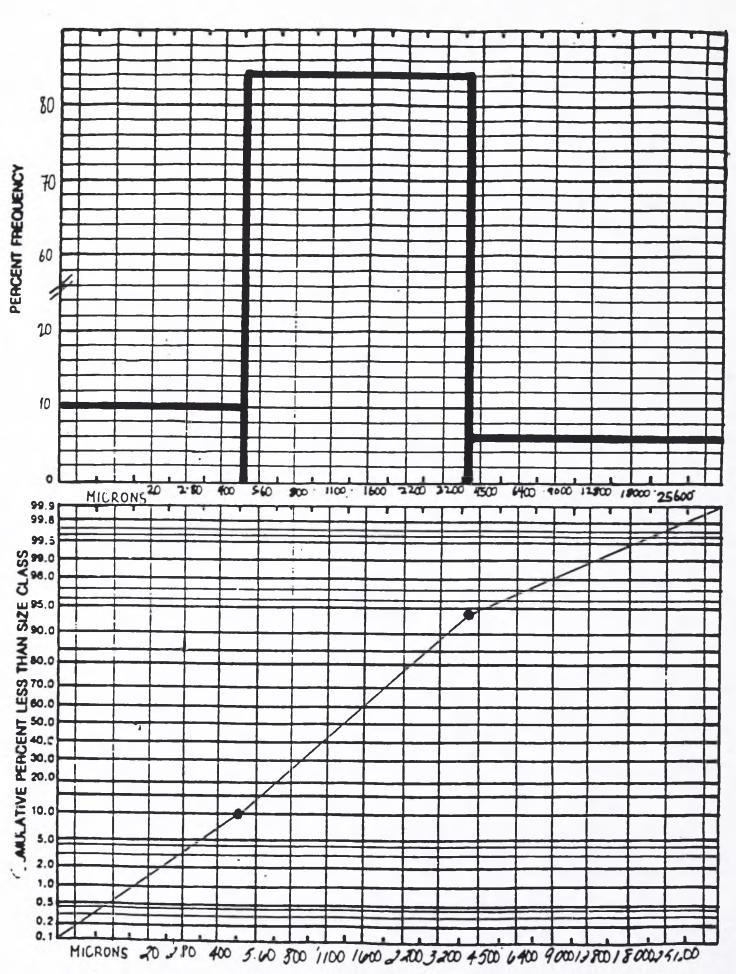


Figure 5.c. Size fractions of sediment from Opunohu River.

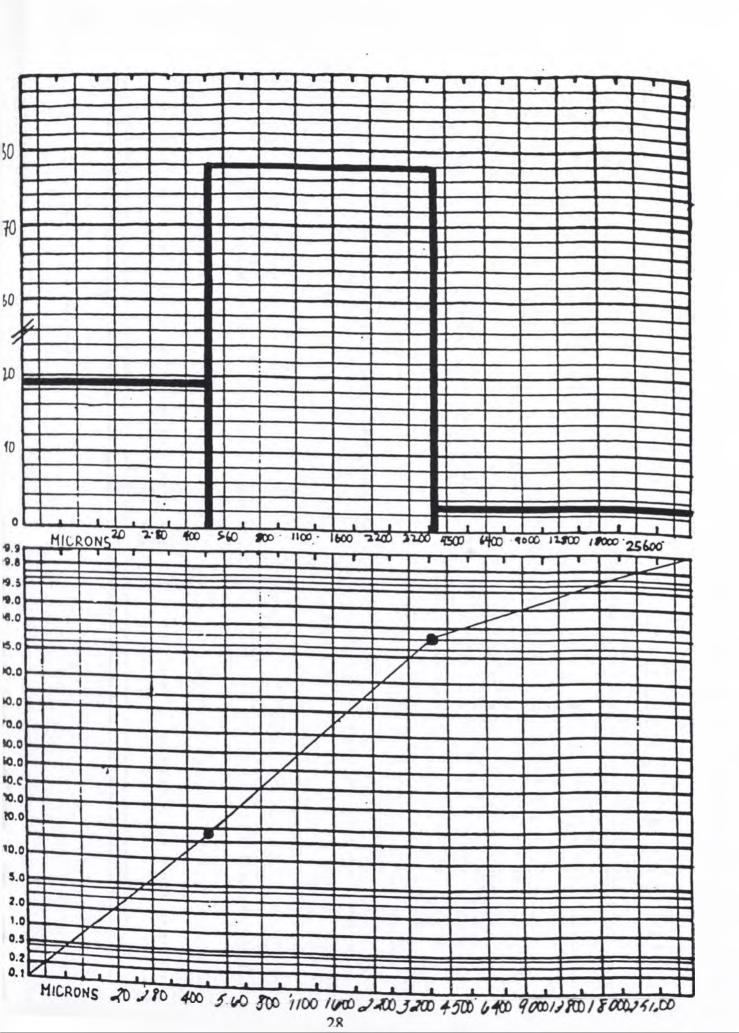
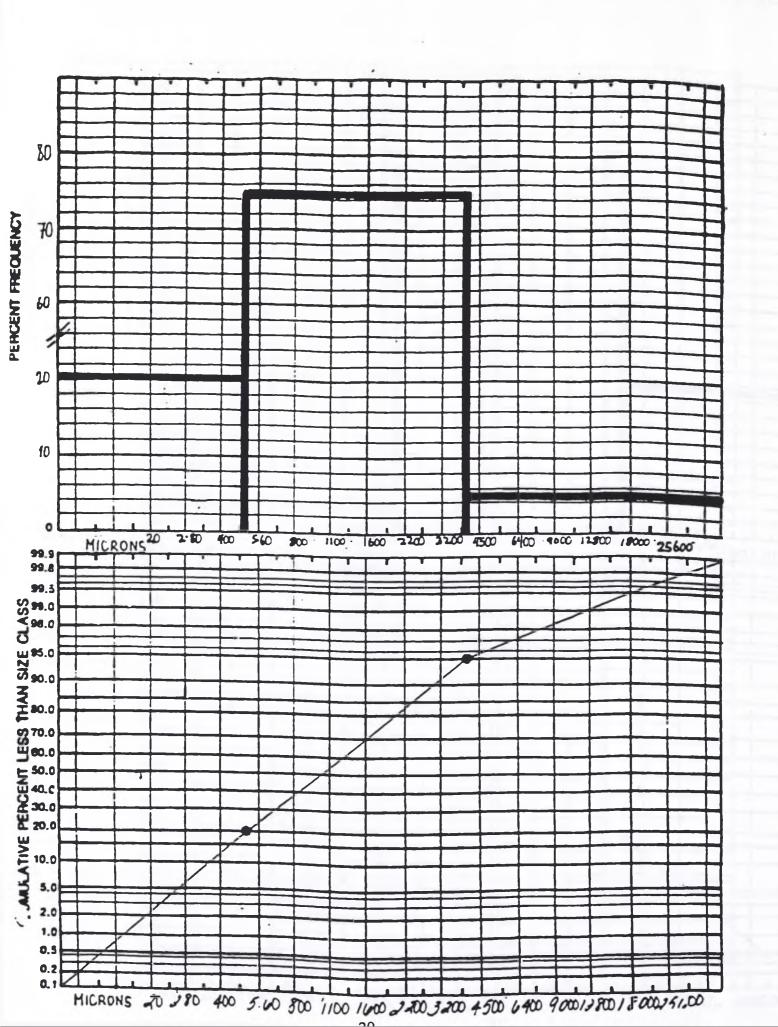
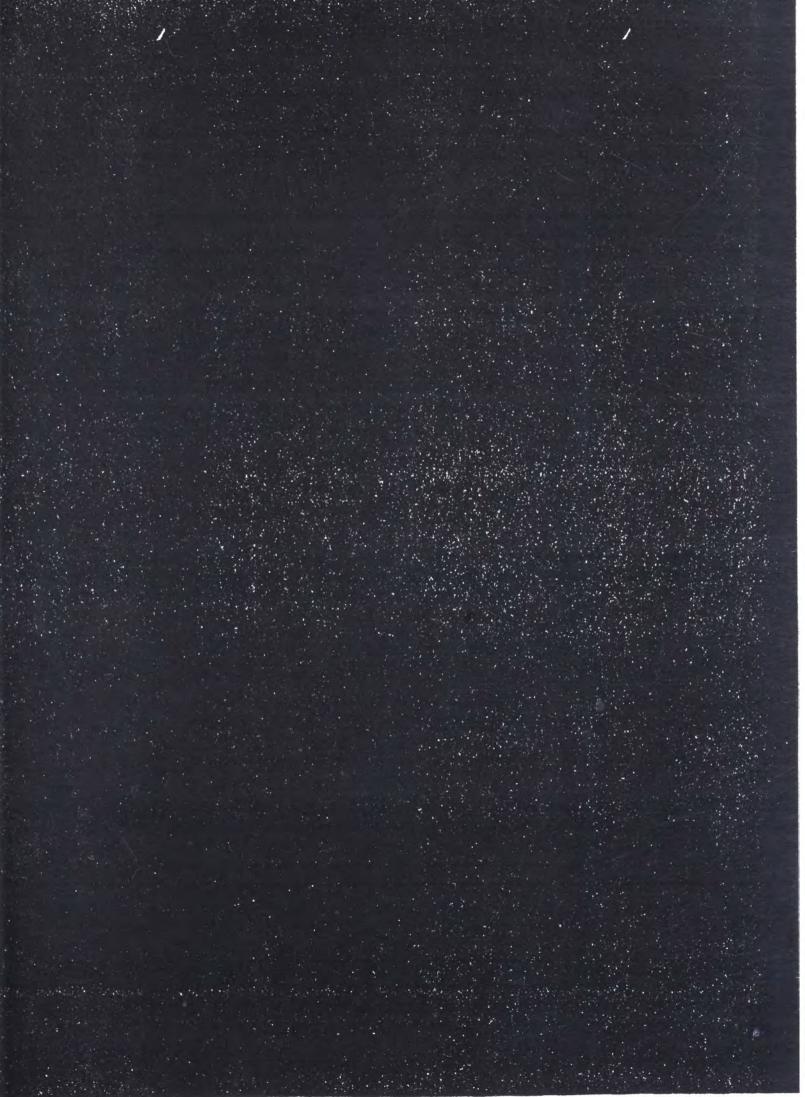


Figure 5.d. Size fractions of sediment from NW Opunohu.



Fungiid #	Gump Station	Baie de Cook	Opunohu River	NW Opunohu	untreated
1.1	36	38	22	12	5
1.2	40	41	20	14	1
1.3	38	37	23	17	9
2.1	43	37	24	15	4
2.2	48	36	25	13	0
2.3	40	32	21	11	7
3.1	51	33	24	14	2
3.2	42	34	21	12	7
3.3	40	36	26	18	1
average	42	36	23	14	4
s.d.	4.5	3.6	1.9	2.2	3

	Α	В	С	D
1	Table 7.	Breakdown of p	ercent mortality	by treatment
2				
3				
4	Fungiid	Caged	Open	Cage Control
5	Gump	38	40	36
6	avg. = 42	40	18	43
7		40	42	51
8		avg. = 39	avg. = 43	avg. = 43
9				
10	Baie de Cook	37	41	38
11	avg. = 36	32	36	37
12		36	34	33
13		avg. = 35	avg. = 37	avg. = 36
14				
1 5	Opunohu River	23	20	22
16	avg. = 23	21	25	24
17		26	21	24
18		avg. = 23	avg. = 22	avg. = 23
19				
20	NW Opunhohu	17	14	12
21	avg. = 14	11	13	15
22		18	12	14
23		avg. = 15	avg. = 13	avg. = 14
24				
25	untreated	9	1	5
26	avg. = 4	7	0	4
27		1	! 7	2
28		avg. = 6	avg. = 3	avg. = 4
29				
30				
31	All values are in percent mortality.			





Disturbance on a Coral Reef Flat: The effects of rock inversion on associated organisms

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Abstract:

The inversion of rocks on the reef flat of Moorea, French Polynesia resulted in a change of species composition on both the exposed and undersides of the rocks. The species richness of the undersides decreased when turned over to become the exposed sides while the species richness increased for the exposed sides which were inverted to become the undersides. The amount of encrusting algae increased on the new undersides of inverted rocks and decreased on the new exposed sides of those rocks. The amounts of other, non-encrusting algae which occur more on the exposed sides of rocks in most cases did not significantly change upon inversion within the time frame of the study. After inversion the sea urchin *Echinometra mathaei* initially decreased in numbers associated with inverted rocks, but recovered after one week.

Introduction:

Disturbance is defined by Sousa (1984) as a "discrete, punctuated killing, displacement or damaging of one or more individuals (or colonies) that directly or indirectly creates an opportunity for new individuals (or colonies) to become established." This definition emphasizes the idea set forth by Paine and Vadas (1969) that intermediate disturbance is important in maintaining high species diversity. A lack of disturbance may result in the monopolization of space by a dominant species and the reduction of local species diversity (Sousa 1979a). This idea has been supported in temperate marine communities (Dayton 1971), in coral reefs (Connell 1978), and in intertidal boulder fields (Sousa 1980). High levels of disturbance can also stress communities and result in a decrease in species diversity (Sousa 1979b). This decrease can be especially drastic when human impact is added to natural disturbance increasing the effects of the disturbance (Kaufman 1986).

This study is a preliminary look at the effects of overturning rocks on a coral reef flat on the organisms living on or underneath those rocks. Rock inversion is an event which occurs during heavy storms and also as a result of human recreation. The

protection of a biological system, such as the coral reef, from excessive human disturbance involves knowing how man affects the system and which organisms are involved in the disturbance, as well as their interactions (Underwood & Kennelly 1990). This study is an attempt to identify the organisms affected by rock inversion and the extent of the disturbance in order to have a better understanding of the effects of human actions.

Study Site:

This study was undertaken on the reef flat north of the Gump Field Station on Moorea, French Polynesia (149°W, 17°S) (Figure 1). At this site the density of moveable rocks with a maximum length greater than 20 cm is 1.5 rocks/m². A moveable rock is defined as any rock not cemented to the bottom and less than approximately 40 kg. The size of moveable rocks decreases slightly with distance from the reef crest, but not in a linear fashion (Figure 2). The dominant alga on the exposed sides of the rocks is the red seaweed *Hypnea cervicornis*, followed by the brown seaweeds, *Padina australis* and *Dictyota sandvicensis* (Figure 3). The rocks are shallowly covered by water, but may be slightly uncovered at low tide.

Methods and Materials:

This study was conducted from October 25 through November 19 with most data collected between 5 AM and 9 AM. One 50 m x 1 m band transect running parallel to the reef crest, as well as three 20 m x 1 m band transects perpendicular to the reef crest were used to map all moveable rocks with a maximum length greater than 20 cm. The following information was recorded or each rock: location along the transect, maximum length and width, dominant alga on its exposed side, and the degree of algal cover.

Twenty pairs of rocks with maximum lengths greater than 30 cm were then chosen along the 50 m transect. Pairs were selected on the basis of similarities in size, location along the transect, degree of algal cover and type of algal cover. One rock from each pair then became the inverted rock which was turned over and left upside-down, while the other became the control rock which was turned over and then returned to its original orientation. These rocks were sampled at the time of inversion, 24 hours later, 1 week later and then 2 weeks later using a 50 cm x 50 cm grid with intersecting points every 5 cm. This grid was placed on the surface of both sides of each rock and used to record the organism living under each intersecting point. An average of 30 points were counted on each rock. Mobile organisms were also counted when found on or underneath the rocks.

The data were tabulated and combined for the inverted rocks as well as the control rocks. The new undersides of the inverted rocks (c, Figure 4) were then compared with the exposed sides of the control rocks (d, Figure 4) to show the effects of burial, while the newly exposed sides of the inverted rocks (a, Figure 4) were compared with the undersides of the control rocks (b, Figure 4) to show the effects of exposure. These comparisons were statistically analyzed for differences using a Wilcoxon matched-pairs signed-ranks test.

Results:

The exposed sides of the inverted rocks showed a significant decrease in species richness over time when compared with the undersides of the control rocks (p < .05 after 24 hrs, p < .01 after 1 wk)(Figure 5). The undersides of the inverted rocks, however, showed a significant increase in species richness over time when compared with the exposed sides of the control rocks (p < .01 after 1 wk)(Figure 6).

The three most common species on the undersides of the rocks, Lithothamnia sp., Mesophyllum mesomorpham, and Porolithon onkodes are all encrusting calcareous algae. Lithothamnia and Mesophyllum both decreased significantly (p < .01) on the exposed sides of the inverted rocks as compared with the undersides of the control rocks over the two week sampling period while Porolithon not change significantly (Figures 7, 8, & 9). Mesophyllum had a more dramatic mortality rate than Lithothamnia. Lithothamnia (p < .05) and Porolithon (p < .01) also increased significantly on the undersides of the inverted rocks as compared with the exposed sides of the control rocks (Figures 10 & 11). In this case Porolithon showed the most dramatic increase. Mesophyllum, however, did not colonize the undersides of inverted rocks.

The three most common species on the exposed sides of the rocks, Hypnea cervicornis, Padina japonica and Dictyota sandvicensis are all non-encrusting plant-like algae. Hypnea decreased significantly (p < .05) on the undersides of the inverted rocks as compared with the exposed sides of the control rocks (Figure 12), while Padina and Dictyota did not change significantly (Figures 13 & 14). None of these algae showed a significant change on the exposed sides of the inverted rocks (Figures 15, 16, & 17).

The sea urchin *Echinometra mathaei* which was found living in crevices, underneath, or stuck to the bottoms of the rocks, showed a highly significant decrease in numbers associated with the rocks 24 hours after inversion (p < .01). However, they recolonized the crevices and undersides of the rocks after one week (Figure 18).

Discussion:

The results of this study show that rock inversion does have an effect on the organisms living on or underneath those rocks. The overall change in species richness on the newly exposed sides of rocks indicates that the organisms living there leave when

they are inverted or else exhibit increased mortality. These results may be due to increased exposure to predation, exposure to excess sunlight, exposure to breaking waves, or desiccation during low tides. The non-encrusting algae also did not colonize the newly exposed sides of the rocks, which may just be a consequence of the short time span of the study. The increase in species richness on the new undersides of inverted rocks is most likely a result of the rapid colonization of encrusting algae as compared with the slow mortality rates of the non-encrusting algae.

Each species of encrusting algae responded differently to the inversion. If success is measured by the resulting change in cover for each species, *Mesophyllum* must be considered the least successful with its high mortality rate when exposed and its complete lack of colonization on the undersides of inverted rocks. *Porolithon*, on the other hand, can be considered more successful because it did not show a significant mortality rate on the exposed sides of the inverted rocks and its colonization rate on the undersides of inverted rocks was the highest. *Lithothamnia* was also more successful since it was able to colonize the undersides of inverted rocks. However, a study over a longer time period is needed to determine the actual fate of these species.

The non-encrusting species, which generally inhabit exposed sides of rocks, also responded differently to the inversion. *Hypnea* showed a significant mortality rate on the undersides of inverted rocks, but *Padina* and *Dictyota* did not. None of these species showed a significant colonization rate on the exposed sides of the inverted rocks over the 2 week time period. These results lead me to believe that the non-encrusting species have a slower response rate to this kind of disturbance than the encrusting calcareous algae. However, one problem with the ability of this study to determine success of the non-encrusting species is that while their presence or lack of presence was recorded, the relative health of each individual was not recorded.

Although most mobile organisms moved too quickly to be counted in this study, the *Echinometra* results are probably representative of other mobile species. While they are initially detrimentally affected by this disturbance, their high degree of vagility allows them to recover quickly and recolonize the inverted rocks.

Further studies on the effects of rock inversion would prove interesting if they considered the cause of mortality for those species which decreased in amounts, and if they included other species which were not considered in this study because of their rarity of occurrence using this sampling method. Of course, a longer time period for the study would also shed light on the long-term effects. In order to fully understand the impact humans have on coral reef flats, a study on the extent of human recreation and rock inversion in areas such as this one is also needed

Acknowledgments:

I would like to thank Dr. Roy Caldwell and Dr. Mary Power for their help in developing and conducting this study, Erik Sandstedt and Russell Iwanchuk for their help in the field, and all of the other people who helped me get to and from my site: Fred Booker, Larry Bernstone, Bryn Sakagawa, Mike Daniels, and Jason Rice.

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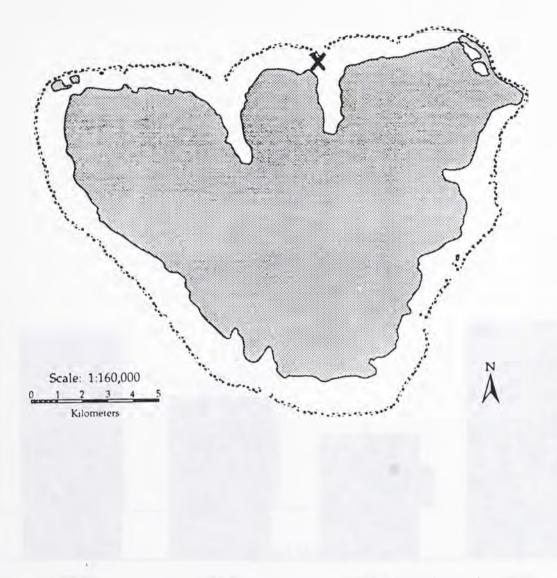


Figure 1: Study site location on Moorea, French Polynesia

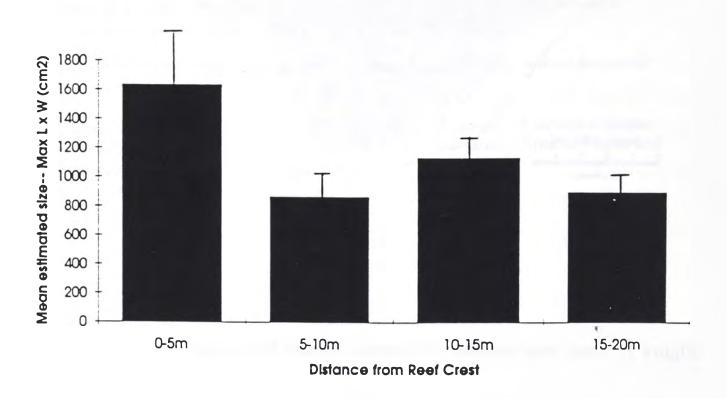


Figure 2: The distribution of different sizes of rocks within the three transect bands running perpendicular to the reef crest (N = 52). Vertical lines = mean estimated area + 1 standard error.

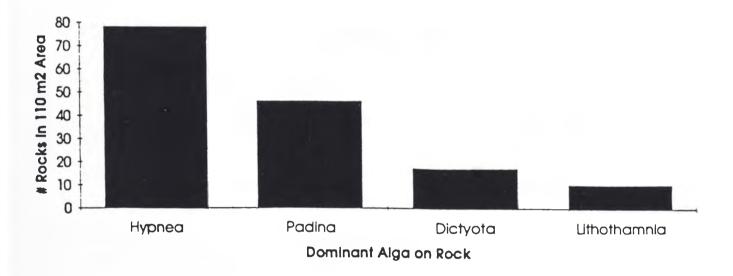


Figure 3: The number of rocks within all 4 transect bands exhibiting each of the primary types of algae as their dominant alga (N = 167).

Before Inversion

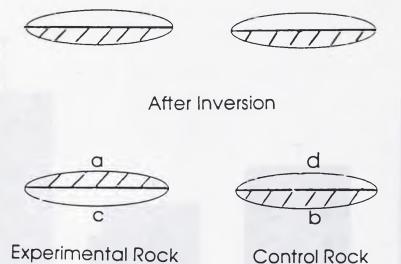


Figure 4: Diagram of the control and experimental treatments. A and b are compared to show exposure disturbance. C and d are compared to show burial effects.

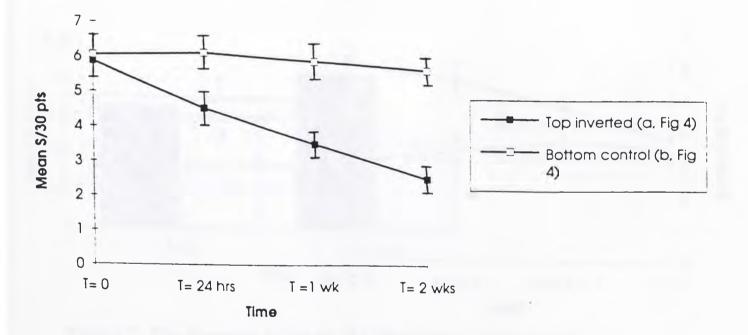


Figure 5: The change in species richness for the newly exposed sides of inverted rocks as compared with the undersides of control rocks (p < .05 at t = 24 hrs, p < .01 at t = 1 wk and t = 2 wks). Vertical lines = mean + 1 standard error.

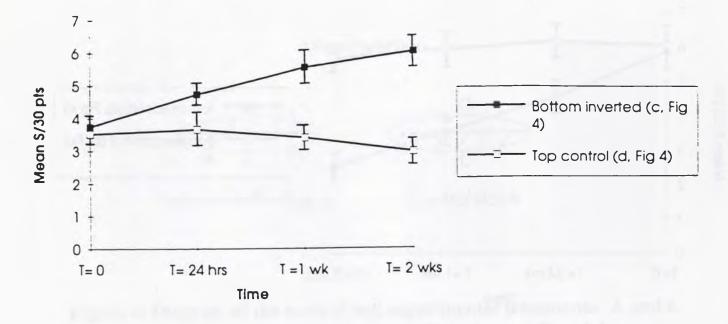


Figure 6: The change in species richness for the new undersides of inverted rocks as compared with the exposed sides of control rocks (p < .01 at t = 1 wk and t = 2 wks). Vertical lines = mean + 1 standard error.

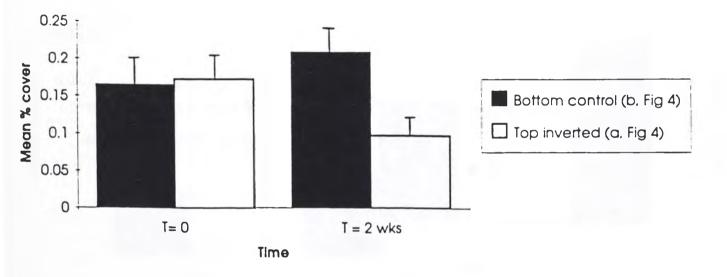


Figure 7: The decrease in cover of Lithothamnia on the newly exposed sides of inverted rocks as compared with the undersides of control rocks (p < .01 at t = 2 wks). Vertical lines = mean + 1 standard error.

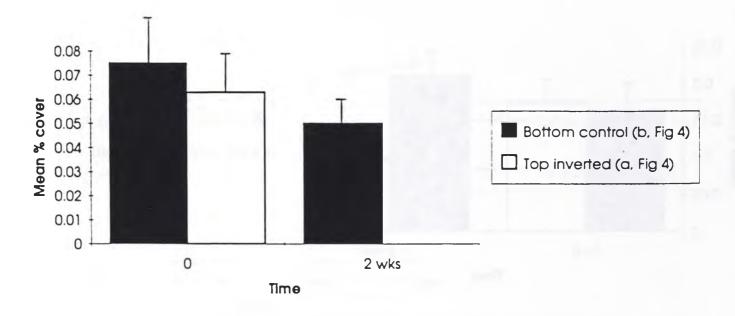


Figure 8: The decrease in cover of *Mesophyllum* on the newly exposed sides of inverted rocks as compared with the undersides of control rocks (p < .01 at t = 2 wks). Vertical lines = mean + 1 standard error.

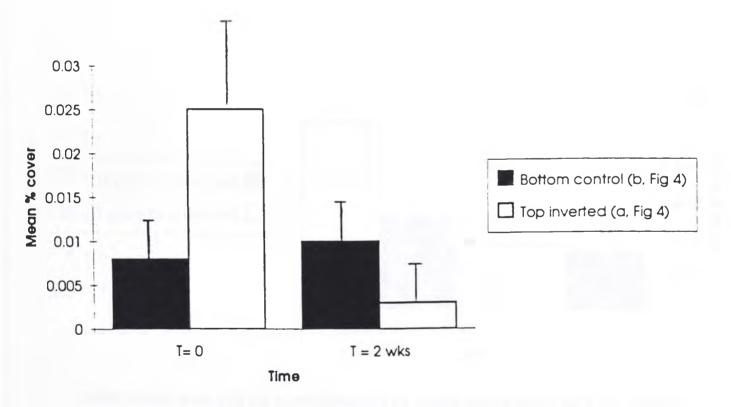


Figure 9: The insignificant change in cover of *Porolithon* on the newly exposed sides of inverted rocks as compared with the undersides of control rocks. Vertical lines = mean + 1 standard error.

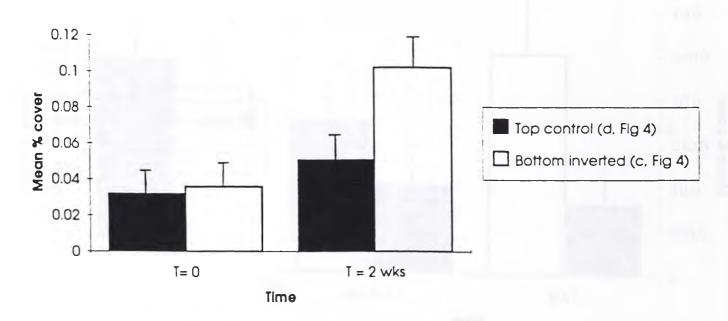


Figure 10: The increase in cover of *Lithothamnia* on the new undersides of inverted rocks as compared with the exposed sides of control rocks (p < .05 at t = 2 wks). Vertical lines = mean + 1 standard error.

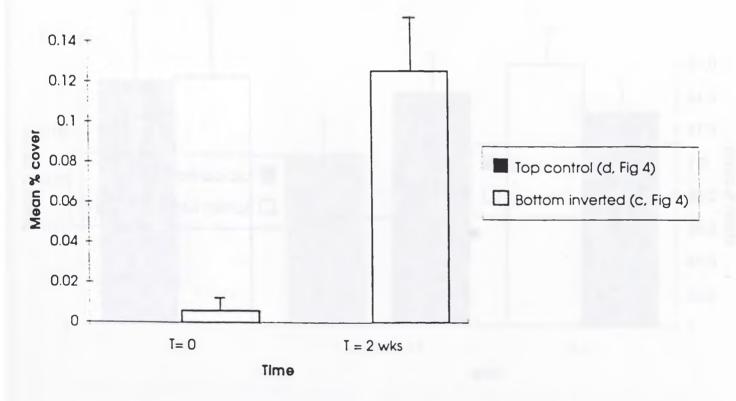


Figure 11: The increase in cover of *Porolithon* on the new undersides of inverted rocks as compared with the exposed sides of control rocks (p < .01 at t = 2 wks). Vertical lines = mean + 1 standard error.

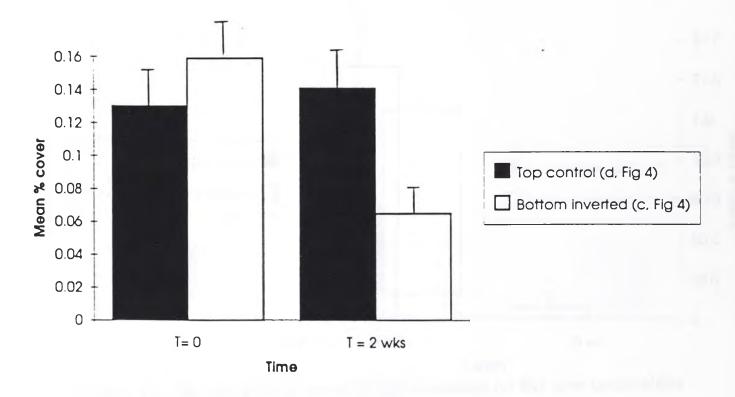


Figure 12: The decrease in cover of Hypnea on the new undersides of inverted rocks as compared with the exposed sides of control rocks (p < .05 at t = 2 wks). Vertical lines = mean + 1 standard error.

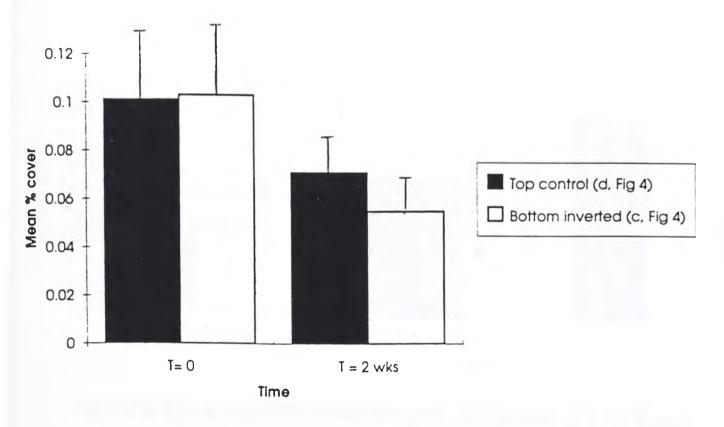


Figure 13: The insignificant change in cover of *Padina* on the new undersides of inverted rocks as compared with the exposed sides of control rocks. Vertical lines = mean + 1 standard error.

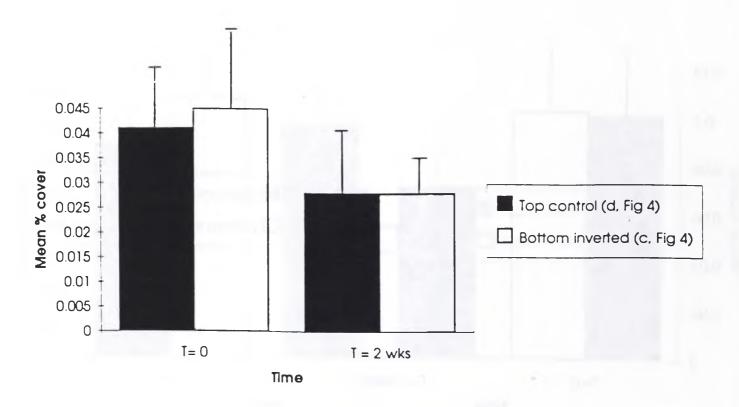


Figure 14: The insignificant change in cover of *Dictyota* on the new undersides of inverted rocks as compared with the exposed sides of control rocks. Vertical lines = mean + 1 standard error.

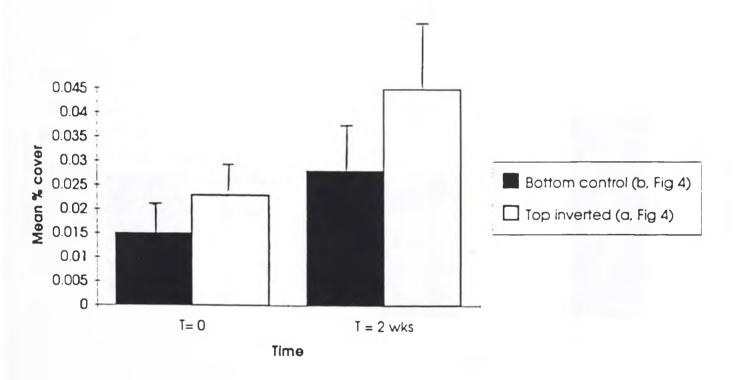


Figure 15: The insignificant change in cover of *Hypnea* on the newly exposed sides of inverted rocks as compared with the undersides of control rocks. Vertical lines = mean + 1 standard error.

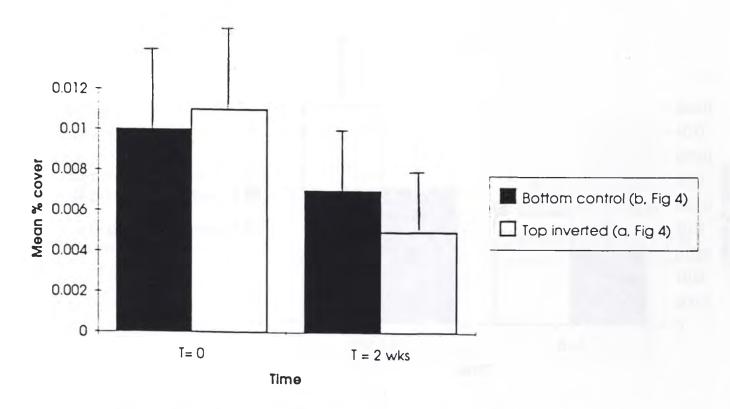


Figure 16: The insignificant change in cover of *Padina* on the newly exposed sides of inverted rocks as compared with the undersides of control rocks. Vertical lines = mean + 1 standard error.

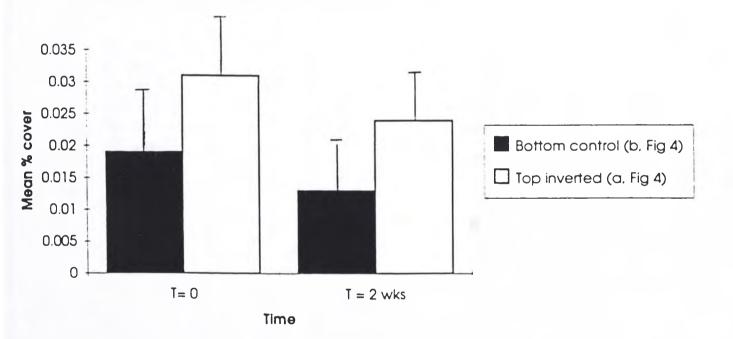


Figure 17: The insignificant change in cover of *Dictyota* on the newly exposed sides of inverted rocks as compared with the undersides of control rocks. Vertical lines = mean + 1 standard error.

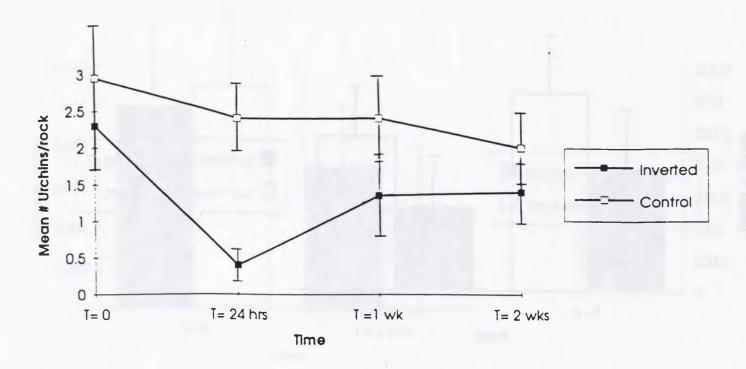
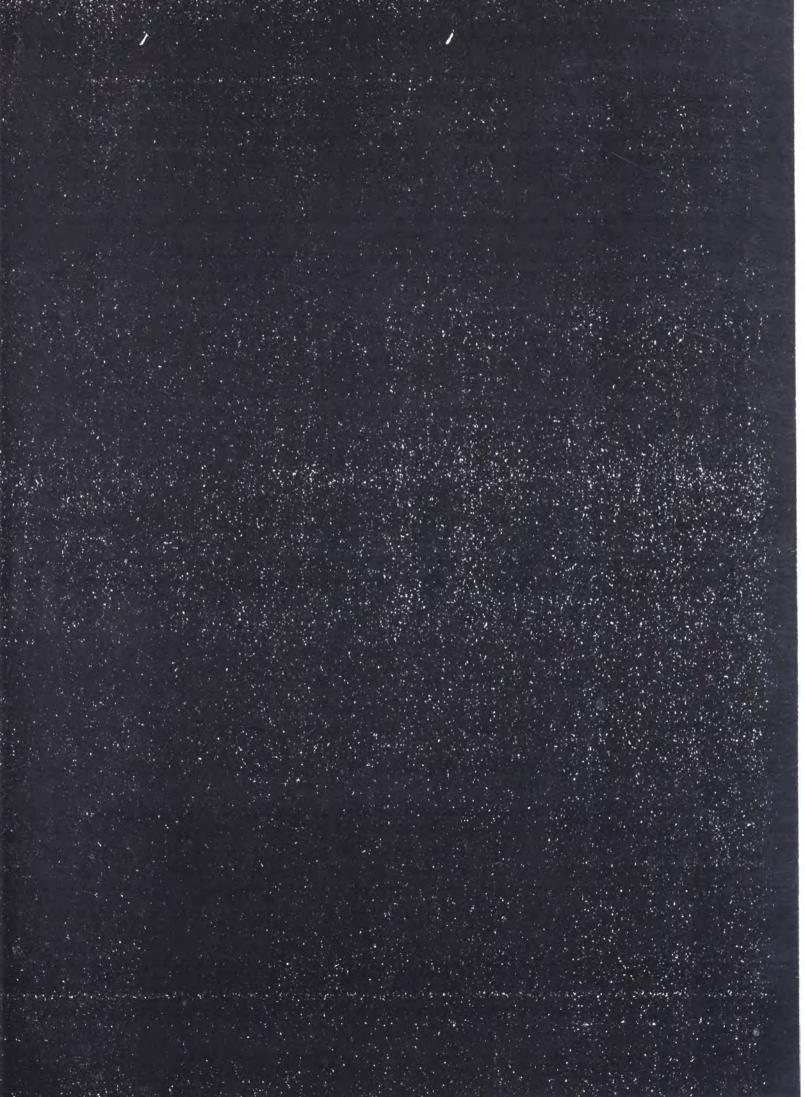
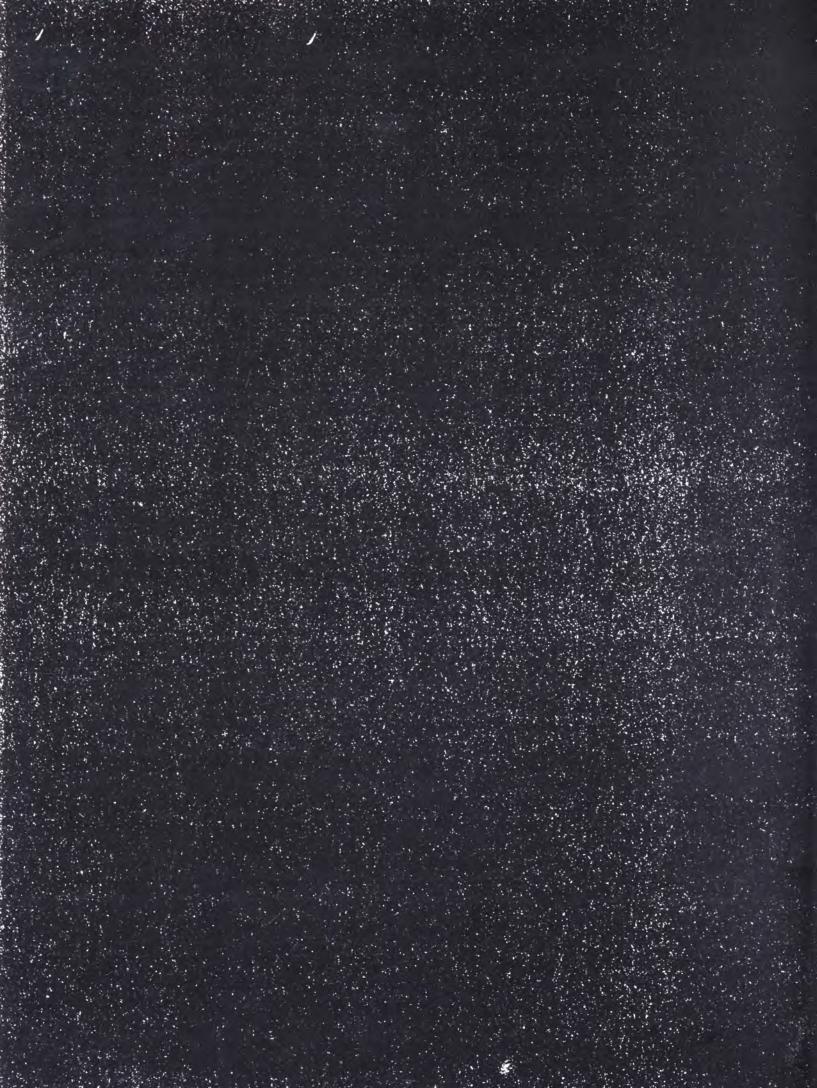


Figure 18: The change in numbers of *Echinometra* associated with the inverted rocks as compared with the control rocks (p < .01 at t = 24 hrs). Vertical lines = mean + 1 standard error.





Aggregations of *Diadema savignyi* in the High Energy Channel at Temae Public Beach, Moorea, French Polynesia: an investigation into this habitat and strategies the urchins use to survive there

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Aggregations of *Diadema savignyi* in the High Energy Channel at Temae Public Beach, Moorea, French Polynesia: an investigation into this habitat and strategies the urchins use to survive there

Abstract

Diadema savignyi were studied in the patch reef and near shore channel at Temae Public Beach, Moorea, French Polynesia. The urchins were found on and around coral heads in the patch reef and in unsheltered aggregations in the channel. At Temae, high velocity currents move sand, creating an ever-changing and unstable substratum. Hence, urchins were found aggregating on coral rubble and coral pavement in both habitats. Flow velocities in the channel are higher than the patch reef so aggregating on sand there may be especially risky for the urchins. In response, the unsheltered urchins in the channel interlock their spines and use velocity shadows to avoid being swept away by the high velocity current.

Introduction

Studies have been done on the aggregations of *Diadema setosum*, *Diadema antillarum*, *Diadema savignyi* (Pearse and Arch, 1969) as well as other urchins (Grunbaum, 1978) noting, in particular, the possibility of social behavior. D. savignyi are noted for their high densities observed at and around Temae public beach in Moorea, French Polynesia and their near shore unsheltered aggregations (Pearse, 1989, unpublished). At Temae the urchins can be observed in two different adjacent habitats. One is in the patch reef where urchins cluster on and around coral heads, using the shelter that the crevices in the coral provide. The other is a high velocity, near shore channel which lacks the shelter of the coral heads. Few, if any, studies have described the habitat at Temae and the near shore aggregations found there.

In this paper I will address the following questions:

- (1) How does the habitat at Temae effect the D. savignyi aggregations?
- (2) How do the urchins respond to the conditions that they face? Understanding the processes that are occurring is essential in understanding the integral role this urchin plays in the coral reef ecosystem.

Methods and Materials

Study Site. Field work was conducted on the island of Moorea, French Polynesia (17°30'S,149°50'W) during the months of October and November, 1993, between 800h and 1300h. The study site at Temae Public Beach (P.K. 0, the Km marker on the road side, Fig. 1) is divided into two regions: the near shore channel and the patch reef.

The lagoon west of Temae is both narrow (ca. 30m) and shallow (<1.5m). At Temae the lagoon widens (Fig. 2), although the channel maintains the

characteristic high velocity of the narrow western lagoon. This could be a result of the obvious separation between the channel and the lower velocity patch reef (Fig. 3). In addition, water from the eastern lagoon as well as waves flowing over the barrier reef from the north are adding to the volume of water in the lagoon. All of the water is pushed into the channel where it flows east, with a high velocity, to a pass out of the lagoon (Fig. 4). The site studied in the channel was 200mX30m, 10m from the shore, and oriented longitudinally to the shore. This region consisted of the following substrates: sand (defined by a grain diameter < 8mm), rubble (defined by a grain diameter > 8mm) and consolidated coral pavement (defined as patches of the lagoon floor made of eroded coral that no longer show the characteristics of the coral skeleton). There were intermittent small coral heads (ca. 0.5m) around which *D. savignyi* aggregated. There was no live coral, little algae, and the current in this area was quite strong (10cm/sec-30cm/sec). The most common fish in the channel were gobies, although wrasses, surgeonfish, goatfish, and triggerfish were observed.

The patch reef was much different. It began approximately 30m from shore and often was raised above the channel (Fig. 3). Large *Porites* coral heads were scattered around the sandy lagoon floor, where one might also observe large dunes of this sand. Some coral heads were observed covered in a red filamentous algae, typical of damselfish territories. Areas of coral rubble or coral pavement were observed at the base of some coral heads. *D. savignyi* were very abundant in this area (ca. 4 urchins/m²), aggregating around the base of coral heads, on the coral itself, and in crevices. The current in this area varied more from day to day than the near shore channel; the surface currents were often much stronger than the currents at the lagoon floor. The sea life in the patch reef appeared to be much more diverse and abundant than the channel.

Procedure. In order to characterize the near shore channel, two 20m line transects were laid. Transect #1 was located 200m and transect #2 was located 150m east of the fence separating the public beach and the private property. D. savignyi aggregations were common here. The transects were laid transversely to and 10m from shore. Flow velocities were recorded every meter along the transects, both on the surface and on the lagoon floor. Surface velocities were estimated by floating a neutrally buoyant plastic bottle, tied with a 3.0m length of flagging tape, down the channel. The loose end of the flagging was held stationary and the bottle allowed to float (completely submerged yet at the top of the water column) down the channel until the flagging pulled tight. The amount of time this took was used to assess velocities. Bottom velocities were estimated by injecting a phosphorescent dye over the substrate and recording the time taken for the dye to travel 1.0m with the current. Three trials for both bottom and

surface velocities were performed. Depth at each meter was also recorded where possible. A point count survey of the substrate was performed along the transects. Forty points were haphazardly sampled in qualitatively defined zones along the transects. The grain diameter was measured and classified as sand, coral rubble, or coral pavement.

In order to characterize the patch reef, three 10m line transects were haphazardly laid. Transect location data is given in Figure 4. The dominant substratum or sessile benthic organism was noted every 0.5m and percent covers determined. The line transects were converted into 10mX2m band transects, divided into ten 2mX1m quadrants. Urchins were counted in each quadrant and their densities determined. Sand samples were collected and sieved to determine particle diameter. Percent frequency was plotted against particle diameter.

D. savignyi aggregations in the channel were haphazardly sampled. Aggregations oriented around rocks or coral heads were compared to those that were not. Aggregations were also visually assessed and mapped. Those with their long axis directed into the flow (subjectively determined) were compared to those with their short axis facing the flow. Substrate was noted and lagoon floor flow velocities estimated, by methods described above. To determine velocities over the aggregations, a meter stick was placed on top of the urchins and not on the floor to insure the safety of both the urchin and researcher.

Urchin aggregations were also haphazardly sampled in the patch reef. Their substrates were noted and lagoon floor flow velocity estimates were attempted. Velocity measurements, attempted by the above procedure, could not be determined because each time the dye was injected into the water column it dissipated before traveling one meter.

Statistical Analysis. Where counts were taken, chi-squared tests were performed to determine if urchins were found in greater proportions than might be expected by chance alone.

Results

Near shore transect data revealed a gradual deepening of the lagoon at both transects (Fig. 5a,6a). For both transects, surface flow velocities increase as the lagoon deepens (Fig. 5b,6b). The bottom velocities, however, show more noise (Fig. 5c,6c). At transect #1 the patch reef begins 27m from shore. Both surface and bottom velocities drop at or near 27m (Fig. 5b,c). The patch reef began 24m from shore at transect #2. Surface and bottom velocities decrease there as well (Fig. 6b,c). The point count survey of transect #1 revealed that from 0m to 18m the substrate was a mixture of sand and coral rubble. From 18m to

27m the lagoon floor was mostly consolidated coral pavement scattered with small pieces of coral rubble (Table 1). This corresponds to the deepest and highest velocity region along the transect (Fig. 5). Transect #2 followed a similar pattern. From 0m to 20m the floor was sandy with various sized coral rubble pieces. At 20m a 4m transition, between the channel and the patch reef was observed. Here the percent of sand decreased (Table 2). The bottom velocities mimic this transition, rising from 20m to 24m and falling sharply at the interface of the channel and patch reef (Fig. 6b).

The patch reef is primarily sand (Fig. 7). The sand ranges from medium pebble gravel, flat or platy in nature, to very fine sand (Table 3, Fig. 8), the most common being the coarse sands.

The *D. savignyi* aggregations in the channel selected for habitat around a rock or coral head (Table 4, $X^2=18.69$, df=1, p<0.001). In addition, the aggregations were non randomly oriented such that their long axis pointed into the flow (*Table 5*, $X^2=4.67$, df=1, 0.025<p<0.05). Aggregations observed in the near shore environment rested on sand less commonly, and on coral pavement, rubble, or a combination of both more often than would be expected by chance alone (*Table 6*, $X^2=20.7$, df=1, p<0.001). In addition, the aggregations also were found in the highest percentages in the regions with the slowest flow velocity (Fig. 9).

In the patch reef, both aggregations and individuals were found on coral rubble and pavement more often and in the sand less often than would be expected by chance alone (Table 7, $X^2=8.4\times10^4$, df=1, p<0.001). The trouble in determining bottom velocities suggests that the current on the lagoon floor in the patch reef is very slow, almost 0cm/sec.

Discussion

Densities of *D. savignyi* aggregations appear higher in the patch reef than the channel, but the nature of the aggregations show some similarities. It is interesting to note that the patch reef urchin aggregations are located primarily on the coral rubble and coral pavement despite the fact that sand makes up the majority of the patch reef.

Why are the urchins avoiding the sandy areas in the patch reef? The currents at Temae are strong and unpredictable. When the currents are strong enough they may actually move sand and the urchins resting there. All of the sand sampled in the patch reef can be moved by a velocity of only 8 cm/sec (Fig. 10). Higher velocities were very common, this is why the area is composed of sand dunes. Apparently when the currents are strong enough, as in a storm event, large amounts of sand are being deposited in particular places. Perhaps they are being deposited at coral heads or perhaps there are natural eddies

where the sand is deposited. It would be interesting to survey the lagoon floor over a period time to see the degree to which the floor changes.

In addition to displacing them, high currents could tip urchins over revealing their vulnerable oral surfaces. This is the only area that is not covered by spines and the easiest area for a predator to attack. In fact, when an urchin was placed upside down in the sand with its mouth vulnerable, urchin predators were observed nearby.

Many sea urchins have been described as competitive (Nelson and Vance, 1979; Grunbaum, et al., 1978). Urchin fidelity to a crevice or coral head is common (Nelson and Vance, 1979) and has been noticed in D. savignyi (Sherrod, 1991, unpublished) in areas where densities are much lower than Temae. Such homing abilities enable an urchin to ensure that it will have shelter during the day (Nelson and Vance, 1979). It seems reasonable to assume that D. savignyi may be more competitive for shelter, at Temae, due to their higher density. This increase in competition may force urchins into the high velocity channel where the risk of displacement and predation are higher. When competition forces urchins out of shelter they have been known to form aggregations in the open (Mangus, 1967). Those individuals that are out competed may seek each other out in the open channel using scototaxic (dark attracted) and thigmotaxic (touch attracted) responses (Pearse and Arch, 1969). They may form aggregations in the open channel because there are less obstacles to keep them apart. More experiments, including estimates of habitat availability and site fidelity at Temae, might better support this theory.

In the high velocity channel, *D. savignyi* are aggregating on coral rubble and coral pavement, just as in the patch reef. Transect data shows that coral rubble and coral pavement are common in areas where the surface velocities are high, due to the flushing out of sand. Apparently the urchins' need for a hard substrate out weighs the dangers associated with high velocities. The urchins seem to combat the dangers of the channel by several methods.

One such method might be to search for areas where the velocity is low. *D. savignyi* in the channel do not display the same group fidelity as those in the patch reef (Engel, 1992, unpublished). Considering the importance of velocity to urchin safety, the urchins may have to search for the optimum aggregation site, upon returning from foraging, each morning based on current velocities and the amount the lagoon floor has changed. It would be interesting to manipulate both the urchin aggregations and the environment to see how the urchins respond.

Another strategy may be demonstrated in the urchins selectivity to aggregate around coral heads. The coral then acts as a velocity shadow (Fig. 11), slowing and re-routing the current. The urchins, in effect, find a mini patch

reef in the channel.

Finally, urchins within the aggregations group very close together, such that their spines are interlocked. The aggregation, with spines interlocked, takes on the characteristics of a superorganism which is more difficult to move and turn over. In addition, the aggregation is oriented such that it's long axis is pointing the same direction as the current. This decreases the aggregation's surface area being directly hit by the current and decreases the lift as well (Vogel, 1981). With less lift the aggregation is more likely to stay grounded. By using hydrodynamics, the urchins in front are also creating velocity shadows for other urchins so that fewer individuals lie directly in front of the current and more urchins benefit from the velocity shadow.

Acknowledgments

Many thanks to Mary Power, Roy Caldwell, David Stoddart, Frank Murphy, Tim Krantz, and the other faculty and staff members responsible for finally making science tangible. For their invaluable assistance in the field, I thank Lisa Angeloni, Larry Bernstone, Kathryn Bickel, Ute Gigler, Russel Iwanchuk, and Erik Sandstedt. A very special thank you to Fred Booker for all of his time, both in and out of the field. To all of the friends I've made and to Moorea, Maruru.

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Tables

Zone	Dist. from	Sand	Coral rubble	Coral
	shore			pavement
Sand/Rubble	0m-18m	25%	70%	5%
Rubble/Pavement	18m-27m	7.5%	37.5%	55%

Table 1. Near shore transect #1: point count survey results.

Zone	Dist. from	Sand	Coral rubble	Coral
	shore			pavement
Sand/Rubble	0m-20m	12.5%	87.5%	0%
Transition (less sand)	20m-24m	10%	75%	15%

Table 2. Near shore transect #2: point count survey results.

Grain diameter (mm)	Classification
4.0-8.0	fine pebble gravel
2.0-3.99	very fine pebble gravel
1.0-1.99	very coarse sand
.4599	coarse sand
.25449	medium sand
.125249	fine sand
.11249	very fine sand

Table 3. Classification of grain diameter found in the patch reef sand (Compton, 1985).

	Number observed	Number expected
Aggregations around rock/coral head	33	19.5
Aggregations on open floor	6	19.5

Table 4. Observed and expected frequencies of near shore aggregation locations with respect to rocks/coral heads. Number of expected aggregations is half of the sample size. This is a conservative estimate of the expected value because the percent of the channel covered with rocks is unknown.

	Number observed	Number expected
Aggregations with long axis pointing into the current	26	19.5
Aggregations with short axis pointing into the current	13	19.5

Table 5. Observed and expected frequencies of near shore aggregation orientations. Number of expected aggregations is half of the sample size.

	No. of	No. of	No. of	No. of
Substrate	aggregations	aggregations	individuals	individuals
	observed	expected	observed	expected
Sand	1	3.13	106	382.3
Coral rubble	10	14.45	1255	1765
Coral	9	2.42	1082	295.6
pavement			25-31-71	

Table 6. Observed and expected frequencies of near shore aggregation resting on different substrates. Only three substrates were found in the channel to any large degree therefore only three categories exist. The expected values are the (sample size)X(percent of available habitat). The percent of available habitat was estimated by averaging the data from the point count survey (Table 1,2). Care was taken to consider the distance of each zone when calculating expected.

Substrate	No. of aggregations observed	No. of aggregations expected	No. of individuals observed	No. of individuals expected
Sand	10	43.7	26	545.9
Coral rubble	29	0	367	0
Coral	30 .	8	469	100.6
pavement				1001
Other	0	17.3	0	215.5

Table 7. Observed and expected frequencies of patch reef aggregations resting on different substrates. The expected values are the (sample size)X(percent of available habitat). The percent of available habitat is taken from Fig. 7.

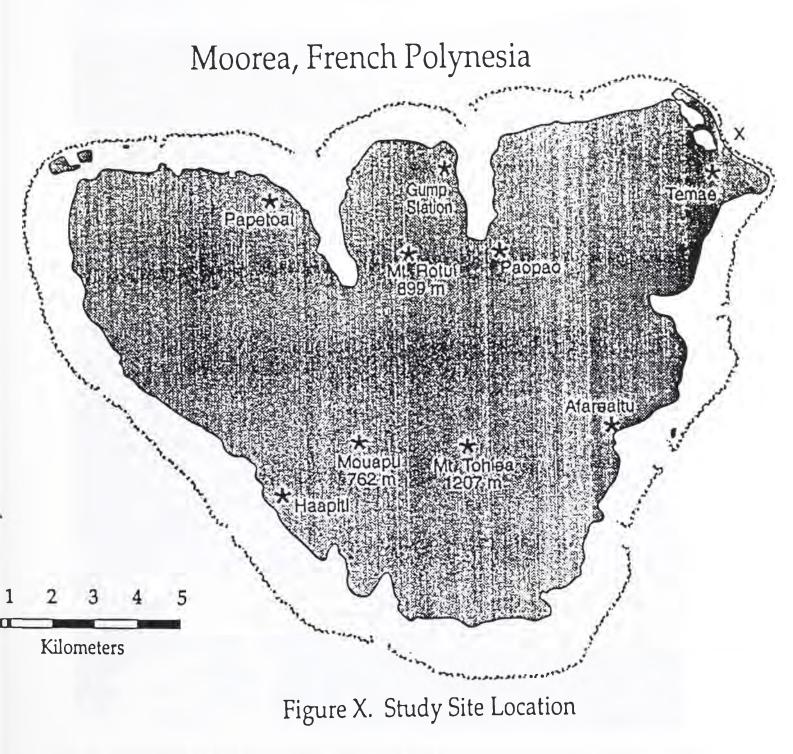


Fig. 1. Study site: Temae Public Beach



Fig. 2. Beach at Temae. Notice the point around which the current flows into the near shore channel.

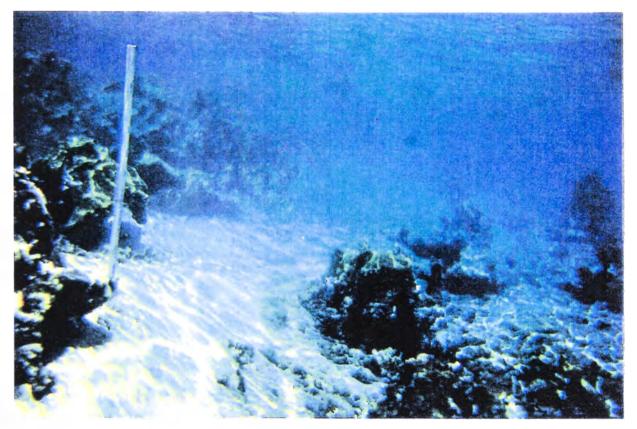


Fig. 3. Interface of the patch reef (left) and the near shore channel (right). Note 1.0m pole for refrence.



Fig. 2. Beach at Ternee. Notice the point around which the current flows into the



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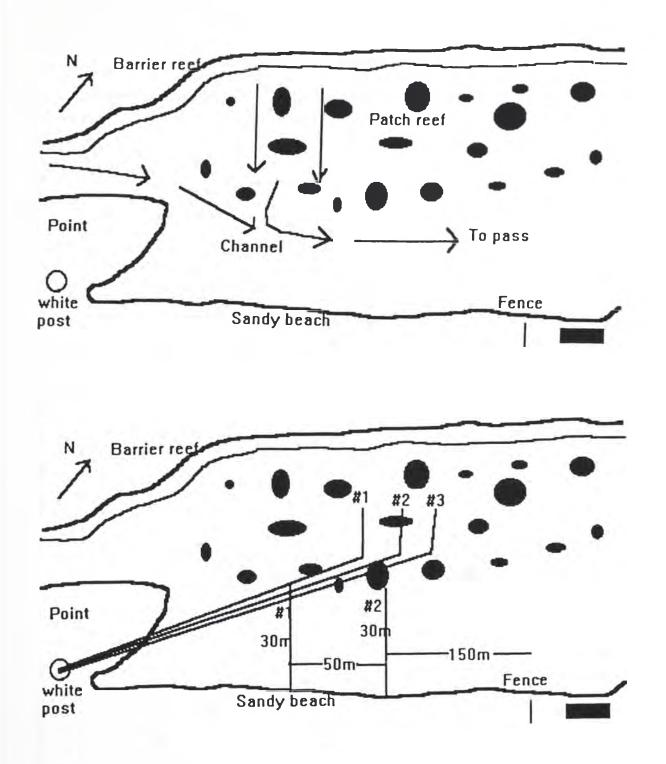


Fig. 4. Map of currents and locations of transects at Temae. Arrows show direction of current. In the patch reef transect #1 was 175m @ 55 from the post, it ran at 175. Transect #2 was 180m @ 52 from the post, it ran at 165. Transect #3 was 192m @ 50 from the post, it ran at 160. All of the patch reef transect were 10m. Note: not drawn to scale.

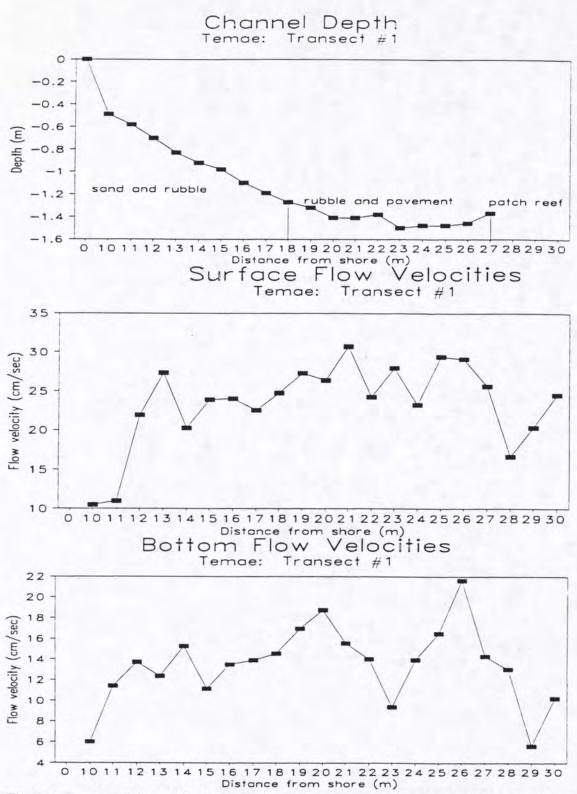


Fig. 5. Depth (a), surface velocity (b), and bottom velocity (c) for transect #1 in the near shore channel. Standard error of velocity never greater than 3.3.

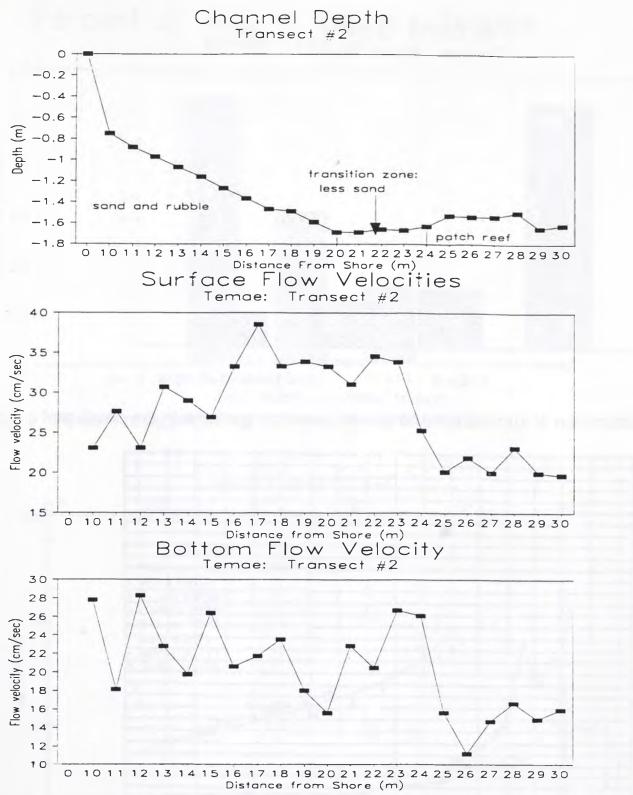


Fig. 6. Depth (a), surface velocity (b), and bottom velocity (c) for transect #2 in the near shore channel. Standard error never greater than 3.8.



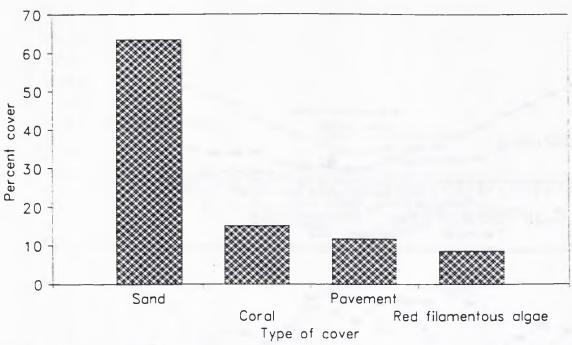


Fig. 7. Estimation of substratum and sessile benthic organisms in the patch reef (n=63)

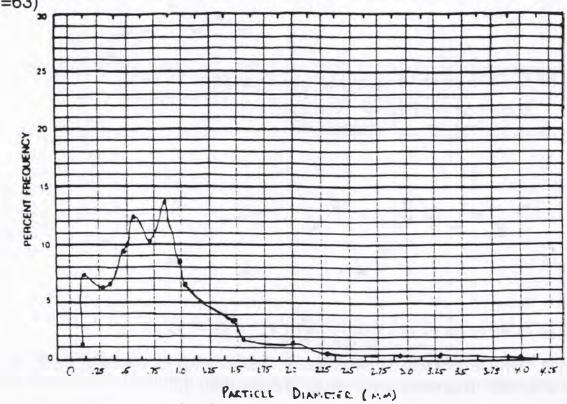


Fig. 8. Frequency distribution curve for sand in the patch reef.

Percent of Agg. in Velocity Regime Bottom Velocities

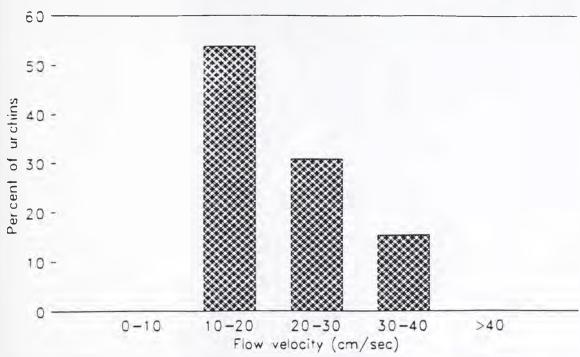


Fig. 9. Percent of aggregations in a velocity regime (n=13).

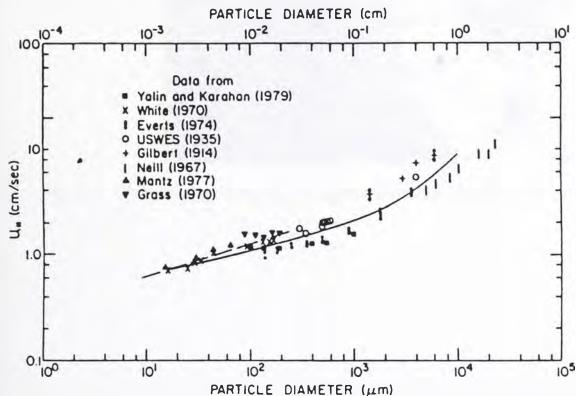


Fig. 10. Critical velocities for moving sand vs. particle size diameter (Nowell, 1985).



Fig. 2. Estimation of substitition) remigatificalistics organizating applied to 1970-1970.



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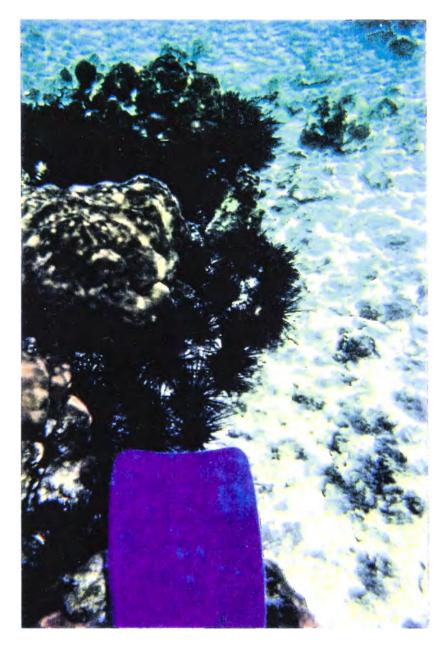
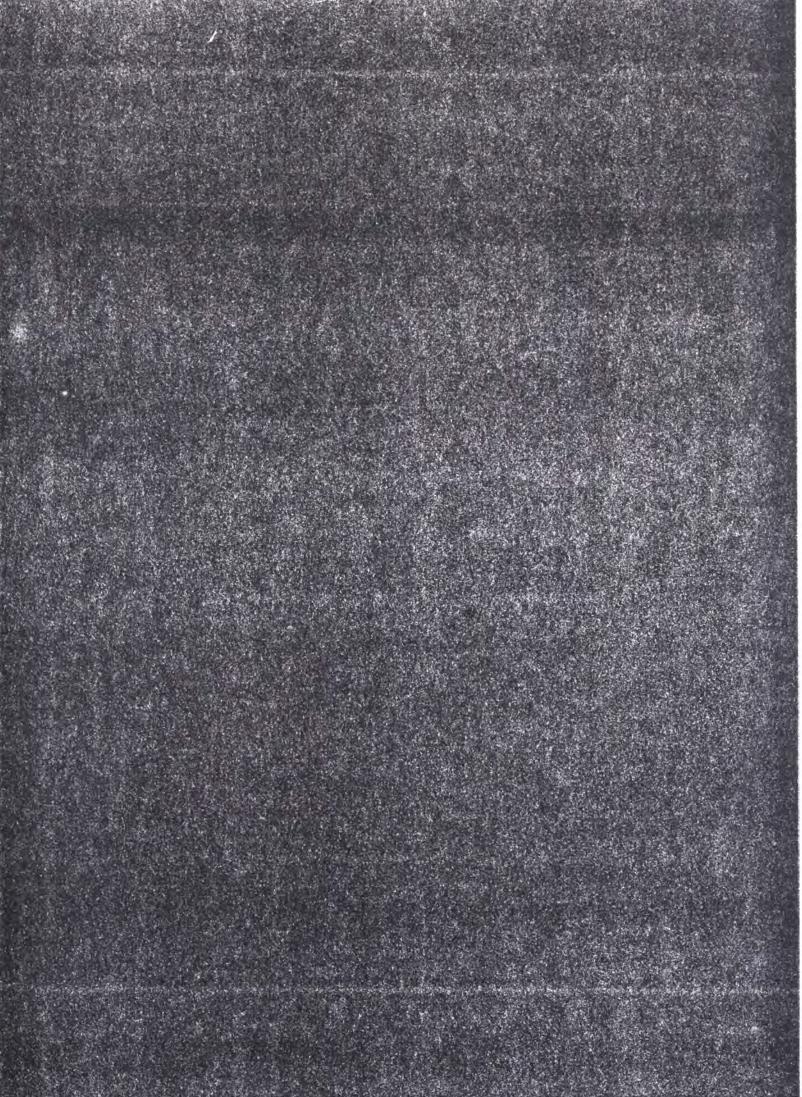
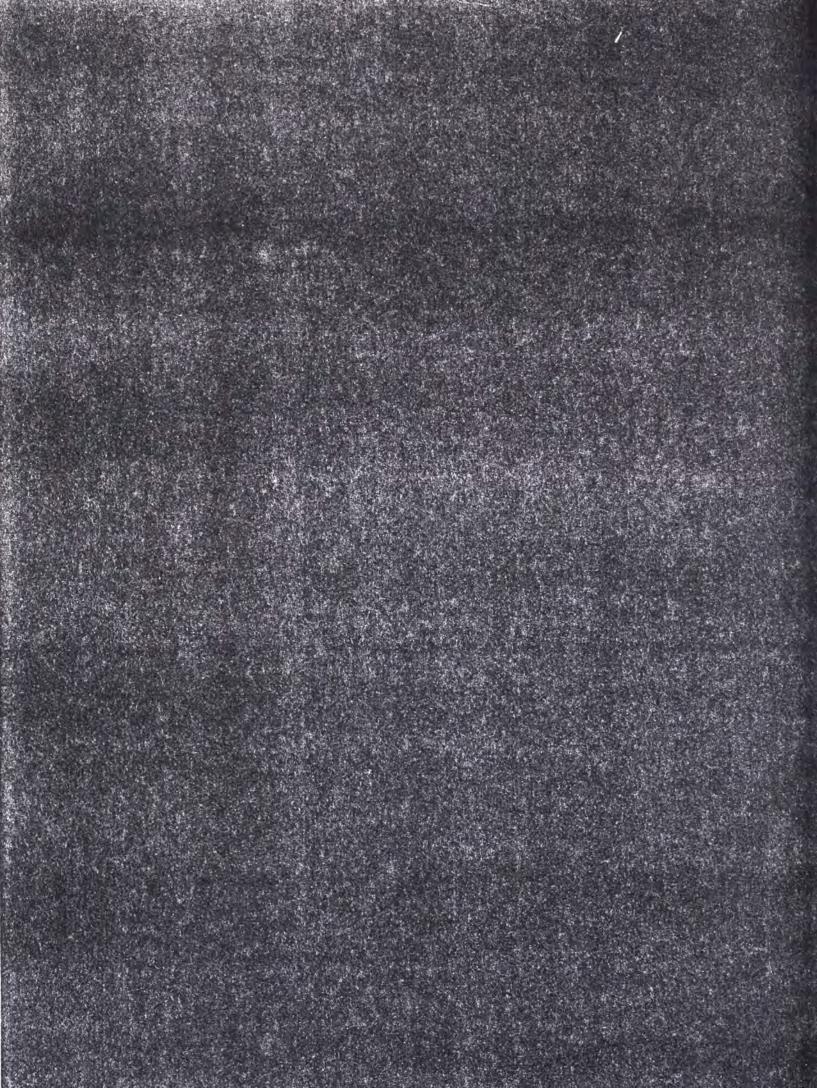


Fig. 11. Urchins aggregating in a velocity shadow behind a small coral head.



Fig. 11. Urchins aggregating in a valority shadow behind a small coral head





Islands within the Sea
The Theory of Coralline Boulder Biogeography

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Fall 1993

Abstract

Boulders of coralline rubble are common substrates on tropical ocean shelves which support a variety of invertebrate life as isolated "islands". In this study we attempted to correlate boulder depth, porosity, and volume to the species richness and diversity within these island habitats. We found positive correlations between boulder volume and number of individuals. We also found that boulder depth was negatively related to the number of taxonomic classes within the boulders as well as to the number of individuals within these islands.

Introduction

In 1967 MacArthur and Wilson presented their theory of island biogeography, which altered the way ecologists thought about species diversity and community organization upon islands. Since then, many empirical and theoretical studies have focused on explaining variation in species richness among islands (Diamond and Mayr 1976, Wilcox 1978, Dueser and Brown 1980, Heaney 1984, Hobbs 1988, Heatwole 1991). The emphasis of most of these studies has been on oceanic islands, but the same principles are applicable to any isolated community (Deshmukh 1986).

On many flat marine shelves we find a different type of island setting as the coralline boulders which lay upon these shelves serve as habitats for numerous crustaceans, molluscs, and echinoderms.

These organisms are further isolated by the high predation rates which exist in these areas, deterring any boulder denizens from

leaving their protective dwellings. For these islands we proposed that the species richness and number would vary with boulder volume, porosity, and depth.

MacArthur and Wilson (1967) found that the number of species on a given island is usually related to the area of the island. Furthermore, species number has been positively correlated with area (Nybakken 1993). MacArthur and Wilson's area was a measure of the two-dimensional size of their islands. This area would be inadequate for our boulders, since a two-dimensional measurement would not account for boulder girth. For this reasons boulder volume was substituted as a better approximation of our island size.

MacArthur (1965) also stated that much of what constrains diversity has to do with the physical nature of the habitat. The structural complexity of a island can affect diversity by creating more and varied habitats, as well as by providing competitive refuges and/or prey refuges (MacArthur and Wilson 1967, Hixon 1991). Typically, field observations have further indicated that local diversity does increase with habitat complexity (MacArthur and MacArthur 1961, Rosenzwig and Winakur 1966, Kohn 1967, Pianka 1967, Murdoch et al. 1972). For coralline boulders we also hypothesize that structural complexity will affect island diversity, with more porous boulders providing increased habitats and refuges.

MacArthur and Wilson (1967) showed that island distance played a key role in island biodiversity. For our coralline boulders we

propose that depth, or distance from the surface, would be the key player in determining boulder biodiversity. We hypothesize that increased depths will provide decreased sunlight which tends to be a major limiting factor in ocean communities.

Site

We conducted our study on the island of Moorea, French Polynesia (Longitude 149°50' W, Latitude 17°30' S). Our work was concentrated in Cook's Bay on the coastal shelf south of the Richard P. Gump Biological Research Station dock (see Figs. 1 & 2). The shelf consists mostly of coralline boulders and rubble. It had a characteristically flat shelf that was approximately 30 m in length and then broke off into a deeper trench (see Fig. 3).

Methods

We conducted a point-transect of the shelf in order to obtain a description of the typical bottom material. The transect started on shore, 1 m above the water line, and continued approximately 5 m beyond the shelf drop-off. Points were sampled at every half meter along a straight line across the shelf. The bottom material at these points was measured for average diameter in cm.

We established five line-transects (T1-T5) along the shelf, running from the shoreline out, at bearings of 80° east of north. The transects began on shore, 1 m above the water-line and continued

out to 4 m beyond the shelf drop-off into the bay, for a total length of approximately 35 m. The transects were 3 m apart from each other, starting at transect T1 working south. Both ends of the transect were marked with rebar.

Transects were tied into a benchmark at the station using compass bearings and distance measurements. A heading of 275° North (North 85° West), 18.6 m was taken from the southwest corner of the station lab to a cement pole at the edge of the station boat ramp. Another heading was taken from the cement pole to transect T1 on the shoreline of the shelf: 182° North (South 2° west), 29.1 m (see Fig. 2).

Boulders were sampled at even intervals of 5 m along the line-transects, starting at m 0, the water end of the transect (see Fig. 3). If a boulder did not lie along the line transect, the nearest boulder to the point was taken. Only non-buried coralline boulders with a diameter of 14 cm or greater (a plastic dish was used as a guide) were considered in our study.

Before removal, the depth of the bolder was taken, with a meter stick in water less than 1 m, or in water deeper than 1 m, with a weighted rope, which was marked with a knot and measured later with a meter tape on shore. Time of day was also noted.

Boulders were removed from the shelf and transported to shore in a plastic bag or bucket. To remove the boulder, the bag or bucket was

lowered down to the level of the boulder and allowed to fill with water. The boulder was then placed into the bag or bucket with minimal vertical or horizontal movement, and was closed off in the case of a bag, or raised above water level in the case of a bucket, to minimize any possible loss of animals, especially quick-drop species. The boulder was then carried to shore.

Out of water, the boulder was placed into a plastic tank (area = 1351.1 cm2) filled with salt water. To obtain an approximate measure of volume, the amount of water displaced was measured using a meter stick and a permanent mark on the side of the tank. The boulder was then placed into a pre-weighed bucket partially filled with salt water, and weighed on a bathroom scale. Density was calculated by taking the boulder mass or weight and dividing by the water displaced or volume.

Three measurements of the boulder were then taken to approximate the most fitting geometric shape to obtain a measure of boulder volume.

The boulder was then broken up with hammers, and all representatives of the Kingdom Animalia were sampled and counted. Only those organisms visible to the naked eye were taken. Boulders were broken up until only solid pieces with no observable organisms on them remained. A running tally of all organisms was kept for each boulder. Furthermore, any water in the plastic bag, buckets, or tank used for transporting, measuring, and weighing the boulder was

inspected for organisms. Any organisms found were added to the tally. All organisms were then returned back to the ecosystem.

Identifications were made using Raven and Johnson (1989), Meglitsch (1972), and Smith (unpublished).

Seven boulders were sampled and counted for transects T1, T2, T3, and T4. For transect T5 only four boulders were taken. Even sampling of transect T5 was stopped at meter 15, since at this point we felt that an adequate sample size had been obtained.

Preliminary analysis of the present data revealed gaps in the amount of deep and large boulders we had obtained, so we sampled additional boulders for a better representation of the shelf habitat..

We conducted a random stratified transect along transect T2. Only large boulders (volume of 8000 cm³ or greater) were taken at 5 m intervals along the transect, with a total of three being taken. For the deep boulders all five original transects were used. The boulder at m 2.5 or the nearest deeper, down slope boulder, was sampled. All other methods for removal, measuring, and breaking up of boulders were followed for both of these samples.

Results

The survey of substrate composition upon the shelf provided a good picture of particle size (see Fig. 4). Furthermore, it showed that 90%

of the substrate was smaller than our established boulder size of 14 cm in diameter (see Fig. 5).

We sampled 40 boulders and recorded quantifiable trends for our variables of depth, density, and volume. Richness measurements were made via the breakdown of organisms into three groups: number of individuals, number of operational testing units or OTU, and number of taxonomic classes. The class level was the lowest taxonomic level we could use with great confidence, as many of the organisms have no recorded breakdown into the lower levels, or were only identifiable by the very experienced invertebrate taxonomist. For example, snapping shrimp have no know record available to the genus species level, so identification would be impossible. However, an acceptable separation was still possible at these levels, with a total of 88 OTU and 17 taxonomic classes being found (see Fig. 6).

For depth we discovered that the number of individuals, taxonomic classes, and OTU showed a decreasing trend in relation to depth (see Figs. 7, 8, & 9). With density we were unable to recognize any trends for number of individuals, taxonomic classes, or OTU (see Figs. 10, 11 & 12). Volume played an important role in determining the number of individuals within a boulder (see Fig. 13), but showed very little importance in terms of the number of taxonomic classes or OTU (see Figs. 14 & 15). Further trends were also seen on the organism level and will be discussed herein.

Discussion

In 1967, MacArthur and Wilson derived their theory of island biogeography, and demonstrated the relationships between island size and distance to species diversity. With our coralline boulders, we attempted to prove similar relationships between boulder volume, depth, and density in relation to species richness. First we had to prove that our boulders were in fact islands and could be considered non-contiguous entities. The sampling of the shelf composition strongly supported this hypothesis, as 90% of the shelf was made up of uninhabitable substrate that was much too small for colonization. Furthermore, travel from one boulder to another is very unlikely, as predation upon the inhabitants is very high. Following initial planktonic colonization, it is very unlikely that any of the boulder denizens left their much safer boulder habitats.

Since we now had very plausible "islands" it was necessary to see how our different parameters affected the inhabitant composition. The volume of the boulder seemed like an elementary factor in terms of numbers alone, and did show definite trends in individual numbers (see Fig 13). Depth probably compounded the error seen, so boulders of similar depths were taken and used to reanalyze the effects of volume upon individual number. As can be seen in figure 16, the distribution is almost linear with an r² value of .79. Volume however seemed to have a very limited effect upon OTU and taxonomic class richness (see Fig. 15 & 17). Smaller boulders were obviously limited in numbers, but the coralline boulders contained

many different habitats within that provided opportunities for many different taxonomic classes to colonize. For instance, annelids and sipunculids were able to inhabit the much less porous centers, while crabs and other crustaceans were able to occupy the larger cavities near the boulder periphery, and urchins then dominated the larger indentations on the boulder surface and underside. Regardless of volume, these different habitats were usually present. Volume then played an important role in organism abundance, but not in taxonomic class richness.

Depth was also found to hold a very important role in determining species composition within the boulders. The number of boulder inhabitants appeared to decrease with depth, but this is somewhat compounded by the boulder volume (see Fig. 7). By isolating boulders of similar volume and comparing depths we see a much clearer picture, as depth does show a decreasing trend, with deeper boulders supporting less inhabitants to a minimum level of about 40 individuals (see Fig. 18). Taxonomic class changes with depth showed a very strong decreasing trend, with an r² value of .92 (see Fig. 19). One stray point was omitted from the regression as we felt it was an anomaly. This boulder appeared to be very new to the shelf, as its coral composition showed very little erosion compared to other boulders and in turn probably had less time for colonization. The taxonomic class richness then is less affected by volume, but more importantly by depth. Possible explanations for this trend may have to do with decreased algae growth at greater depths due to decreased sunlight. Furthermore it is possible that algae species are also less diverse at greater depths, and this algal base in turn may not be able to support as many taxonomic classes as the more diverse algal base in the shallow flats could. Sediment build-up along the edge of the shelf and the sloping cliff may also clog boulders and provide less suitable habitats than the cleaner shallow waters for both algae and boulder denizens.

Rex (1981) has demonstrated for most benthic organisms that diversity does not continue to increase as one goes deeper into the ocean. In fact, he has shown that diversity is higher at intermediate depths and decreases both downward and upward to the continental shelf. However, in our study of coralline boulders we find merely a downward trend with depth and its relation to diversity.

Depth also had interesting affects upon some species composition within the boulders. For instance, brachiopods and bivalves were almost non-existent past 1 m (see Fig. 20). This may be explained by the increased sediment load that could cause the bivalve to continuously expend energy to clear itself of sediment. The bivalve would then prefer the shallower, cleaner waters as was seen.

Density was initially thought to be a good estimate of boulder porosity which was hypothesized to provide more habitats and in turn increase richness. Density however failed to show how solid a boulder was, as some of our more solid boulders had a smaller density than other very porous boulders. This led to the belief that even though some coralline boulders seemed very solid, they were

made up of a lighter less deteriorated coral center. This center had no visible porosity, as it was more likely made of millions of small holes. Density itself had no effect on number of individuals, taxonomic classes, or OTU (see Fig. 10, 11, & 12). This could also be due to the hypothesis that the different substrates within the coralline boulders allowed for different habitats. Therefore a very solid boulder may have 30 sipunculids, and a very porous boulder may have 30 crabs. Their individual and taxonomic class richness would then be identical even though density and porosity were different. This is of course unproved and seems very hard to do so without any good measurement of porosity. We will conclude though that density has no noticeable affect upon boulder diversity.

Predation also seemed to play an important role in increasing diversity within the boulders. Those boulders found with dwarf octopii, the major predator upon crustaceans within the coralline boulders, always had a high number of taxonomic classes. This could be due to the fact that predation may prevent competitive dominance and thus leads to increased diversity (Jones 1933, Paine 1966). However, the increased diversity could also be related to the habitats that the octopii chose, as these were the larger more porous coralline boulders.

Many of the boulders found seemed to be dominated by a single crustacean species. The species may have varied between different crabs, galatheids, and shrimp, but very often one organism would be more populous than the others found. This leads one to the

hypothesis that the boulders may serve as breeding grounds for those similar species and allow for exclusion of other species, as the boulder becomes a well defended home to this dominant species.

This is hard to examine with our data though, as more often than not the most populous species were crabs that were too tiny to identify with the naked eye.

Disturbance was hypothesized as possibly playing an important role in determining boulder species composition, as overturning of boulders by large storms affects diversity (Sousa 1979). A few storms passed through the area during our study, and large wave activity was seen upon our shelf, but inspection following these events showed little to no disturbance of the boulders. As for human disturbance, this is always a growing problem and is tough to analyze. Development often increases sediment load into the oceans and this could have an affect upon boulder diversity as was hypothesized above. It would be impossible to say that human intervention doesn't affect diversity, as this problem is so prevalent today, but to quantify this effect is equally troubling as who can say exactly which human development caused what.

Conclusion

Through this study we have made strong correlations between boulder richness and its relationship to boulder volume and depth.

These seem to be the most important factors in determining richness as individuals increase with volume, and taxonomic classes decrease

with depth. Other factors such as density and non-human disturbance seem to have no effect, but further study on the latter is necessary. Furthermore, boulder porosity may have a large affect upon species composition, but a good measure of this parameter is necessary before any such hypothesis can be supported. A theory of coralline boulder biogeography may then be possible in the future after some of these other parameters have been investigated.

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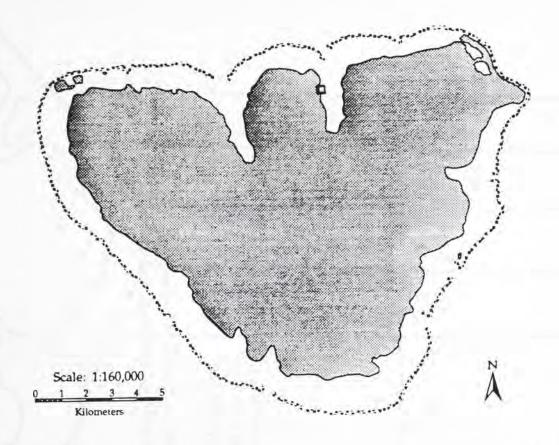
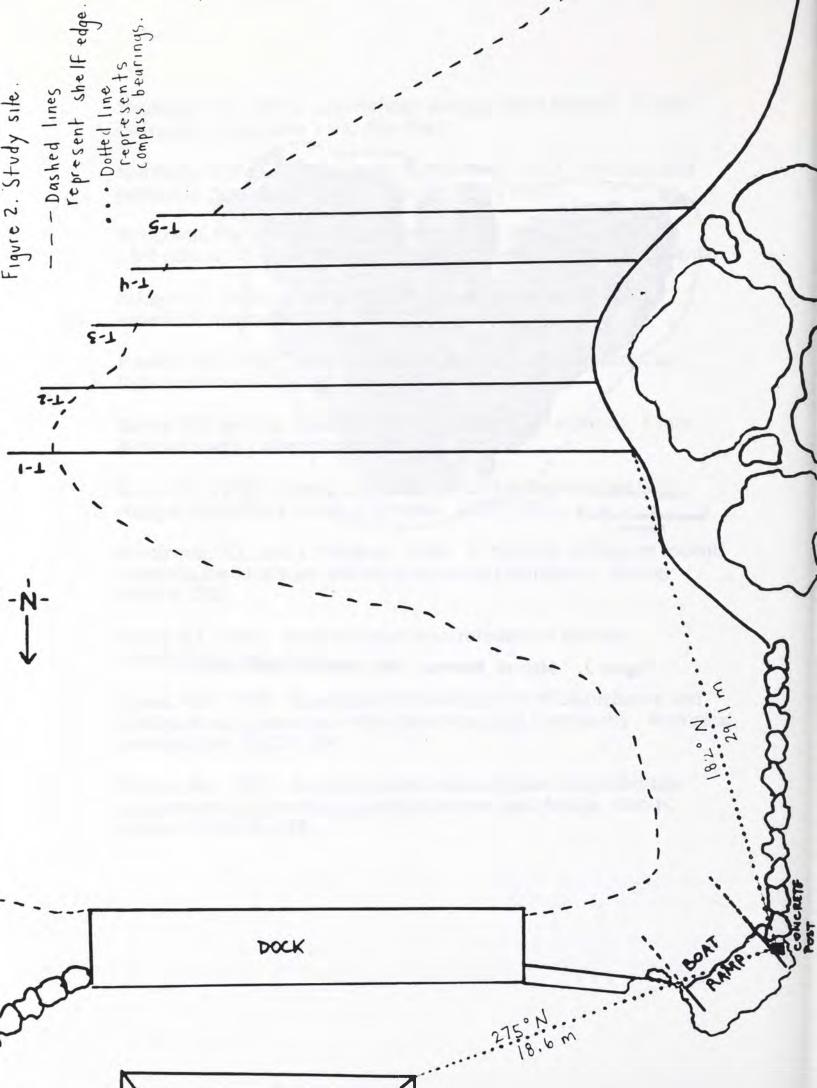
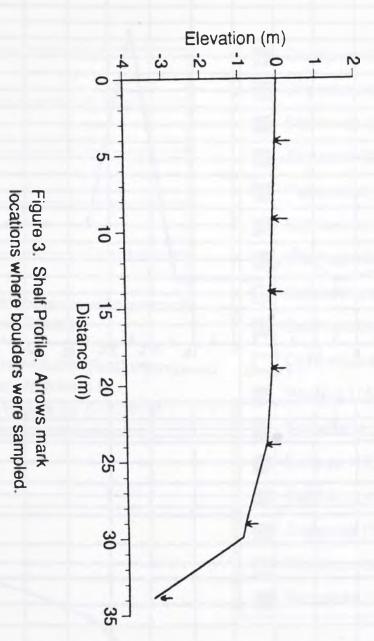
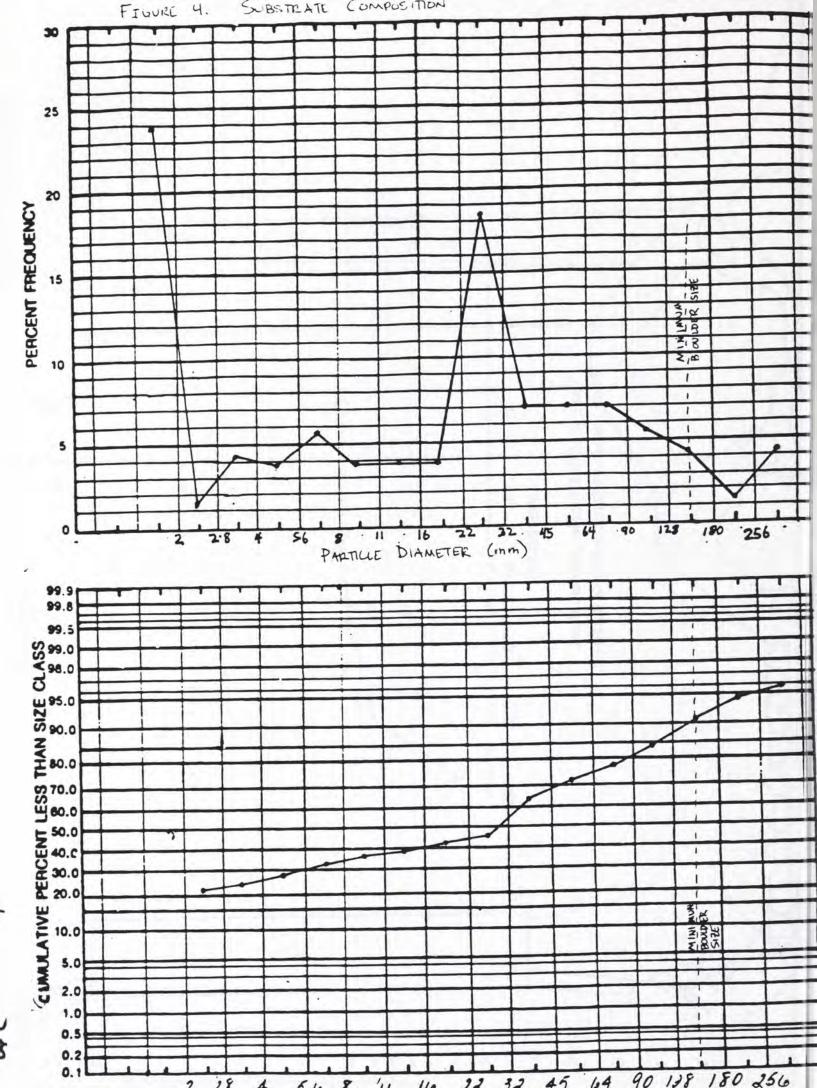


Figure 1. Map of Moorea. Box indicates study site.







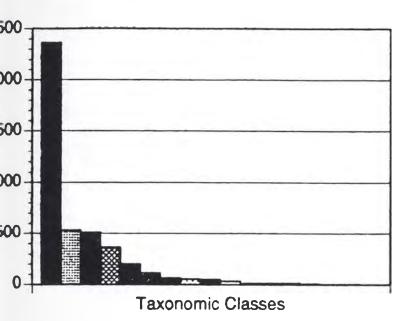
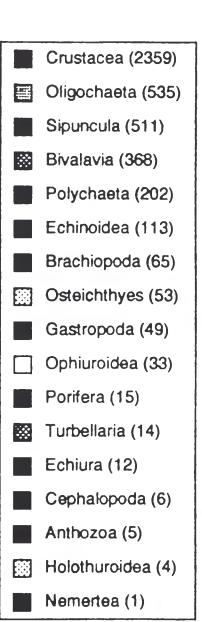


Figure 6. Number of Individuals found per each Taxonomic Class. Numbers in parenthesis are exact counts for number of individuals found within each taxonomic class.



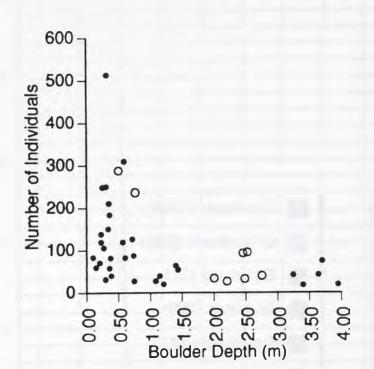
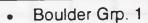


Figure 7. Boulder Depth vs. Number of Individuals. Boulder group 1 are those initially sampled, and group 2 are those added to complete the study (see text).



Boulder Grp. 2

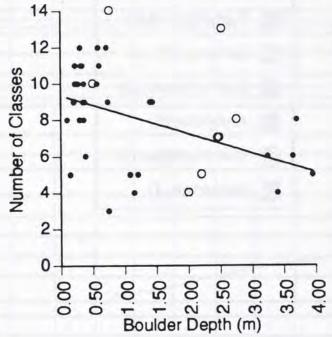


Figure 8. Boulder Depth vs. Number of Taxonomic Classes. Boulder group 1 are those initially sampled, and group 2 are those added to complete the study (see text).

Boulder Grp. 1

Boulder Grp. 2

 $R^2 = .23$

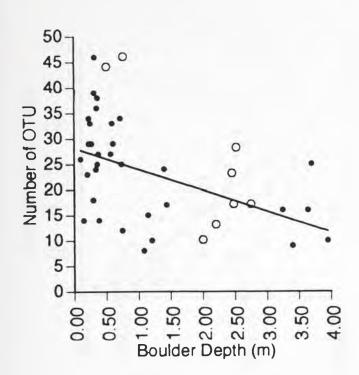


Figure 9. Boulder Depth vs. Number of OTU. Boulder group 1 are those initially sampled, and group 2 are those added to complete the study (see text).



o Boulder Grp. 2

 $R^2 = .18$

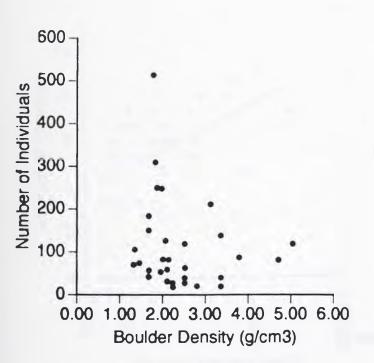


Figure 10. Boulder Density vs. Number of Individuals.

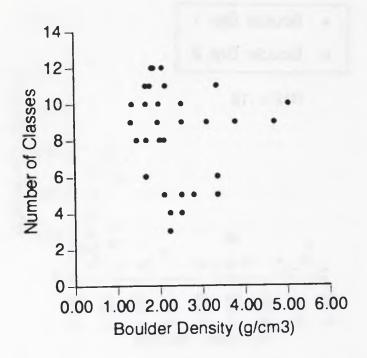


Figure 11. Boulder Density vs. Number of Taxonomic Classes.

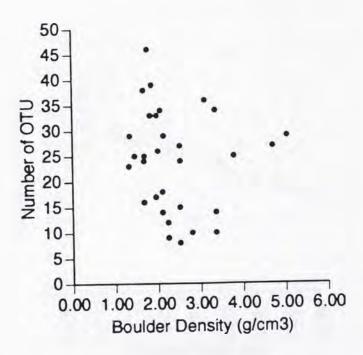
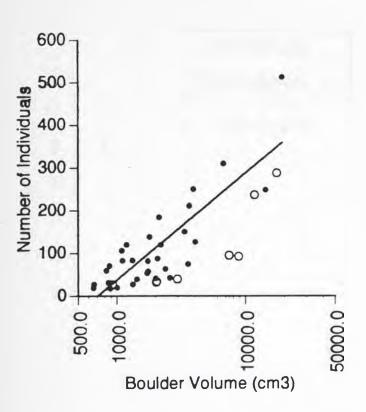


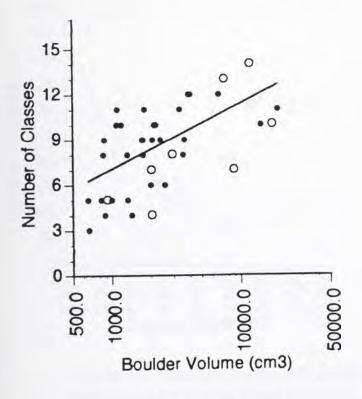
Figure 12. Boulder Density vs. Number of OTU.



- Boulder Grp. 1
- o Boulder Grp. 2

 $R^2 = .70$

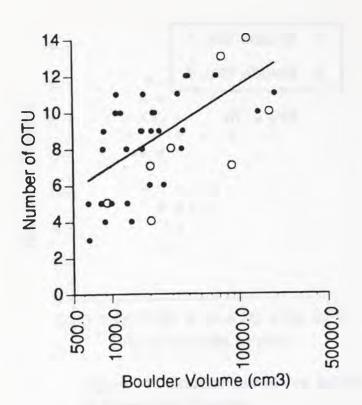
Figure 13. Boulder Volume vs. Number of Individuals. Boulder group 1 are those initially sampled, and group 2 are those added to complete the study (see text).



- Boulder Grp. 1
- o Boulder Grp. 2

 $R^2 = .34$

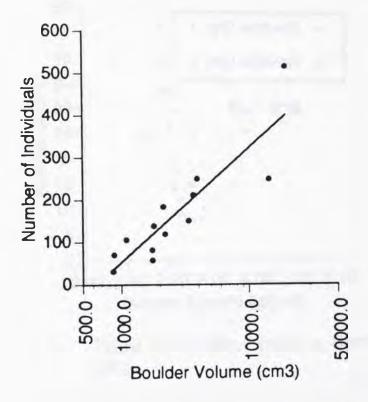
Figure 14. Boulder Volume vs. Number of Taxonomic Classes. Boulder group 1 are those initially sampled, and group 2 are those added to complete the study (see text).



- Boulder Grp. 1
- o Boulder Grp. 2

 $R^2 = <.01$

Figure 15. Boulder Volume vs. Number of OTU. Boulder group 1 are those initially sampled, and group 2 are those added to complete the study (see text).



 $R^2 = .79$

Figure 16. Boulder Volume vs. Number of Individuals for Boulders of Similar Depth.

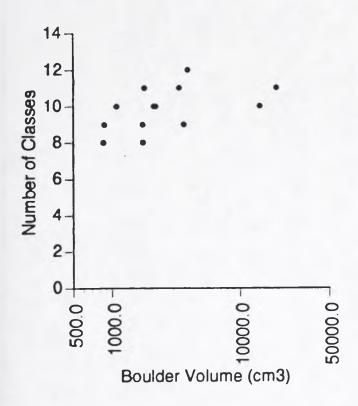


Figure 17. Boulder Volume vs Number of Taxonomic Classes for Boulders of Similar Depth.

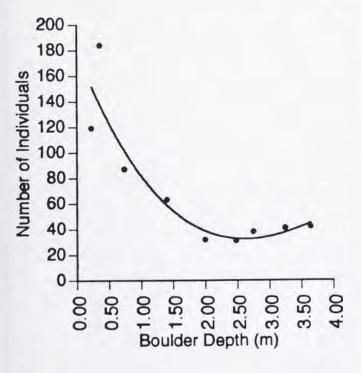
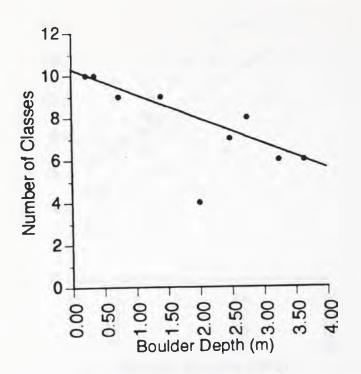
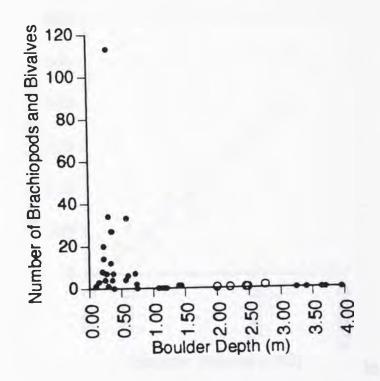


Figure 18. Boulder Depth vs. Number of Individuals for Similar Sized Boulders.



 R^2 with = .55 R^2 w/out = .92

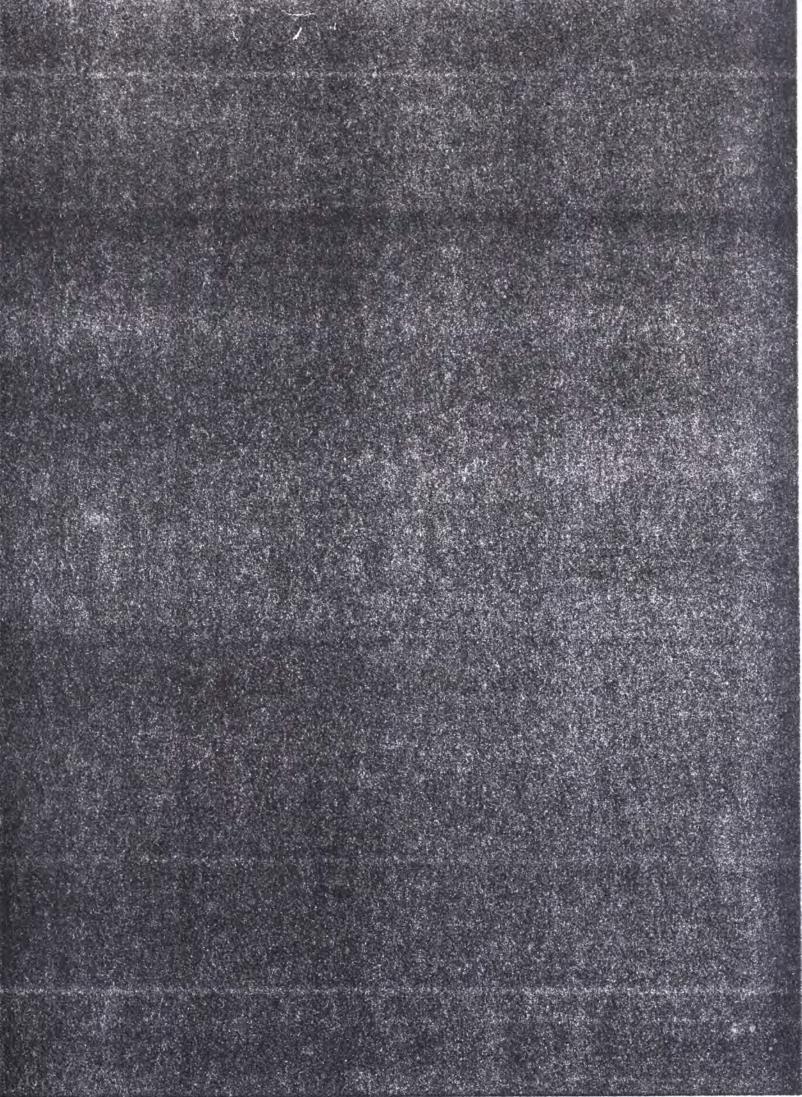
Figure 19. Boulder Depth vs. Number of Taxonomic Classes for Similar Sized Boulders. Regressions were done with and without the stray point, as it was considered an anomaly (see text).

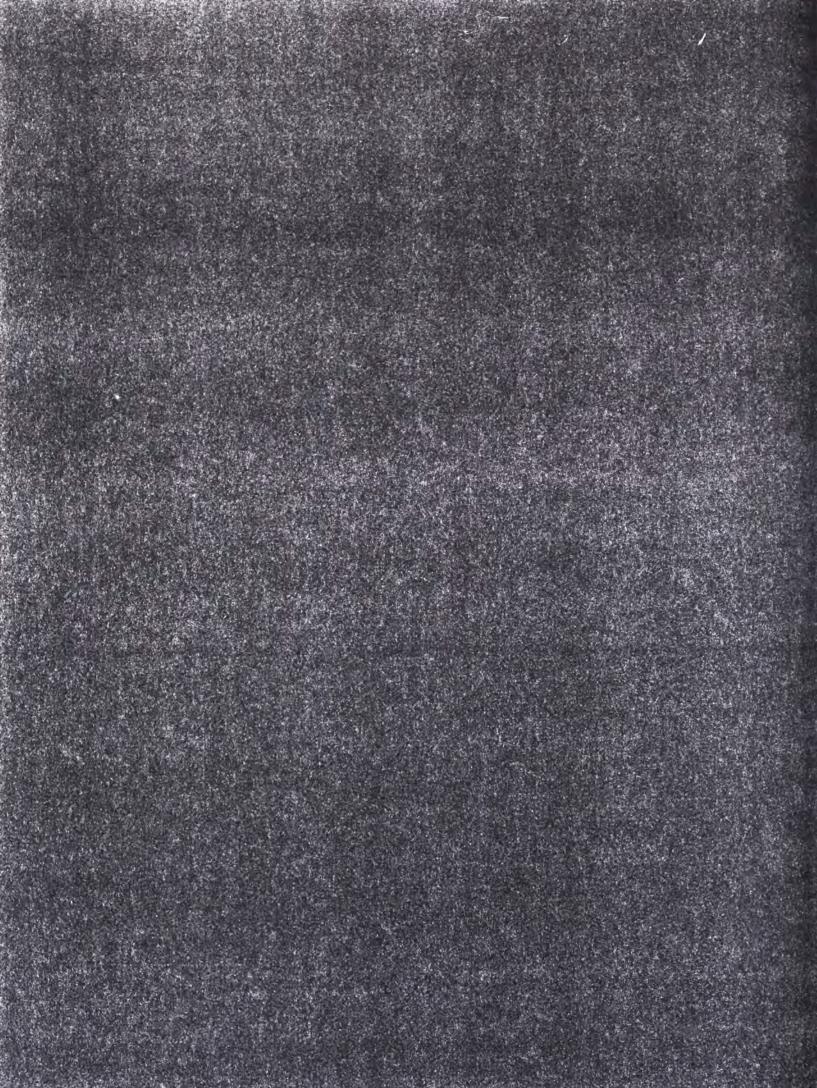


Boulder Grp. 1

o Boulder Grp. 2

Figure 20. Boulder Depth vs. Number of Brachiopods and Bivlaves. Boulder group 1 are those initially sampled, and group 2 are thse added to complete the study (see text).





Calcium Budgeting on a Tropical Reef

Abstract

A quick, inexpensive method of determining the rate of calcification over the algal crest on an island in the South Pacific (Moorea, French Polynesia) by measuring the depletion of calcium concentrations, and water flow rates was tested. Average depletion of calcium concentration was 17 mg/L (±16 mg/L) and average water flow rate was 170 L/sec (±50 L/sec) over a 1m wide "channel". The average rate of calcification was calculated at 1.4*10⁴ g CaCO₃/m²/day (±2.0*10⁴ g CaCO₃/m²/day). Depletion of calcium across the ridge was insignificant (.1<p<.2), and difficulties in the measurement of flow rates led to an overestimation of calcification rates by as much as an order of magnitude.

Introduction

Calcium plays an important role in the precipitation of carbonate by marine organisms in shallow waters. Kinsey & Hopley (1991) have estimated that 10⁸ tonnes carbon is deposited as calcium carbonate by marine organisms every year. This estimate was made based on measurements of alkalinity depletion as described by Smith & Kinsey (1977). In their method, samples are titrated with acid in order to release carbonate alkalinity from the water as CO². Corrections must be made for temperature and sample pH. In waters in which biological activity is high, as are the coastal reefs, alkalinity may be returned to the water by respiration and decomposition, thereby confounding this method. A rapid laboratory titration for the determination of calcium concentrations requires no complex calibration. It is therefore the aim of this experiment to determine whether calcium can be used as a conservative, mineral element to measure rates of reef growth, and indirectly monitor biological activity on the reef.

Calcium in Seawater

Calcium exists primarily in seawater as free calcium ions (Ca⁺⁺). Free calcium is ionically bound to carbonate ($CO3^{=}$), the principal form of alkalinity in seawater. In the open ocean, water is saturated or supersaturated with the ionic pair. When carbon dioxide or carbonate alkalinity is taken up by

photosynthetic organisms, the alkalinity is reduced and calcium carbonate is precipitated. Solubility of precipitated limestone increases under conditions of high alkalinity, as during periods of respiration on the reef, or under pressure, as on ocean floors below 4000m depth (Sverdrup, *et al.*, 1942).

Previous Work on Measurement of Calcification Rates

Smith (1973), measured rates of calcification on the Eniwetok reef flats using the alkalinity-based method described in Smith & Kinsey (1977). This method determines the difference in carbonate alkalinity of water between two sites on a reef. Calcium carbonate deposition can be calculated, as one mole of CaCO3 is precipitated for every two equivalents of carbonate alkalinity removed. This method has been applied to areas on the island of Moorea twice within the last five years. Le Campion-Alsumard *et al.* (1993), reported a net calcification rate of 5.22 g/m²/day on October 24-25, 1988. Gattuso, *et al.* (1993) measured the net calcification rate as 24.3 g/m²/day in November and December, 1992. Both studies were conducted at the Tiahura reef flat on the northwest corner of the island.

Methods and Materials

Study Area

The experimental site was located on Moorea, French Polynesia (17°29'S;14°50'W) at a point between Cook's Bay and Opunohu Bay known as Vaipahu (figure 1). A transect extended from a point 1050m from shore (as measured by triangulation) to the shoreline at the Moorea Lagoon Hotel. Three points were located along this transect: one site approximately 50 meters outside the algal ridge, hereafter called the forereef site; one just inside the algal ridge, 950m from shore, called the ridge site; one near the shoreline, at 15m, called the shore site. The ridge itself was measured and found to be 32.2m wide along the transect. On November 3, 1993, a reinforcement bar was planted in the algal ridge, 980m from shore, to be used as a gauge of wave heights.

Methods of Analysis

Water samples were taken ten inches below the water's surface and stored in closed polyethylene water bottles. Samples were all analyzed within 24 hours of collection. Analysis was done as per method 311C (APHA, 1985), with a slight modification as deionized or distilled water was unavailable for the analysis. Calcium concentration was determined by a titration with ethylenediaminetetraacetic acid (EDTA). At a pH of approximately 12,

magnesium is precipitated from a water sample as magnesium carbonate. EDTA can then be added to selectively complex with calcium ions. When no calcium is present in the water sample an indicator, ammonium purpurate (Murexide™) will undergo a color change. A standard of 10ml of 1g/L CaCO₃ (4.08mg Ca⁺⁺) and a 50ml blank of tap water was run with each set of samples. 3ml of sample was then diluted with 47ml of blank. Calcium concentration in the sample was then calculated using the equation:

$$[Ca]_{sample} = (A-(C*47ml/50ml))*B/.003L$$

in which A is the volume of EDTA solution used to titrate the sample, B is the ratio of mg Ca**: ml EDTA determined from the standard, and C is the volume of EDTA solution needed to titrate the blank.

Experimental Design

Two experiments were run to analyze the depletion of calcium over two time frames. Experiment #1 ran from November 1-17, 1993. This experiment was to determine the daily variability of calcium concentrations. Experiment #2 was run over a 24-hour period, November 11-12, 1993, in order to measure diurnal variations in calcium concentration.

Samples were taken every other day during experiment one. Samples were always taken in the order: forereef, at approximately 0815; ridge, at 0830; then shore, at 0920-1000. Between October 26 and November 5, different procedures to ascertain water velocity were tried in order to determine an effective and quick method. On October 26, direct velocity measurements were attempted, first using a fluorescent dye, which dispersed far too rapidly in the strong surge, and then using a water bottle tied to ten feet of cord. The water bottle method was effective and was used to determine surface current when filled with air, then bottom current when filled with water to neutral buoyancy. Also on this date, three rebar stakes were pounded into the ridge to serve as a tidal gauge. These rebar stakes were not marked well enough to be seen, so on November 3, the stakes were marked with high-visibility flagging at 10cm divisions. By November 7, one stake had fallen, and much of the flagging had gone with it. On the 11th of November, the flagging was restored, and tidal measurements were possible until the end of the experiment. Twenty wave crest and gully heights were measured and the results averaged to find wave amplitude. Whenever tidal measurements were made, three sets of ten wave crests were timed, the results averaged, and then divided by 9 to find the wave period.

In order to determine the rate of storage of calcium on the reef, both the flow of water and the change in the composition of that water must be monitored. Water flow in a channel can be mathematically represented as Q=hvw, in which h is the average height, v is the average velocity, and w is the width of the channel. If the width of the channel is set arbitrarily at 1m, then the height and velocity must be determined to find water flow. Height can be easily determined by watching waves moving over the reef, but in order to determine water velocity, more complex equipment is needed. As this equipment was not available, an approximation was made for the average water velocity. In shallow water the surface velocity is dependent on the average height of the wave, $v=(gh)^{1/2}$. Since the water over the ridge is so shallow, surface velocity was taken to be the velocity of the entire column. Therefore, in the shallow water environment of the reef, water flow was approximated as $Q=h(gh)^{1/2}(1m)$.

On November 11, the diurnal study began at 0800. Samples were taken every four hours, for a total of 6 samples at each site. Samples were taken simultaneously at 0800, 1200, 1600, and 2400. Samples were unavailable from the forereef during the night, so the 2000 samples and 2400 samples were from the ridge and shore sites only. The 2000 shore sample was taken at 1915 rather than simultaneously with the ridge. At 0500 a ridge sample was taken, a forereef sample was taken at 0515, and a shore sample at 0530. During daylight hours, wave measurements were taken using the tidal gauge and period measurement as in experiment one.

Results

Experiment 1

The results of the calcium analyses are plotted versus date in figure 2 and presented numerically in table 1. Concentration at the ridge is consistently lower or equal to the forereef sample. Shore samples vary widely in relation to the forereef. Average concentrations for each site are shown in figure 3. A test of the difference between the [Ca]_{forereef} and the [Ca]_{ridge} proves insignificant (.05<p<.10). Depletion from forereef to shore seems unlikely, as concentrations at the shore actually exceeded concentrations at the ridge by an average of -.04mg/L.

Water velocity was directly measured on 10/26/93. Surface current averaged 1.1m/sec (n=5), while the neutrally buoyant bottle averaged .7m/sec (n=5). Measurements of velocity by the tidal gauge averaged 1.4m/sec over the five days on which measurements were taken. Changes in concentration were combined with water flow data to calculate calcium flow and aragonite

deposition (table 2). Differences in calcium concentrations between forereef and ridge appear strongly correlated with water flow ($r^2=.94$, Q=4.7+184 Δ [Ca]).

Experiment 2

Data collected during the diurnal study is presented in table 3 and plotted in figure 4. Though data is sparse, a general trend can be seen in the calcium concentrations behind the ridge. The concentration has two peaks at 1200 and 2400 hours, corresponding to the high water levels of Moorea's solar tides.

Discussion

Comparison of Results with Previous Work

The rates of calcification presented here are 3 orders of magnitude higher than the rates determined by Gattuso, *et al.*, and Le Campion-Alsumard, *et al.* The figures are three orders of magnitude higher than the estimate of 9*10³ g CaCO₃ by Chave, *et al.*(1983) for the algal ridge. Assuming a density of 2.9 g aragonite/cc (Carmichael, 1984), the growth rate of the algal ridge would be 1.8m/year. This is nearly 20 times the highest growth rate attributed to calcifying organisms (Chave, *et al.*, 1983).

Calcium Depletion and Flow Rates

The correlation between calcium depletion and water flow is a perplexing find. It would seem that the decrease in residence time of water over the ridge would cause a negative correlation, since organisms living on the reef would have more time in which to remove calcium from the overlying waters. Instead, a positive correlation was found. This is most likely due to a nutrient limitation, which causes calcium uptake to rely on carbon or iron flow, more than simple biological activity. This also might be due to bioerosion on the ridge, which is at a minimum when waves are too powerful for grazers to hold fast to the ridge.

Sources of Error

Many assumptions were made in order to perform the calculation of calcification rates. First, it was assumed that the rate of calcification at 0800 hours was representative of the rate for the entire day. It was hoped that the diurnal study would shed some light on the validity of this assumption, but the lack of forereef samples during the night made any sort of analysis of diurnal rates impossible.

The major assumption made in the study was that used to calculate velocities. The surface velocity of the wave was considered to be the average velocity of the entire water column. In a theoretical wave this is absolutely false, as the average velocity of the whole wave mass should be zero, with water flowing backward in troughs to replace water moving forward with the wave crests. This does not seem to be the case on the algal ridge. Since the troughs of the waves typically leave the ridge dry, water moving forward over the ridge would not have any means of escape backwards.

Another assumption made was that the wave shape was a sine curve. Water waves can remain stable with a minimum angle between troughs of 120° (Tricker, 1964). In this scenario, the water flow would be described by the equation Q=1.73h²/T (in which h is the height of the wave). Were the wave of this form, the average water flow would be 19 L/sec, and the average rate of calcification would be 2.5*10³ g CaCO₃/m²/day. Without knowing the shape of the wave, it is impossible to say with confidence whether the actual rate is closer to one extreme or the other.

Conclusions

The results of this study were a mixed success. The method for the determination of depletion of calcium concentration over the ridge was effective, and was correlated to an environmental factor which was easily observed. However, the failure of the method for the measurement of water flow and the lack of information on the diurnal variability of calcium depletion make immediate application of this method for biological monitoring impossible. Further research on this topic should continue in an attempt to make correlations between wave heights and water flow as well as calcium depletion during different times of day, so that a record of tidal height would be all that would be required to perform a long term, continuous analysis of the rate of calcification on the algal ridge.

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- Figure 1. The island of Moorea with a closeup of the study site and sampling locations.
- Figure 2. Data collected from calcium analyses on the three sampling sites, experiment one (11/1/93-11/17/93).
- Figure 3. Average calcium concentrations at the three sites during experiment one (11/1/93-11/17/93). Bars are equivalent to one standard deviation.
- Figure 4. Data from calcium analyses during experiment two, (11/11/93-11/12/93).
- Table 1. Concentration of calcium determined by analyses performed on samples from three sites, experiment one (11/1/93-11/17/93).
- Table 2. Tidal measurements, 11/5/93-11/17/93, combined with calcium depletion over the ridge to calculate water speed, mass flow and rate of calcification (see text for equations).
- Table 3. Calcium concentrations during experiment two (11/11/93-11/12/93) at the three sampling sites.

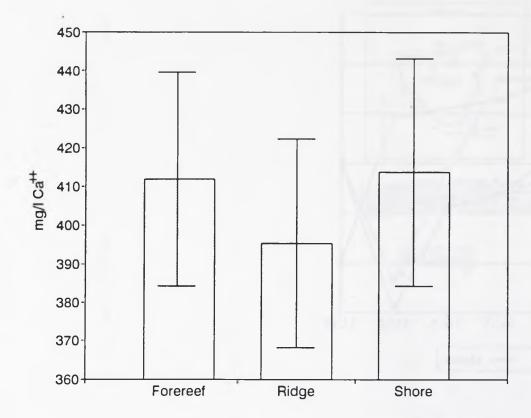
	Concentrations			Depletion		
	[Ca]fore	[Ca]ridge	[Ca]back	fore-ridge	fore-back	
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
AVG	412	395	414	17	-0.04	
STDEV	28	27	29	16	37	
Date						
11/01	413	408	442	5	-29	
11/03	410	409	430	1	-20	
11/05	449	442	424	7	25	
11/07	415	384	375	31	40	
11/09	435	402	433	32	1	
11/11	434	388	426	46	8	
11/13	397	382		15		
11/15	353	341	419	12	-66	
11/17	400	400	361	0	39	

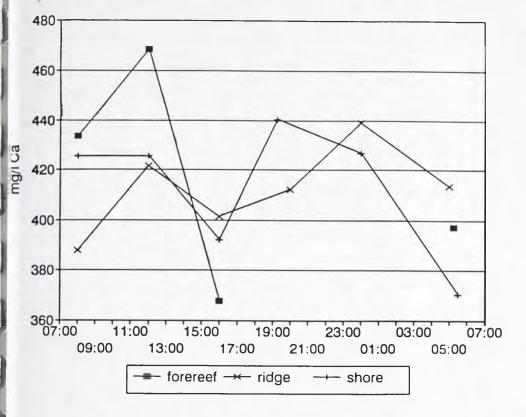
		Tide Gauge		Ridge	Water	Water	Calcium	CaCO3
	High	Low	Period	Depletion	Velocity	Flow	Flow	Deposition
	(cm)	(cm)	(sec)	(mg/L)	(m/sec)	(L/sec)	(g/sec)	(g/m ^ 2/day)
AVG	33.0	4.7	7.5	16	1.35	260	5.30	1.4E+04
STDEV	6.7	1.9	0.8	18	0.14	86	7.33	2.0E+04
Date								57900
11/05	26.7	4.8	8.1	7	1.24	196	1.37	3.7E+03
11/11	43.5	7.0	8.2	46	1.57	397	18.09	4.9E+04
11/13	35.8	5.0	6.3	15	1.41	288	4.27	1.1E+04
11/15	30.0	5.0	7.0	12	1.31	229	2.76	7.4E+03
11/17	29.2	1.7	7.8	0	1.23	189	0.00	0.0E+00

Turn w

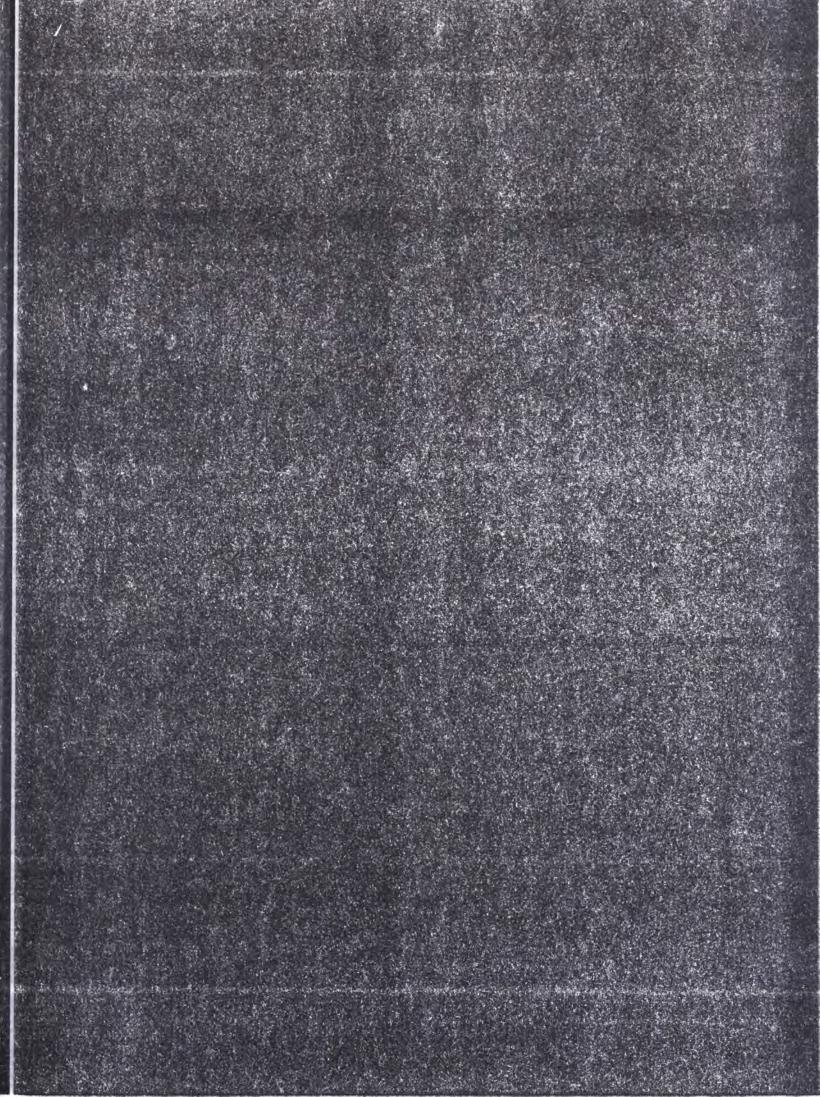
	Concentrations			Depletion		
	[Ca]fore	[Ca]ridge	[Ca]back	fore-ridge	fore-back	
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
Time						
08:00	434	388	426	46	8.048193	
12:00	468	421	426	47	42.92369	
16:00	368	401	392	-33	-24	
19:15			440			
20:00		412				
00:00		439	427			
05:00		413				
05:15	397					
05:30			370			

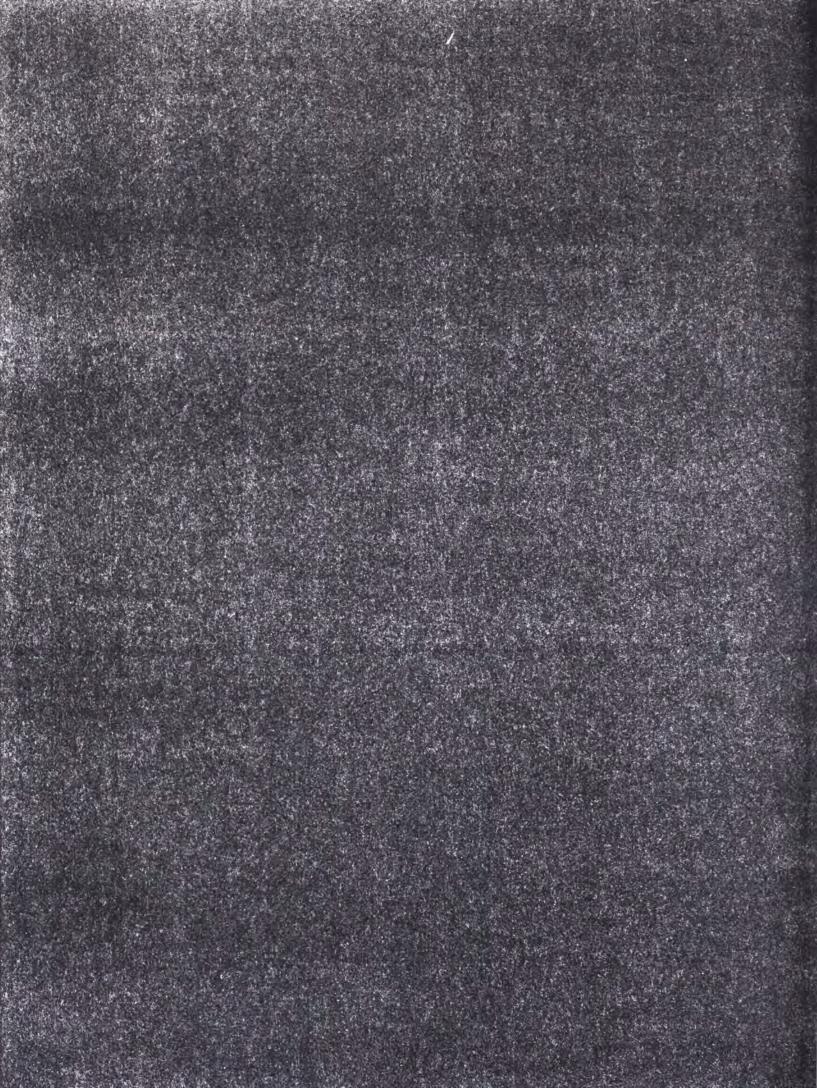
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Distribution of an Invasive Introduced Plant,

Miconia calvescens,

on the Island of Moorea, French Polynesia

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Abstract:

This paper presents the results of field reconnaissance efforts to map the distribution of Miconia calvescens (subsequently referred to as Miconia), an invasive introduced plant species on the island of Moorea, French Polynesia. A survey was accomplished of major watersheds, highlands, and montane landforms to identify the presence or absence of Miconia. Upon verification of Miconia presence in a surveyed area, more detailed field observations were recorded. Data sheets were compiled for each occurrence including a description of the landform, slope, elevation, and aspect of the site. A detailed description was recorded with respect to precise location, structure (canopy cover, height, abundance, etc.) and associated species for each Miconia occurrence. Miconia was observed in four highly invaded areas. Miconia was observed in the elevation range of 20 to 898 m above sea level. Miconia occupies 741.9 hectares or 31% of the 2413.4 ha surveyed in this study. Included is a discussion of possible physical and biological mechanisms facilitating and/or inhibiting the Miconia invasion. Possible relationships between Miconia's observed distribution pattern and history on Moorea are presented. And finally, management and/or control implications are reviewed.

Introduction:

Miconia calvescens (subsequently referred to as Miconia) is an arborescent species in the Melastomataceae family native to South and Central America (Hurley, 1991). Miconia was first introduced to the island of Tahiti in 1937 at a botanical garden by Harrison Smith, a Harvard physicist (Gaubert, 1992). Fifty-six years later, Miconia is now found on 60% of Tahiti's landmass. Scientists estimate 1/4 of indigenous Tahitian species are threatened with extinction (Gagne and Montgomery, 1992).

Thomas (1980) showed that on islands invasive plant species can suppress and eventually kill established forest trees through

shading and inhibiting the subsequent recruitment of native species. *Miconia*'s large (>1 m long) dark green leaves with purple undersides enable it to thrive in shade as well as sunlight and provide excessive competition for native plants (Gagne and Montgomery, 1992). After only a few years of growth, a *Miconia* tree can produce more than 100,000 seeds annually (Hurley,1991).

Possibly as a result of avian seed dispersal or tropical storms, Miconia has been dispersed from Tahiti to Moorea and Raiatea islands (Thibault and Monnet, 1990; Meyer, in press)(Figure 1).

First observed on Moorea on Mouaputa summit in 1974, *Miconia* has subsequently been observed at several other areas on the island (Meyer, in press). The primary objective of this study is to elaborate on the locations of *Miconia calvescens* and provide a more detailed map of its distribution on the island of Moorea. In addition, a discussion of management and/or control implications is presented.

Material and methods:

Fieldwork was undertaken between October 2, 1993 and November 19, 1993. Fieldwork was accomplished on foot, with an attempt to survey all of Moorea for the presence of *Miconia*. Due to time constraints imposed by the six-week fieldwork period, only areas on the eastern half of the island were surveyed (Figure 2).

The 11 survey areas in this study are Paopao highlands,
Vaiterupe River valley, Opunohu Valley, Vaianae River valley,
Teaharoa highlands, Niuroa Valley, Vaipohe Valley, Mouaputa summit,
Papeahi River valley, Mount Rotui, and Hotutea Valley.

Several data sheets (Appendix) were compiled for each survey area. Each data sheet corresponds to a specific, relatively contiguous site within a survey area. All sites have been numbered and are illustrated on Figures 3 and 4. The specific boundaries of each site were selected based on observed ecological differences between the site and surrounding area. Thus, a *Miconia* occurrence such as that observed on Mount Rotui (see Figure 3) includes six separate sites as a result of differences in *Miconia* abundance and structure between the sites.

Included in these data sheets are site location descriptions based on references to the numbered main route PK kilometer markers and other geographic features found on maps created by Ministere de l'Urbanisme des Transports Terrestres in Papeete, Tahiti. Other environmental attributes such as the slope and aspect of a site were recorded. These two characteristics were estimated based on analysis of site position plotted on a topographical map. When observed, the *Miconia* plants at the site were described. The following descriptive parameters of the *Miconia* plants were recorded: structure (height and dbh), estimated percent canopy cover, abundance, anthesis status and associated plant species. The observational vantage point for each site was noted on the data sheets as being above and/or below the forest canopy. Supplemental observations were contributed by Tim Krantz (TK), Mary Power (MP), Ute Gigler (UG), and Chrissy Underwood (CU).

Data relating to the location and abundance of *Miconia*, as well as the type of observation (above or below forest canopy), are illustrated in Figures 3 and 4.

Values calculated for areas of sites were obtained by planimetric analysis of a topographic map (Figure 5). Note that values given for 'absent' do not incorporate the observed areas of negative findings along primary and secondary roads.

Visual observation was accomplished using 10 X binoculars and 40-60 X telescopes. Elevation measurements were obtained using a Leitz brand electronic altimeter or from topographical maps. Road and trail distances were measured using a Rolatape brand measuring wheel.

Results:

Miconia was observed in 8 of the 11 surveyed areas. Miconia was observed in the elevation range of 20 to 898 m above sea level.

Miconia occupies 691.5 hectares or 29% of the 2363 ha surveyed in this study (Figure 5).

Field observations have identified four major *Miconia* invasion areas on Moorea(Figures 3 and 4): Mouaputa summit (site 23,24,26), Mt. Rotui (sites 1,2,4,5,6), Trois Cocotiers col (sites 9,10), and the ridge separating Papeahi River valley from Vaipohe Valley (sites 18,22,27). These sites comprise 98.7 percent of the total area where *Miconia* was observed. The four highly invaded areas are each inhabited by thousands of individual *Miconia* plants and occur on near-vertical slopes above 300m elevation.

Miconia occupies the forest canopy in three of the four highly invaded areas (Figure 6). The dominant tree in these areas is Metrosideros collina in association with Fagraea, Freycinetia, and various pteridophytes (Fosberg, 1992).

At Trois Cocotiers col, *Miconia* is present in the understory of *Hibiscus tiliaceus*, *Pandanus tectorius* and other arborescent species. At this location, hundreds of *Miconia* plants were observed growing on the caudices of *Angiopteris evecta*.

Apart from the four highly invaded areas, *Miconia* was observed at six other sites (7,8,12,13,14,27). These are isolated from the other major *Miconia* occurrences by at least 500 m. Five of the six sites are situated below 100 m and the sixth is at 260 m elevation. The six sites contain from 2 to 80 individuals each. No more than two *Miconia* individuals obtain canopy level at any one of these sites.

Less than 5% of all *Miconia* plants observed were in fruit and/or flower. Ranging in height from seedlings shorter than 1 cm to canopy level trees greater than 7 m high, *Miconia* was observed in areas both with and without forest canopy.

Miconia was absent in Vaiterupe River Valley (15), in Teaharoa highlands (19) and in Hotutea Valley (25).

Discussion:

Analysis of the observed pattern of *Miconia* distribution on Moorea may be useful in identifying specific ecological factors relating to inter- and intra-island seed dispersal and recruitment success. Identification of these factors may provide an explanation of the physical and biological mechanisms facilitating and/or inhibiting the *Miconia* invasion. In addition, the observed pattern of distribution may reveal certain aspects of *Miconia*'s history on Moorea.

The most obvious feature of the *Miconia* distribution on Moorea is the presence of four major invasion areas: Mouaputa summit (site

23,24,26), Mt. Rotui (sites 1,2,4,5,6), Trois Cocotiers col (sites 9,10), and the ridge separating Papeahi River valley from Vaipohe Valley (sites 18,22,27). These areas exhibit both the largest *Miconia* plants and the greatest abundance of *Miconia* plants. As *Miconia* plant size can be an indication of age (Meyer, pers. com.), these are perhaps the oldest *Miconia* occurrences on Moorea.

There are several facts which suggest that Mouaputa may have been one of the first introduction points of *Miconia* from Tahiti. For example, the largest *Miconia* plant observed in this study (height > 7 m, dbh>14 cm) was found on Mouaputa. Secondly, Mouaputa was the site of the first official observation of *Miconia* on Moorea (Meyer, in press) and Mouaputa is windward relative to Tahiti.

The presence of *Miconia* at these four areas may be a result of a single or several inter-island dispersal event(s). Endozoochory (Thibault and Monnet, 1991), tropical wind storms, and humans (Meyer, in press) have been suggested as possible dispersal mechanisms. The presence of *Miconia* at one or several of these areas may also be due to intra-island dispersal by the above listed mechanisms.

There are several environmental characteristics shared by these four highly invaded areas. First, they are all situated at elevations greater than 300 m above sea level. Plant community types vary with respect to elevation on Moorea. At these elevations, the dominant tree is *Metrosideros collina* in association with *Fagraea*, *Freycinetia*, and various pteridophytes (Fosberg, 1992).

In these four areas, *Miconia* is most abundant where it is associated with *Metrosideros collina*. *Miconia*'s ability to penetrate the *Metrosideros* forest may be due to the unique structure of this

forest. As *Metrosideros* trees are short statured (2 to 5 m high), *Miconia* trees can reach canopy-level and hence receive more sunlight than in taller forests at lower elevations.

In addition, *Miconia*'s ability to invade a forest may be regulated by the amount of leaf litter present on the forest floor (Gigler, 1993). *Metrosideros* trees have small (<5 cm long) leaves and do not produce as much leaf litter as other taller trees. Thus, the absence of leaf litter in areas of *Metrosideros* forest may facilitate *Miconia* invasion.

Another common characteristic of these four highly invaded areas is their slope. Miconia is most abundant in areas of very steep slopes (>75°). For example, on Mt. Rotui, Miconia is most abundant on the near-vertical west-facing cliff-face. Likewise, in the Papeahi River valley, Miconia is found in greatest abundance on the nearvertical northwest-facing upper valley headwall. Miconia's ability to colonize these steep slopes may be explained from two observations. First, steep slopes do not accumulate leaf litter as readily as flatter areas can. Thus, the gravitational removal of leaf litter down a slope might facilitate invasion. This may be the reason for Miconia's presence on Angiopteris evecta caudices on the south-facing slope of the Trois Cocotiers col. Although seeds can easily fall on and stick in the small grooves of a caudex, leaf litter can not. Leaf litter probably falls off the spherical caudices. Thus, the microslopes created by the caudices facilitate Miconia seedling survival. Secondly, a Miconia plant living on a sloped surface may have increased insolation as a result of sunlight being able to penetrate not only from above the plant, but also from beside it.

Finally, the relatively high presence of *Miconia* in these four areas at elevations above 300m may be related to the amount of orographic precipitation received. Measured rainfall data suggests that the amount of precipitation in an area varies according to elevation on Moorea (Stoddart, 1992).

On Figures 3 and 4 it can be seen that *Miconia* plants are most abundant at elevations below the four highly invaded areas on the west-facing, or leeward, slopes of the highly invaded landforms. For example, it is clear that the west-facing surfaces below the summit of Mount Rotui are more highly invaded than those facing east. Likewise, sites 28 in the Paopao highlands is west of and below the highly invaded ridge separating Papeahi River valley from Vaipohe Valley. Also, site 26 is west of and below Mouaputa summit.

The dominant winds in Moorea are the Tradewinds. These winds blow from the North-east to the South-west and represent 50 percent of the wind in the area, as measured by the National Meteorological Service from Tahiti. Winds from the South-east blowing to the North-west represent 16 percent of the total. (NMST, 1958–1981) Together these two wind systems contribute to a dominant wind direction with a dominating western-heading component.

The distribution of *Miconia* plants on the west-facing slopes directly below the four highly invaded areas may be resulting from wind-blown seed dispersal. Observations made from the summit ridge of Mt. Rotui clearly indicate a greater abundance of *Miconia* plants on the leeward slopes. Moreover, the strength of these upper elevation wind currents is exhibited in the deformation of the plants growing along the summit ridges of Mt. Rotui. *Miconia* plants were observed at

this site having only 1 set of leaves positioned just below the apical meristem. The lower leaves have apparently been blown away. The 5 m high nearly leafless stems were completely lignified. Unlike most *Miconia* plants observed, ones with total stem lignification may be responding to a need for increased structural support.

Furthermore, *Miconia* seedlings were observed in greater abundance on the south-facing slope the Trois Cocotiers col than on the north-facing slope. This may be a resulting from seeds produced by *Miconia* plants on the summit blowing over the ridge with the south-heading component of the dominant Tradewinds. The summit ridge of the Trois Cocotiers col is situated between two peaks, both exceeding 800 m in elevation. These peaks may in some way contribute to the creation of irregular wind currents blowing through the col.

Miconia was observed growing in six additional sites (7,8,12,13, 14, 27). These sites are each isolated from the other Miconia occurrences by at least 500 m. Five of the six sites are situated below 100 m and the sixth is at 260 m elevation.

These six isolated *Miconia* sites may each be the result of individual dispersal events. These dispersal events were most likely intra-island, but also may have been inter-island. All six seem to be leeward of the major invasion areas.

The isolated sites in the Paopao highlands may be the result of west-heading wind-blown seeds coming from the ridge between Papeahi River valley and Vaipohe Valley. Endozoochory is also a possible cause. These three sites each contain less than 50 individual *Miconia* plants. No more than two *Miconia* individuals obtain canopy

level at any one of these sites. The low number of fruiting and/or flowering canopy height plants at these sights may be indicative of an initial difficulty *Miconia* may have in penetrating lowland forest. Forests at these elevations have a higher canopy, more leaf litter, and less sloped landforms than montane forests.

However, data from the isolated site Paopao highland site(2) may illustrate the process by which *Miconia* can get established in lowland forest. At this site, one canopy level *Miconia* plant (> 6 m high) was observed surrounded by more than 20 smaller (<3 m high) *Miconia* plants. The canopy level plant may have been the progenitor of all the other plants. This site illustrates one step in the process by which a single dispersal event can lead to a heavy invasion of the lowland forest understory.

The lowland forest (site 2) above the cow pasture at the base of Mt. Rotui is another example of forest where *Miconia* has yet to establish many canopy level positions. It does not appear that the absence of many *Miconia* plants in this area is due to a lack of invading seeds, because *Miconia* is abundant in the pasture (site1) below. If *Miconia* seeds are falling from the summit to the pasture, they may also be falling into the forest above.

The isolated *Miconia* occurrence (site 7) beside the pine plantation in the Opunohu Valley may be a result of human-assisted dispersal. Meyer (1993, in press) suggests the possibility that these pine trees may have been brought to Moorea as juveniles in buckets with soil from Tahiti. This soil may have been a unintentional transport mechanism for *Miconia* seeds.

Conclusion:

Field observations indicate the presence of four areas of heavy (>1000 plants) *Miconia* invasion. These areas are all at elevations above 300 m above sea level. Moreover, *Miconia* was observed at six additional sites. These are isolated from the other major *Miconia* occurrences by at least 500 m. Five of the six sites are situated below 100 m and the sixth is at 260 m elevation. The six sites contain from 2 to 80 individuals each. No more than two *Miconia* individuals obtain canopy level at any one of these sites.

These facts are especially interesting with respect to Vitousek, Loope, and Stone's (1987) assertion that "most lowland areas of...oceanic islands will continue to be dominated by exotic species, and invasions will continue to move into the uplands." *Miconia* on Moorea is doing the exact opposite of what they describe. It appears that *Miconia* currently dominates the highlands of Moorea, and is moving downwards.

In almost all cases the successful elimination or control of invasive introduced species has only been possible where management has been initiated during the early stages of the invasion (MacDonald, Loope, Usher and Hamann, 1989). It seems clear that it is too late to remove the founder *Miconia* populations from Moorea. *Miconia* is abundant on near-vertical cliff-faces in several major invasion areas where humans can not safely go.

The most realistic approach to this problem seems to be one of control. Once all major invasion zones have been identified, a program focusing on containment using manual eradication may prove beneficial.

Areas deemed valuable for having rare plant life or noteworthy attributes and are still free from invasion can be set up as protected reserves where routine monitoring systems can be installed. This may involve trail improvement programs to better assist people in their efforts to survey the areas.

It has been suggested that in the case of a plant species with wind blown seeds, it is often necessary to create impermeable barriers along reserve boundaries or to initiate control programs in areas adjacent to reserve areas in order to limit invasive species recruitment (MacDonald, Loope, Usher and Hamann, 1989). Experiment of this sort may be attempted at the top of Hotutea Valley, where Miconia has yet to invade.

The future of the native plant community on Moorea is threatened by the invasion of Miconia calvescens. Whether or not human intervention can preserve these species is unknown. Acknowledgements:

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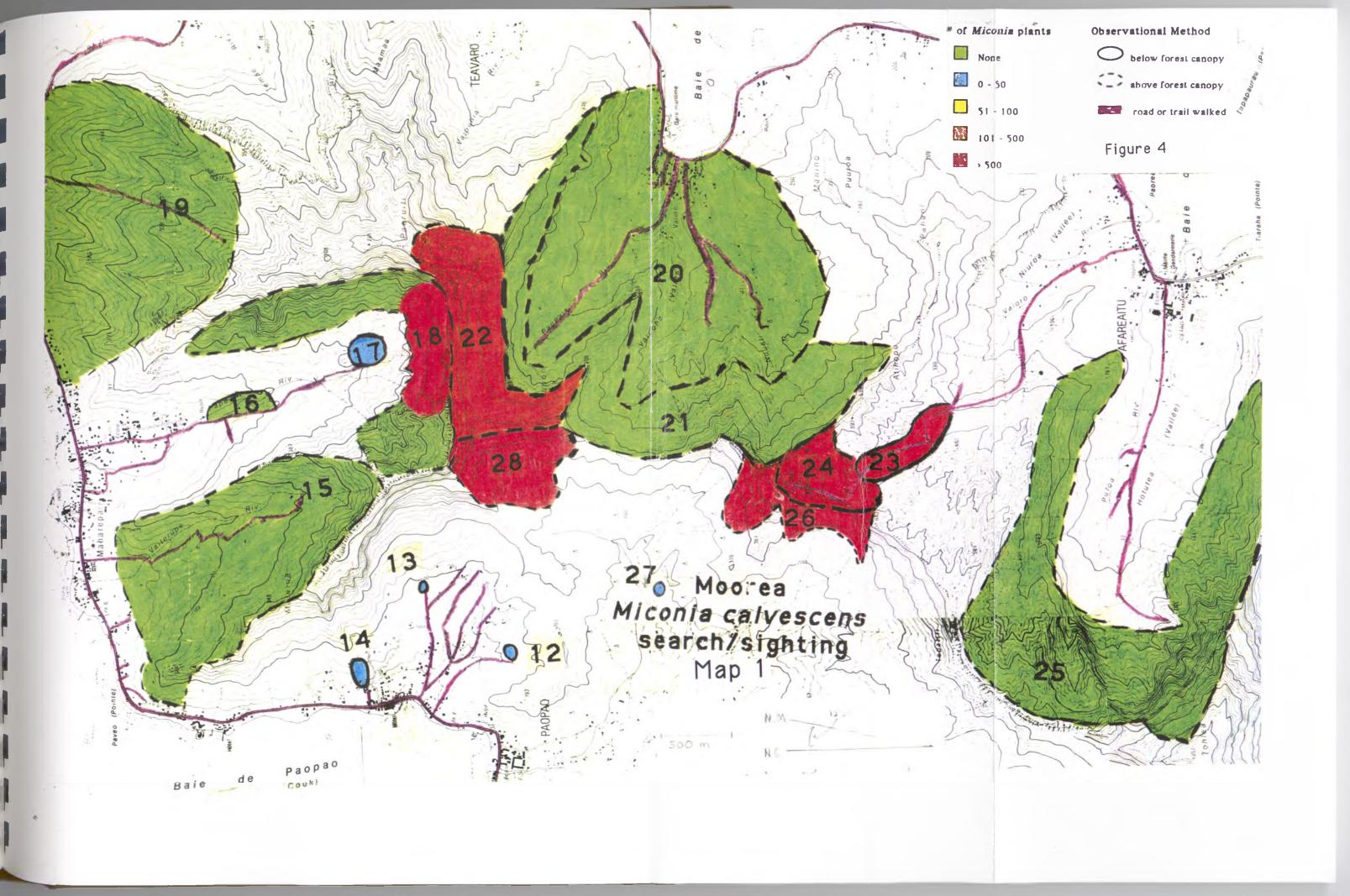
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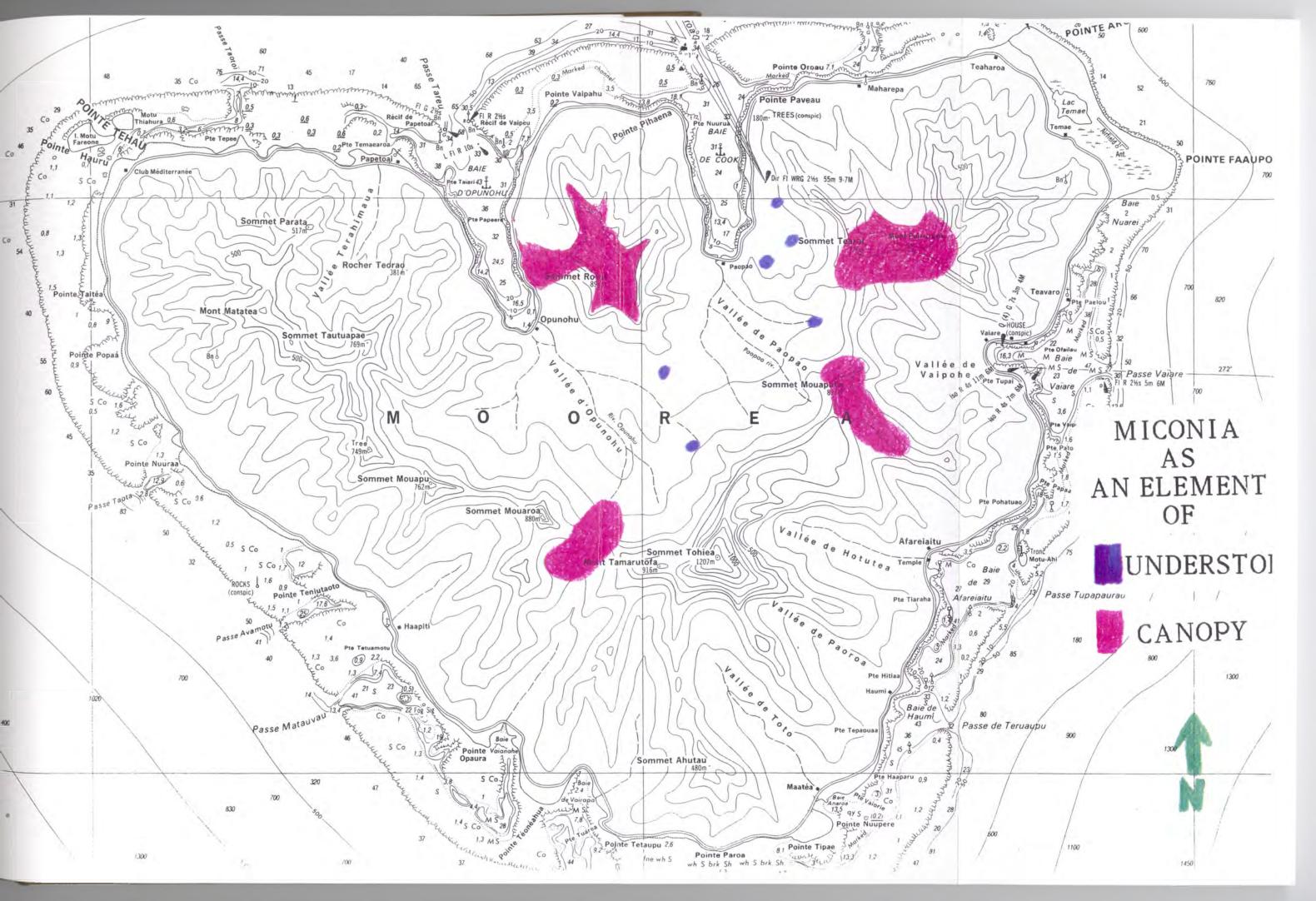
Figure 1

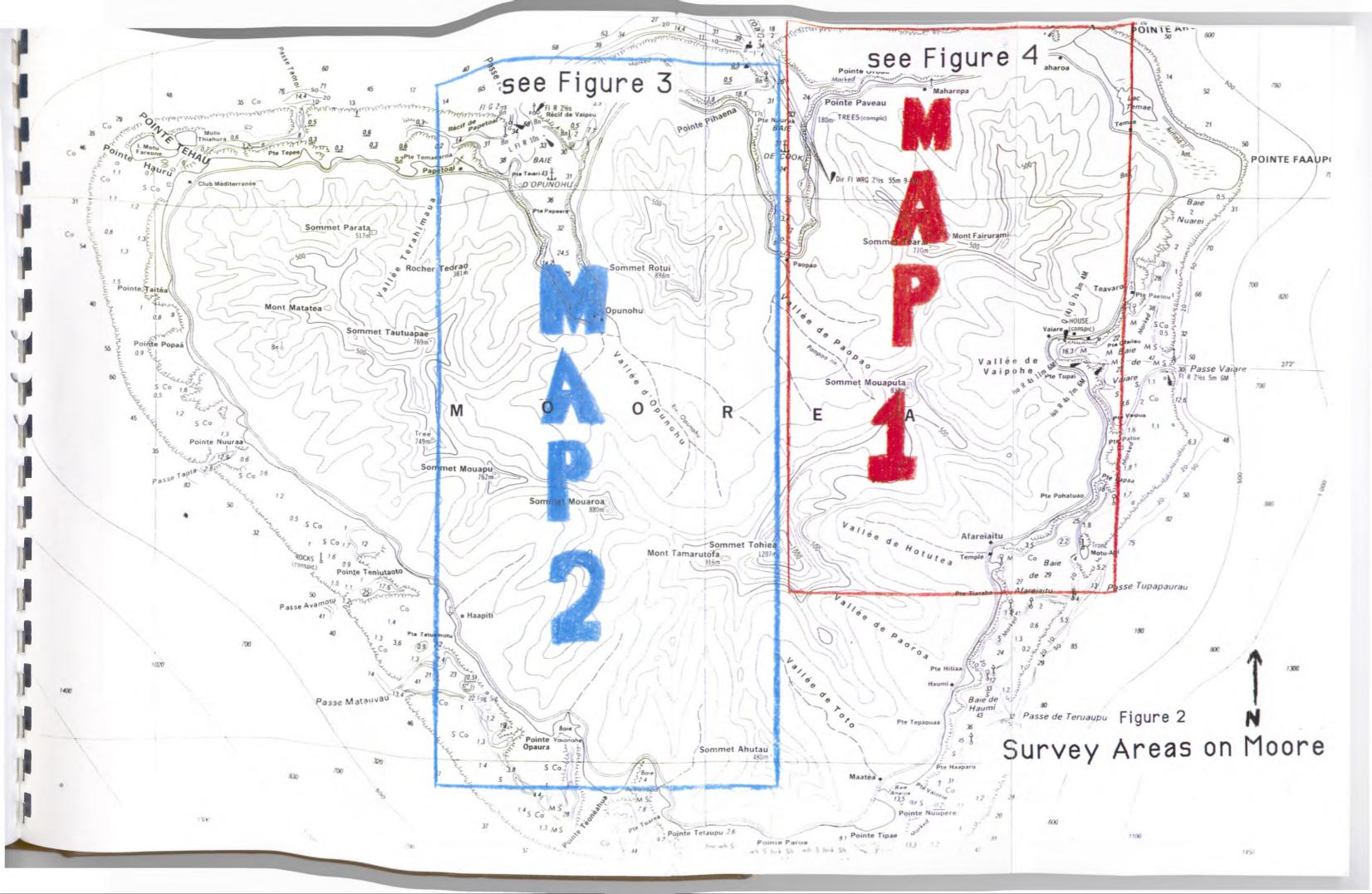
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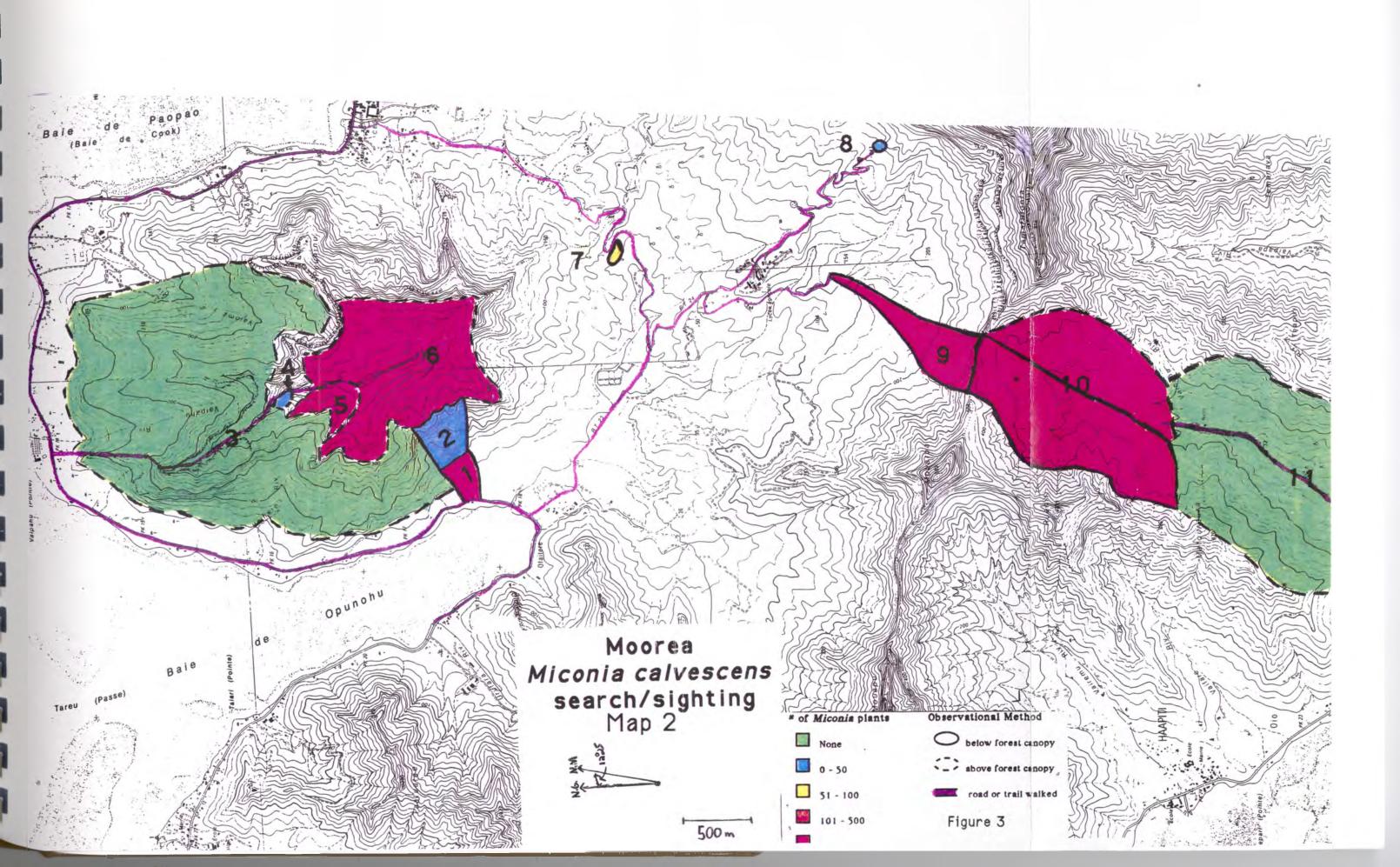
Source: Times (London, England) The times atlas of the world. Mid-century ed. Edited by John Bartholomew. London, Times Pub. Co., (1955-59)













Appendix:

DATE OBSERVED: 10/28/93 OBSERVERS: JS, UG, CU, and TK SITE NUMBER:001 SITE AREA: Mt. Rotui MAP NUMBER: 001

<u>SITE LOCATION DESCRIPTION</u>: This mountain is on the north coast of Moorea and is in between Paopao Bay and Opunohu Bay. This site borders the main route on the island between PK 17 and PK 18 and is owned by Mari Mari Kellum.

<u>LANDFORM</u>: This site is a cow pasture at the base of Mount Rotui with two streams running through it. Trees and bushes are scattered throughout the grass grazed cow pasture.

<u>ELEVATION RANGE</u>: The front pasture fence bordering the main route is at an altitude of 6 m above sea level and the back fence of the pasture is at an elevation of 53 m.

ASPECT: The pasture is on the west-facing side of Mount Rotui. SLOPE: The slope rises from the road at less than 10 degrees. OBSERVATIONAL METHODS: The observations at this site were made from several hap-hazard walks in the canopy understory. POPULATION DESCRIPTION: The observations made at this site were obtained from several visits to the pasture. Several point-quarter transects were done to develop a sense of the features of the Miconia population. The average point-to-individual distance for Miconia in the area of the pasture was to be 3.455 meters. The Miconia invasion-front extends downward across the pasture. Miconia calvescens is found growing at elevations as low as 20-25 m. At the lower elevations, the Miconia plants observed seemed more likely to be individually spaced and scattered than at higher elevations. As the elevation rises in the pasture, the Miconia seems to be found in clusters or dense aggregations more frequently. The most dense clusters of Miconia plants can be found along the banks of the streams in the pasture. Miconia was observed to be growing at the highest elevations in the pasture, along the fence at 53 m above sea level.

POPULATION STRUCTURE: Throughout the pasture, there is great variation in the size and age of *Miconia* plants. Many juvenile seedlings have been observed. Most of the *Miconia* plants observed were 0.5 m to 4.0 m in height. Along the streams and at other various microsites, *Miconia* plants were often observed to be greater than 4 m high. The basal diameters of the *Miconia* plants in the pasture vary greatly, few exceeding 10 cm. The majority of the plants observed had basal diameters in the range of 1-4 cm.

ESTIMATED % OF CANOPY COVER: At elevations less than 20 m in the pasture, *Miconia* comprises zero percent of the canopy. At many intermediate elevations, the *Miconia* plants occupy a niche somewhere above understory herbaceous vegetation, but below the canopy forming trees. At these elevations, *Miconia* forms a subcanopy where it is in aggregate clusters. Along the stream banks, where *Miconia* can often be found in tall denser clusters, the *Miconia* plants occupy 100% of the forest canopy and greatly restrict the survival of associate vegetation.

ESTIMATED ABUNDANCE/DENSITY: Although the number of *Miconia* plants per unit area varies greatly with altitude, the data from our three transects indicate that the density of *Miconia* in this pasture is 840.3 plants per hectare. Observations indicate that there are more than 500 *Miconia* plants at this site.

ANTHESIS: No plants were observed in flower in the pasture. Less than 10 plants were observed in fruit, all of which were growing along the stream banks. Most plants were neither fruiting nor flowering.

NOTES: Miconia was first observed in this pasture by the Kellum family in the early 1970's. Most of the Miconia seedlings were found growing on the sides or under rocks and/or boulders in the pasture. Cows currently live, and graze in the pasture.

ASSOCIATED/OTHER SPECIES: The understory of the pasture is extremely disturbed due to the cows and consists of a grass spp., Colocasia esculenta, Lantana montevidensis, flowering and fruiting Rubus spp., and various ferns. The trees scatted throughout the pasture are Annona muricata, Annona Reticulata (Coeur de boeuf), Cocos nucifera, Hibiscus tiliaceus, Inocarpus fagifera, Psidium guajava, Spathodea campanulata, and others.

DATE OBSERVED: 10/26/93 OBSERVERS: JS, UG, CU, and TK

SITE NUMBER: 002 SITE AREA: Mt. Rotui MAP NUMBER: 001

SITE LOCATION DESCRIPTION: This mountain is on the north coast of Moorea and is in between Paopao Bay and Opunohu Bay. This site is inland and can only be accessed by passing through the upper barbedwire fence of Mari Mari Kellum's cow pasture, which lies along the main route between PK 17 and Pk 18.

LANDFORM: This site is a mountain-side tropical forest.

<u>ELEVATION RANGE</u>: The forest begins at an elevation of 54 m, at the top edge of Mari Mari Kellum's cow pasture. The upper boundary of the site is at 255 m above sea level.

ASPECT: This forest is on the west-facing side of Mount Rotui.

<u>SLOPE</u>: The slope of this forest varies between 30 and 45 degrees at different positions. At various elevations, there are cliff-forming rocks which create short 90 degree microslopes.

OBSERVATIONAL METHODS: The observations made at this site were made from several hap-hazard walks in the canopy understory and from binocular observation from the cow pasture below.

POPULATION DESCRIPTION: It is important to note that the observations at this site were made from beneath the canopy. The Miconia plants observed at this site are invisible from an overhead aerial view. The forest is comprised of large canopy forming trees and a variety of understory plant communities. Less than 25 Miconia plants have been observed in this area. 4-8 Miconia plants were observed along the pasture/forest boundary fence. All other Miconia plants were observed individually. There were no aggregations of Miconia plants in this forest site. Other than the few plants growing along the pasture/forest fence, all observed Miconia plants were found in two microhabitats; either on or beneath rocks or boulders or in treefall created canopy gaps. The forest floor was nearly 100% covered with leaf litter.

<u>POPULATION STRUCTURE</u>: The *Miconia* plants growing along the forest side of the pasture fence boundary were estimated to be greater than 3 m high. All other *Miconia* plants observed in this site were less than 2 m tall. Many seedlings were found.

ESTIMATED % OF CANOPY COVER: The Miconia plants occupy zero percent of the canopy at this site.

ESTIMATED ABUNDANCE/DENSITY: We estimate their to be less than 25 *Miconia* plants in this site.

<u>ANTHESIS</u>: No *Miconia* plants were observed in flower or fruit at this site, and none showed signs of previous flower/fruit production.

NOTES: As we did not observe any mature flowering/fruiting *Miconia* plants in this forest, it may be suggested that the presence of all seedlings and small plants is a result from direct seed invasion from outside the forest.

ASSOCIATED/OTHER SPECIES: Aleurites moluccana, Annona muricata, Cocos nucifera, Colocasia esculenta, Freycinetia impavida, Hibiscus tiliaceus, Inocarpus fagiferus, Lantana montevidensis, Pandanus tectorius, Psidium guajava, Spathodea campanulata, and others.

DATE OBSERVED: 10/28/93

OBSERVERS: JS and TK

SITE NUMBER: 003 SITE AREA: Mt. Rotui MAP NUMBER: 001

SITE LOCATION DESCRIPTION: This mountain is on the north coast of Moorea and is situated between Paopao Bay and Opunohu Bay. This site is in the Vaiome River valley, which extends down to the coast between PK 12 and PK 13 on the main route, the Vaipahu River valley, (PK 13 to PK 14) on the main route, the Vaihere River valley (PK 15 to PK 16), and continues around the base of Mount Rotui just past PK 17.

<u>LANDFORM</u>: This site a group of valley watershed drainages around the base of a mountain..

<u>ELEVATION RANGE</u>: This site ranges in elevation from 0 m to 350 m above sea level.

<u>ASPECT</u>: This valleys at this site face northeast, north, northwest, and west..

<u>SLOPE</u>: These valleys are estimated to have an average slope of 45-50°.

OBSERVATIONAL METHODS: The observations at this site were made using binoculars from above the canopy. Observations were made from the main route between PK 12 and PK 18. This site was also observed as we hiked up to the summit of Mt. Rotui along the footpath which begins by PK 14 on the main route. From this "knife-edge" trail, we looked down to this site using binoculars standing at elevations up to 625 m above sea level.

<u>POPULATION DESCRIPTION</u>: No Miconia was observed at this site.

POPULATION STRUCTURE: n/a

ESTIMATED % OF CANOPY COVER: n/a

ESTIMATED DENSITY: n/a

ANTHESIS: At this site no Miconia plants were observed in flower or fruit.

NOTES:

ASSOCIATED SPECIES: Aleurites moluccana, Hibiscus tiliaceus, Lantana montevidensis, Spathodea campanulata, and others.

DATE OBSERVED: 10/28/93 OBSERVERS: JS and TK

SITE NUMBER: 004 SITE AREA: Mt. Rotui MAP NUMBER: 001

SITE LOCATION DESCRIPTION: Mount Rotui is on the north coast of Moorea and is situated between Paopao Bay and Opunohu Bay. This site is in a narrow drainage. This drainage is the first drainage west over from the western ridge of the Vaipahu River valley. This narrow drainage valley opens up downwards towards PK 15.

LANDFORM: This site is on an upper valley slope covered with tropical forest tree species.

<u>ELEVATION RANGE</u>: The *Miconia* plants were observed to be growing in this site between the elevations of 630 m and 520 m above sea level.

ASPECT: This drainage valley faces northwest.

<u>SLOPE</u>: The slope of this site was estimated to be 50-55 degrees. <u>OBSERVATIONAL METHODS</u>: In this narrow drainage valley *Miconia* was observed from above the canopy. It was visible with the naked eye. Closer inspection with binoculars revealed the presence of up to seven distinguishable canopy clusters. From our vantage point on the trail at 625 m above sea level, we were unable to observe the forest understory.

<u>POPULATION DESCRIPTION</u>: The *Miconia* clusters observed at this site were estimated to be evenly spaced down the gulch within the length of the site. However, the *Miconia* clusters were not only near the valley axis, but also on both valley sides.

POPULATION STRUCTURE: Based on the estimated height of the forest canopy in this narrow drainage valley, we determined that all observable *Miconia* plants were greater than 3 m tall. The *Miconia* plants had many branched limbs. No dbh measurements were made at this site due to the narrow valley's inaccessibility to humans. ESTIMATED % OF CANOPY COVER: We estimate that the *Miconia* plants in this site represent 10 % of the canopy cover.

ESTIMATED ABUNDANCE/DENSITY: 25-50 Miconia plants are growing at this site.

ANTHESIS: We observed two *Miconia* trees in flower at this site, while no fruiting plants were seen.

NOTES: This narrow drainage is the least invaded by *Miconia*, with respect to observed percent canopy cover, of all western-facing landforms on Mount Rotui.

<u>ASSOCIATED SPECIES</u>: Aleurites moluccana, Hibiscus tiliaceus, Lantana montevidensis, Metrosideros collina, Spathodea campanulata, and others. DATE OBSERVED: 10/28/93
OBSERVERS: JS and TK

SITE NUMBER: 005 SITE AREA: Mt. Rotui MAP NUMBER: 001

SITE LOCATION DESCRIPTION: Mount Rotui is on the north coast of Moorea and is situated between Paopao Bay and Opunohu Bay. This site is a wide, steep drainage valley descending from the summit peek of Mount Rotui. This valley eventually opens up to form the Vaihere River valley, which intersects the main route near PK 16. LANDFORM: This site is on an upper valley slope descending from the summit ridge covered with tropical forest tree species.

<u>ELEVATION RANGE</u>: This site exists between the elevations of 725 m and 490 m above sea level.

ASPECT: This valley faces west.

<u>SLOPE</u>: From the top of the site down to 600 m above sea level, the slope is estimated to be 60-65 degrees. From 600 m down to 490 m above sea level, the slope is estimated to be 45-50 degrees.

OBSERVATIONAL METHODS: The observations at this site were made from both the hiking trail that leads to the summit (the trail begins at PK 14 on the main route) and from the main route in between PK 17 and PK18. The *Miconia* invasion was first visible from the trail at an elevation of 520 m above sea level. The magnitude of the invasion was assessed from along the trail, using binoculars, from elevations up to 700 m. At 700 m above sea level, this site was no longer visible, as the slope down from the trail was too steep. POPULATION DESCRIPTION: At this site, *Miconia* appears to be the most abundant trees species. The *Miconia* plants at this site are

positioned both along the valley axis and on the sides of the valley. *Miconia* plants were observed growing at this site along the upper valley slopes and lower summit cliff-face. The purple undersides of the *Miconia* leaves make it discernible from the contrasting exposed black rock surface and other green-leafed tree species.

POPULATION STRUCTURE: Miconia trees formed a contiguous canopy blanket over the steep upper cliff-face of this site, with individual patches of bare rock or other tree species scattered throughout. The canopy occupying Miconia plants at this site are estimated to be 4-6 m tall. On the west side of the trail, starting at 575 m and continuing to 700 m, 25-50 Miconia seedlings were observed growing along the edge of the trail under the various ferns and Metrosideros collina trees. Due to the danger presented from stepping off the trail, no dbh measurement were made.

ESTIMATED % OF CANOPY COVER: Miconia plants comprise 50% of the canopy cover.

ESTIMATED ABUNDANCE/DENSITY: Greater than 500 Miconia trees are growing in this site.

ANTHESIS: 20-25 Miconia plants were observed in fruit and/or flower at this site.

ASSOCIATED SPECIES: Aleurites moluccana, Coprosma ernodeoides, Freycinetia impavida, Gleichenia linearis, Lanatana montevidensis, Metrosideros collina, Spathodea campanulata, Spathoglottis plicata and others.

DATE OBSERVED: 10/28/93

OBSERVERS: JS and TK

SITE NUMBER: 006 SITE AREA: Mt. Rotui MAP NUMBER: 001

<u>SITE LOCATION DESCRIPTION</u>: Mount Rotui is on the north coast of Moorea and is situated between Paopao Bay and Opunohu Bay.

<u>LANDFORM</u>: This site covers the summit peaks and descending east and west facing cliff-faces.

<u>ELEVATION RANGE</u>: This site exists between the elevations of 899 m and 300 m above sea level.

ASPECT: The summit of Mt. Rotui is cone-shaped and therefore has an orientation facing 360°. This site also descends down the west-facing cliffs of the mountain.

SLOPE: The slope at this site is estimated to be75-90°.

OBSERVATIONAL METHODS: This site was observed both from the hiking trail that leads to the summit (the trail begins at PK14 on the main route) and from the main route between PK 17 and PK 18. From both vantage points, only above canopy observation was done using binoculars.

<u>POPULATION DESCRIPTION</u>: This sight is one of the two most heavily *Miconia* -invaded areas on Moorea. The *Miconia* invasion of the summit was visible from the trail at an elevation of 625 m above sea level. On the west facing slopes of the summit, *Miconia* plants almost completely comprise the canopy from 899 m down to 450 m. The upper slopes on the east facing side of the summit are as heavily invaded as those on the west side, but the *Miconia* only appears at altitudes estimated to be greater than 625 m above sea level. Based on observed canopy composition, from 450 m to 300 m above sea level on the west-facing cliffs of this site, it is estimated that the *Miconia* invasion is less severe than that on the summit.

POPULATION STRUCTURE: The Miconia plants observed along the west side of the summit ridge between 700 m and 854 m above sea level were unusual in their morphology. Specifically, these plants were estimated to be close to 3 m tall with completely lignified stems as high as the apical meristem. The stem dbh's were estimated to be less than 4 cm. These plants rose at least 2 m above the top of the associate bushy vegetation. These plants did not exhibit trunk branching. The most noteworthy feature of these Miconia plants was that they were only growing leaves at the highest node just below the apical meristem. The trunks were bare. Moreover, the few leaves each plant had appeared ragged and torn in many cases. This may suggest these Miconia plants get wind-

whipped by high altitudinal storm winds coming over the summit ridge.

Just below the summit ridge, the *Miconia* plants appeared healthy and normal. These *Miconia* plants range in size from 1 m to 4 m. *Miconia* seedlings were observed along the thin trail ridge in this site.

ESTIMATED % OF CANOPY COVER: It is estimated that *Miconia* represents 80-100% of the canopy cover at this sight in all areas above 450 m in elevation. Below 450 m at this site, *Miconia* occupies 40-50 %

ESTIMATED DENSITY: There are more than 1000 Miconia plants at this site.

ANTHESIS: No plants were observed in fruit or flower.

ASSOCIATED SPECIES: The summit vegetation was Coprosma ernodeoides, Gleichenia linearis, Lantana montevidensis,

Metrosideros collina, Rubus spp, Spathoglottis plicata, and others.

DATE OBSERVED: 11/1/93

OBSERVERS: JS

SITE NUMBER: 007

SITE AREA: Opunohu Valley

MAP NUMBER: 001

<u>SITE LOCATION DESCRIPTION</u>: This site is in the Opunohu valley on the south side of Mt. Rotui. This site can be accessed by taking RT 24 south from the base of Opunohu Bay. Turn left onto RT 23, heading towards Paopao. About 1.2 km from the RT 23/24 fork, there is a dirt road heading off to the left into a tall plantation grove of *Pinus carribean* trees. This site begins 127 m from RT 23 down this dirt road turnoff. This site borders the pine plantation but does not intersect the pine groves.

<u>LANDFORM</u>: This site is situated on lower colluvial valley slope at the base of a mountain.

<u>ELEVATION RANGE</u>: This site is situated in the elevation range of 40 m to 55 m above sea level.

ASPECT: The slope of this site is south facing.

SLOPE: The slope of this site is estimated to be 30°.

OBSERVATIONAL METHODS: The observations at this site were made from below the canopy without binoculars.

<u>POPULATION DESCRIPTION</u>: The *Miconia* plants growing at this site are growing along the banks of a dirt road and on a valley slope. This site borders a *Pinus carribean* tree plantation.

<u>POPULATION STRUCTURE</u>: 50-60 *Miconia* plants in the 2-3 m height range were observed at this site. The seedling population was estimated to be greater than 20. One *Miconia* plant was observed to be greater than 6-7 m tall.

ESTIMATED % OF CANOPY COVER: Zero; No Miconia plants at this site were observed in the forest canopy.

ESTIMATED ABUNDANCE/DENSITY: 80-100 Miconia plants were observed at this site.

ANTHESIS: No Miconia plants were observed in fruit and/or flower at this site,

NOTES: This site is situated on land which borders a *Pinus carribean* plantation which is annually weeded by government order.

Apparently, only the pine forest is weeded, and the adjoining wild land is left open for invasion. This would be a good area for them to weed this area as well.

ASSOCIATED SPECIES: Hibiscus tiliaceus, Lantana montevidensis, Mangifera indica, Pinus carribean, Spathodea campanulata, and ferns,

DATE OBSERVED: 11/1/93

OBSERVERS: JS and TK

SITE NUMBER: 008

SITE AREA: Opunohu Valley

MAP NUMBER: 001

SITE LOCATION DESCRIPTION: This site is located near the Belvidere lookout point at the end of RT 24. There is a foot-trail heading south and up from the Belvidere parking lot into tropical forest. The trail ends under an *Inocarpus fagifera* grove. A barbed wire fence crosses and terminates the trail. This site on the left side of the Incarpus fagifera grove on an east facing slope of the valley. LANDFORM: This site is situated on a valley cut into a colluvial

slope below an upper valley headwall.

ELEVATION RANGE: This site ranges in elevation from 260 m to 265 m above sea level.

ASPECT: This site is on an east-facing slope.

SLOPE: The site is on a slope estimated to be 45-50°.

POPULATION DESCRIPTION: Many Miconia plants at this site were observed growing under an Inocarpus fagifera tree's canopy, but on a steep slope.

POPULATION STRUCTURE: At this site there were 5 Miconia plants observed greater than 2-3 m in height. 10-15 seedlings were observed growing on this slope. 4 Miconia plants 1-2 m in height were also observed on this slope.

ESTIMATED % OF CANOPY COVER: Zero; the Miconia plants observed at this site did not occupy any of the forest canopy

ESTIMATED ABUNDANCE/DENSITY: There are estimated to be between 25 and 35 Miconia plants at this site.

ANTHESIS: No Miconia plants were observed in fruit and/or flower at this site.

NOTES:

ASSOCIATED SPECIES: Inocarpus fagifera, Freycinetia impavida, and Lantana montevidensis.

DATE OBSERVED: 11/10/93

OBSERVERS: JS, MP

SITE NUMBER: 009

SITE AREA: Opunohu Valley

MAP NUMBER: 001

SITE LOCATION DESCRIPTION: This site is in the southern part of the Opunohu Valley. It can be accessed via the Trois Cocotiers trail, which begins by the pig farm behind the Bureau d'Economie Rurale on RT 24. The trail is marked throughout with orange and blue plastic flagging tape around tree limbs and orange painted tree trunks. Authorization from Economie Rurale is necessary to access this trail.

<u>LANDFORM</u>: This site begins in a valley bottom riparian corridor and continues up a colluvial slope to the top of the upper valley ridge connecting Summit Mouaroa with Mount Tamarutofa..

<u>ELEVATION RANGE</u>: This site ranges in elevation from 64 m to 356 m above sea level.

ASPECT: This site faces north to northwest.

<u>SLOPE</u>: The slope of this site varies. The slope along the trail on the valley bottom riparian corridor is estimated to be 5-10°. The slope of the colluvial slope is estimated to be 30-40°. The slope of the upper valley headwall is estimated to be 70-85°.

OBSERVATIONAL METHODS: The observations made at this site were made from below the canopy with naked eyes while walking along the Trois Cocotiers trail. The trail is marked by orange and blue plastic flagging tape wrapped around tree limbs and orange painted tree trunks.

<u>POPULATION DESCRIPTION</u>: *Miconia* was observed between the elevations of 109 m and 357 m above sea level. The density of *Miconia* plants appeared to increase with altitude. The riparian corridor and lower colluvial slope was dominated by *Inocarpus fagifera* trees. The almost vertical upper valley slope was dominated by *Hibiscus tiliaceus* trees.

POPULATION STRUCTURE: Along the trail, the first observation of Miconia was at 109 m above sea level. There were 9 seedling Miconia plants at this elevation. They were growing on a vertical rock face near Inocarpus fagifera roots on a 45° NW facing slope. Less than 10 m from these Miconia plants we observed a 3-4 m tall (dbh<3 cm) and a 2-3 m tall (dbh<3 cm) Miconia plant growing on flat ground besides a recently fallen (there was still fresh dirt on the exposed roots) Inocarpus tree in a canopy gap. Two other smaller Miconia plants less than 1 m tall were growing in the treefall gap as well. At 150 m above sea level, on a north facing slope, one Miconia seedling was observed growing on a 3 cm vertical microslope under an Inocarpus root. At 176 m, 5 Miconia plants (5

m tall, 2.5 cm dbh; 3 m tall, 2 cm dbh; 3 m tall, 2 cm dbh; <1m tall; 1 cm dbh; 1 seedling) were observed in a level flat treefall canopy gap area among Freycinetia impavida, Psidium guajava, and Hibiscus tiliaceus trees. At 208 m elevation, on a north facing slope, 1 Miconia seedling and 2 Miconia plants less than 1 m tall were growing on the base of a Angiopteris spp. Between 230 m and 240 m, 16 Miconia plants were observed. They were all on a north facing slope. Of these 16, fourteen were seedlings growing on Inocarpus roots or Angiopteris spp. root system. The two other plants were both 1-2 m tall and has dbh's 2-3 cm. From 250 m to the top of the ridge, over 60 Miconia plants were observed. More than 45 of these were seedlings. Only 1 Miconia plant greater than 2 m tall was observed, at 350 m elevation. It had a 5 cm dbh and had withered, wind-whipped upper leaves.

ESTIMATED % OF CANOPY COVER: Zero; only one *Miconia* plant was observed in the forest canopy at this site.

ESTIMATED ABUNDANCE/DENSITY: There are estimated to be over 500 *Miconia* plants at this site.

ANTHESIS: No Miconia plants were observed in fruit and/or flower at this site.

NOTES: Many of the *Miconia* plants observed and measured were destroyed by our group for conservation purposes.

ASSOCIATED SPECIES: Angiopteris spp., Hibiscus tiliaceus, Inocarpus fagifera, and Freycinetia impavida,

DATE OBSERVED: 11/10/93

OBSERVERS: JS, MP

<u>SITE NUMBER</u>: 010 <u>SITE AREA</u>:Vaianae River Valley

MAP NUMBER: 001

SITE LOCATION DESCRIPTION: This site is in the Vaianae River valley, which is inland from PK 21 on the main route. This site can be accessed from the top of the valley via the Trois Cocotiers trail, which begins in the Opunohu Valley by the pig farm behind the Bureau d'Economie Rurale on RT 24. The trail is marked throughout with orange and blue plastic flagging tape around tree limbs and orange painted tree trunks. Authorization from Economie Rurale is necessary to access this trail. This site can also be accessed at the bottom of the Vaianae River valley by a dirt road beginning off the main route between PK 21 and PK 22.

<u>LANDFORM</u>: This site is a valley with a stream running down the valley axis to the ocean.

<u>ELEVATION RANGE</u>: This site ranges in elevation from 0 m to 357 m above sea level.

<u>ASPECT</u>: This valley opens to the southwest. The valley side walls face northwest and southeast.

<u>SLOPE</u>: The slopes of the valley side walls are estimated to be 50°. The slope of the riparian corridor along the valley axis is estimated to be 10°.

OBSERVATIONAL METHOD: The observations made at this site were made from below the canopy with naked eyes while walking along the Trois Cocotiers trail. The trail is marked by orange and blue plastic flagging tape wrapped around tree limbs and orange painted tree trunks. Observation began from the upper valley ridge at 357 m and proceeding down to sea level. At 345 m elevation, there was a forest canopy gap along a steep slope on the trail which allowed above canopy observation of valley sidewalls.

POPULATION DESCRIPTION: We observed over 1000 Miconia plants growing in the first 30 m immediately down from the upper ridge line in this valley. Seedlings comprise an estimated 80% of these Miconia plants. More than 50 Miconia seedlings were often observed on a single basal structure of Angiopteris spp. Miconia plants were observed along the trail from the upper ridge line down to 135 m above sea level. Miconia was observed in the forest canopy in several clusters around 300 m above sea level. Miconia was observed growing in a riparian corridor between 176 m and 140 m above sea level. Many of the Miconia plants growing directly along the trail had been previously chopped above the stems and now show signs of resprouting.

<u>POPULATION STRUCTURE</u>: An estimated 85% of the *Miconia* plants observed at this site were less than 1 m tall. In the first 30 m on the trail down from the summit ridge, there were countless numbers (>1000) of tiny seedlings less than 1 cm tall growing on the basal units of *Angiopteras spp*. An estimated 99% of the *Miconia* plants growing at this site are in the canopy understory.

ESTIMATED % OF CANOPY COVER: 1% of the forest canopy at this site is occupied by *Miconia*.

ESTIMATED ABUNDANCE/DENSITY: We estimate there to be greater than 2000 *Miconia* plants in the understory at this site.

ANTHESIS: No Miconia plants were observed in fruit and/or flower at this site.

<u>NOTES</u>: Over 500 *Miconia* plants were destroyed by the observers at this site, yet there are still many more. As most *Miconia* plants at this site were seedlings or less than 1 m tall, this site can has potential for eradication.

ASSOCIATED SPECIES: Angiopteris spp., Hibiscus tiliaceus, Inocarpus fagifera

DATE OBSERVED: 11/10/93

OBSERVERS: JS, MP

SITE NUMBER: 011

SITE AREA: Vaianae River Valley

MAP NUMBER: 001

SITE LOCATION DESCRIPTION: This site is in the Vaianae River valley, which is inland from PK 21 on the main route. This site can be accessed from the top of the valley via the Trois Cocotiers trail, which begins in the Opunohu Valley by the pig farm behind the Bureau d'Economie Rurale on RT 24. The trail is marked throughout with orange and blue plastic flagging tape around tree limbs and orange painted tree trunks. Authorization from Economie Rurale is necessary to access this trail. This site can also be accessed at the bottom of the Vaianae River valley by a dirt road beginning off the main route between PK 21 and PK 22.

<u>LANDFORM</u>: This site is a valley with a stream running down the valley axis to the ocean.

<u>ELEVATION RANGE</u>: This site ranges in elevation from 0 m to 400 m above sea level.

<u>ASPECT</u>: This valley opens to the southwest. The valley side walls face northwest and southeast.

<u>SLOPE</u>: The slopes of the valley side walls are estimated to be 50°. The slope of the riparian corridor along the valley axis is estimated to be 10°.

OBSERVATIONAL METHOD: The observations made at this site were made from above the canopy from the road which begins a the end of the Trois Coccanopy and intersects the main route. Binoculars were used to observe the valley sidewalls.

POPULATION DESCRIPTION: No Miconia was observed at this site.

POPULATION STRUCTURE: n/a

ESTIMATED % OF CANOPY COVER: n/a

ESTIMATED ABUNDANCE/DENSITY: Zero Miconia plants were observed.

ANTHESIS: No Miconia plants were observed in fruit and/or flower at this site.

NOTES:

ASSOCIATED SPECIES: Hibiscus tiliaceus, Inocarpus fagifera

DATE OBSERVED: 10/31/93

OBSERVERS: JS

SITE NUMBER: 012 SITE AREA: Paopao hi. MAP NUMBER: 002

SITE LOCATION DESCRIPTION: This site can be accessed from a dirt road which is the first possible dirt road right turn after PK 9 when one is heading towards PK 8 on the main route. The right turn onto this dirt road comes just before a bridge on the main route crossing a stream. After going 571 m from the edge of the pavement of the main route up this dirt road, always staying to the left at forks, one must head left 5 m through the bushes to a stream running parallel to the dirt road. Just a few meters upstream there is a fork where 2 streams converge into one larger stream. There are many *Inocarpus fagifera* trees in the vicinity of this stream intersection. This site is the area of land between the two converging streams starting at the point of intersection and heading in the upstream direction 40 m measured along the stream on the left when facing upstream.

LANDFORM: This site is on an lower colluvial slope. This site is composed of an area of land between 2 converging streams. There are two steep stream banks forming 2 edges of the site. This plot of land is elevated 4m above the stream beds at its highest point. The site is in a tropical forest.

<u>ELEVATION RANGE</u>: This site is elevated from 57 m to 65 m above sea level.

ASPECT: This site faces northwest.

<u>SLOPE</u>: The slope of this site is less than 10° in the direction of stream flow, but the stream banks create microslopes perpendicular to the direction of stream flow, estimated to be 30-45°.

OBSERVATIONAL METHODS: The observations at this site were made from beneath the forest canopy. The *Miconia* plants observed at this site are invisible from an overhead aerial view. This site was observed on foot.

<u>POPULATION DESCRIPTION</u>: 20-25 *Miconia* plants were observed in this area. All *Miconia* plants at this site except for 5 were on the right bank of the stream on the left when facing upstream. These five other plants were situated on the bank of the stream bordering the other side of the site. The stream which had more *Miconia* plants in its proximity seemed to have a larger volume of water flowing in it.

<u>POPULATION STRUCTURE</u>: 1 *Miconia* plant which reached the forest canopy was observed at this site. This *Miconia* tree is 6-7 m in height. The dbh of this plant was measured at 11 cm. This plant seemed to be a point from which smaller *Miconia* plants (1-3 m in

height) radiated away from. No *Miconia* plants except for the individual canopy occupant was observed to have a dbh greater than 3.5 cm. 10 seedlings were seen at this site. The seedlings were scattered along the bank under *Hibiscus tiliaceus* and *Musa troglodytarum* trees.

ESTIMATED % OF CANOPY COVER: The *Miconia* plants at this site represent less than 1 percent of the canopy cover. Only 1 plant was seen reaching the forest canopy.

ESTIMATED ABUNDANCE/DENSITY: 20-25 Miconia plants were observed at this site.

ANTHESIS: No Miconia plants were observed in flower and/or fruit at this site.

NOTES: It appears that this site may have previously been used as a garbage dump. There is much household trash scattered and partially buried in leaf litter throughout the site. Also, it appears that some of the *Miconia* plants growing in this site have previously had their trunks chopped. 3 *Miconia* plants showed chopping scars and have since resprouted and continued producing leaves.

ASSOCIATED SPECIES: Coffea arabica, Colocasia esculenta, Mangifera indica, Musa troglodytarum, Hibiscus tiliaceus, Inocarpus fagifera, Spathodea campanulata, and various garden ornamentals.

DATE OBSERVED: 10/30/93

OBSERVERS: JS

SITE NUMBER: 013 SITE AREA: Paopao hi. MAP NUMBER: 002

SITE LOCATION DESCRIPTION: This site can be accessed from a dirt road which is the second possible dirt road right turn after PK 9 when one is heading towards PK 8 on the main route. This dirt road is marked on the main route with a sign that points with an arrow to a Renault Motors repair shop. 80 m from the edge of the pavement of the main route, there is a fork in the dirt road. Stay to the left and continue up the road 579 more meters where there is a possible left turn onto a dirt/grass road. (Beware that there is a left turn possible 453 m from the fork, but this is a WRONG TURN!) The correct road to turn on is next to a wooden overhead electric cable pole. At the end of this road (346 m from the electric pole) is this site. It is a disturbed area of land cleared of vegetation surrounded by forest with a irrigation canal running through the clearing. LANDFORM: This site is on a lower colluvial slope. This site is on the edge of a tropical forest and has suffered from human-induced disturbance involving vegetation removal and stream redirection. The Miconia plants border an area of exposed bare soil. ELEVATION RANGE: This site is at an elevation of 80 m above sea

<u>ELEVATION RANGE</u>: This site is at an elevation of 80 m above sea level.

<u>ASPECT</u>: This site is situated on a northwest-facing slope. <u>SLOPE</u>: The slope at this site is 0°, as it appears to have been artificially leveled by humans.

OBSERVATIONAL METHODS: It is important to note that the observations at this site were made from beneath the forest canopy. The *Miconia* plants observed at this site are invisible from an overhead aerial view.

<u>POPULATION DESCRIPTION</u>: 15-20 *Miconia* plants were observed at this site. All the *Miconia* plants were observed to be growing within 5 m from the edge of the land cleared of vegetation in a tall forest. All of the seedlings observed were growing on or beside large rocks in the soil.

POPULATION STRUCTURE: 6 Miconia plants were observed at this site 4-5 m tall. 7 Miconia plants were recorded as being 1-4 m high. All Miconia plant dbh's were less than 5 cm.

ESTIMATED % OF CANOPY COVER: Zero; none of the observed *Miconia* plants reached canopy height at this site.

ESTIMATED ABUNDANCE/DENSITY: 10-20 Miconia plants were observed at this site.

ANTHESIS: No Miconia plants were observed in fruit or flower at this site.

NOTES: All recorded road distances were measured using a hand held rolling wheel instrument.

ASSOCIATED SPECIES: Colocasia esculenta, Hibiscus tiliaceus, Inocarpus fagiferus, and Barringtonia asiatica.

DATE OBSERVED:10/30/93

OBSERVERS: JS

SITE NUMBER: 014
SITE AREA: Paopao hi.
MAP NUMBER: 002

<u>SITE LOCATION DESCRIPTION</u>: This site is on a lower colluvial slope of the Mataiua ridge, which parallels the east side of Paopao Bay. This slope can be reached on foot by heading east and up from the main route about 0.25 km south of PK 8.

<u>LANDFORM</u>: This site is a forested lower colluvial slope at the base of a steep ridge.

<u>ELEVATION RANGE</u>: This site begins at 20 m above sea level and ascends to 54 m above sea level.

ASPECT: This site is on a west-facing slope.

SLOPE: The slope of this site is estimated to be 25-30°.

OBSERVATIONAL METHODS: The observations at this site were made from beneath the forest canopy. The *Miconia* plants growing at this site are invisible from an overhead aerial view. As this site is on private property, it was necessary to use the services of a guide, George. One hap-hazard ascent was made through the forest to an elevation of 54 meters above sea level.

<u>POPULATION DESCRIPTION</u>: This site was a tall forest with many non-native introduced trees. 9 *Miconia* plants were observed at this site. No *Miconia* plants were observed to be growing closer than 5 meters to another *Miconia* plant at this site. Only one branched *Miconia* plant was observed, and the trunk scars seem to indicate that this plant had been chopped down previously, but has since resprouted new living tissue.

<u>POPULATION STRUCTURE</u>: No *Miconia* seedlings were observed in this forest. 9 plants are 1-3 m tall with dbh's less than 4 cm. The one *Miconia* plant observed to have been scarred and branched was 4-5 m tall and had a dbh of 10 cm..

ESTIMATED % OF CANOPY COVER: Zero; none of the Miconia plants at this site are part of the canopy

ESTIMATED DENSITY/ABUNDANCE: 9 Miconia plants were observed at this site.

ANTHESIS: No Miconia plants were observed in fruit or flower.

NOTES: I observed one living Miconia plants at this site which had trunk scars indicating that the trunks had been chopped in the past.

ASSOCIATED SPECIES: Aleurites moluccana, Artocarpus inci, Carica Papaya, Casuarina equisetifolia, Cocos nucifera, Colocasia esculenta, Freycinetia impavida, Hibiscus tiliaceus, Mangifera indica, Musa troglodytarum, Pandanus tectorius, Psidium guajava, and Spathodea campanulata

DATE OBSERVED: 11/3/93

OBERVERS: JS

SITE NUMBER: 015

SITE AREA: Vaiterupe River valle

MAP NUMBER: 002

<u>SITE LOCATION DESCRIPTION</u>: This site is the northern tip of the mountainous ridge which separates Paopao Bay from the Vaiterupe River valley near Maharepa. This ridge is the only elevated landform visible from the main route between PK 6 and PK 7. In addition, the Vaiterupe River valley is included in this site.

<u>LANDFORM</u>: This site composed of two main features. First there is a mountainous ridge which descends to the ocean and separates a river valley from a bay. Second, this site contains a shallow river valley with steep valley headwalls.

<u>ELEVATION RANGE</u>: This descending ridge by Point Paveo ranges in elevation from 0 m to 348 m above sea level. The upper walls of the Vaiterupe River valley are estimated to reach 410 m above sea level. <u>ASPECT</u>: This ridge descends towards the north and has side slopes facing both west and northeast.

<u>SLOPE</u>: The slope of the west-facing side is estimated to be 50-55 degrees. The northeast-facing slope is estimated to be 40-45 degrees.

OBSERVATIONAL METHODS: It is important to note that observations at this site were made both from under the canopy and from above the canopy. The observations made along the road up the valley were made from beneath the canopy. Observations of this site were made on the main route beginning at PK 7. Using binoculars, the westfacing slope was scanned as I headed towards PK 6. Before arriving at PK 6, I hiked up all of the roads breaking off the main route. These were mostly short residential roads, but they afforded me vantage points of both sides of the descending ridge that were not possible from the main route. I continued up the main route after passing PK 6, taking all the short roads I passed leading inland and scanning the valley side walls looking for Miconia plants. None of the side dirt roads penetrated the island for more than 0.2 km until I walked up the road which begins just past the recently constructed shopping development between PK 5 and PK 6 which houses the Bank of Socredo and leads into the Vaiterupe River valley. I walked along this road as it took me to the rear upper elevations of the valley. The road ended at 275 m above sea level. I searched the forest as I walked up with my naked eyes and I thoroughly scanned with my binoculars all of the valley ridges and cliff-faces from the top of the road in a forest clearing where many trees had been removed. POPULATION DESCRIPTION: No Miconia was observed at this site.

POPULATION STRUCTURE: n/a

ESTIMATED % OF CANOPY COVER: n/a

ESTIMATED DENSITY: n/a

ANTHESIS: n/a

NOTES: At the end of the road up the Vaiterupe River valley I was shown around the forest briefly by a man who owned land up there. He told me he had never seen *Miconia* growing in the valley during the past 5 years.

ASSOCIATED SPECIES: In the Vaiterupe River valley I observed Artocarpus altilis, Carica papaya, Cocos nucifera, Coffea arabica, Colocasia esculenta, Hibiscus tiliaceus, Inga edulis, Leucaena leucophylla, Mangifera indica, Musa troglodytarum, Pandanus tectorius, Persea americana, and Spathodea campanulata,

DATE OBSERVED: 11/3/93

OBSERVERS: JS

SITE NUMBER: 016

SITE AREA: Papeahi River valley

MAP NUMBER: 002

SITE LOCATION DESCRIPTION: This site is the large Papeahi River valley inland from Maharepa on north side of Moorea. It is inland from the main route between PK 5 and PK 4.

<u>LANDFORM</u>: This site is a riparian stream corridor running down the wide valley bottom.

ELEVATION RANGE: This site ranges in elevation from 40 m to 90 m above sea level.

ASPECT: The valley bottom slopes down towards the north.

SLOPE: The valley bottom is estimated to have a 15-20° slope.

OBSERVATIONAL METHODS: The observations at this site were made from walking up the Papeahi River riparian corridor from 40 m to 90 m above sea level. Observations were made both with and without the use of binoculars. All observation was from below the canopy.

POPULATION DESCRIPTION: Inocarpus fagifera and ferns were observed growing in and beside the river. No Miconia was observed at this site.

POPULATION STRUCTURE: n/a

ESTIMATED % OF CANOPY COVER: I estimated that the *Inocarpus fagifera* trees created a 85-90 % canopy along this section of the river.

ESTIMATED DENSITY: n/a

ANTHESIS: n/a

ASSOCIATED SPECIES: Inocarpus fagifera, ferns and others.

SITE NUMBER: 017 DATE OBSERVED: 11/4/93

SITE AREA: Papeahi River valle **OBSERVERS: JS and TK**

MAP NUMBER: 002

SITE LOCATION DESCRIPTION: This site is the large Papeahi River valley inland from Maharepa on north side of Moorea. It is inland from the main route between PK 5 and PK 4.

LANDFORM: This site is on a lower colluvial slope below a vertical valley headwall.

ELEVATION RANGE: This site ranges in elevation from 0 m to 250 m above sea level.

ASPECT: This site is on an east-facing slope.

SLOPE: The slope of this site is estimated to be 35-40°.

OBSERVATIONAL METHODS: The observations made at this site were made from beneath the forest canopy. Observations were made by walking up the main road of this valley. This road ends at an elevation of 245 m above sea level.

POPULATION DESCRIPTION: An isolated Miconia plant was observed growing along the left side of the road at 221 m above sea level. A close inspection of this individual Miconia plant revealed that it was actually only one of a large cluster of over 10 Miconia plants on an east facing 30-40 degree slope descending down from the road. No large canopy forming tree species were observed growing near these Miconia plants. In addition, 15 m further along the road, at an elevation of 226 m above sea level, a single Miconia plant was observed growing in the right-hand east-facing road bank. It was under a Hibiscus tiliaceus tree. At the end of the road a foot-trail begins, which heads into the forest. Less than 5 m from the trailhead, 20-25 Miconia plants were observed under a dense canopy of Spathodea campanulata trees. These plants were observed on the same southeast-facing slope of 30°, which descended to a dry stream bed.

POPULATION STRUCTURE: The cluster of Miconia plants growing where a forest canopy was absent (elevation: 221 m) were all 1-3 m tall. The isolated Miconia plant observed in the right-hand road bank was 3.5 m tall and had a dbh of 3.5 cm. Along the trail under the Spathodea campanulata canopy (elevation: 250 m) more than 10 Miconia plants were observed 1-2 m in height. 7 seedlings were observed growing under the Spathodea campanulata canopy at this site. A Miconia plant 5-6 m in height was observed growing in the stream bed at the bottom of this slope. It's dbh measured 4.5 cm. ESTIMATED % OF CANOPY COVER: Zero; the Miconia plants observed at this site did not occupy any of the forest. canopy

ESTIMATED ABUNDANCE/DENSITY: 35-50 Miconia plants were observed growing at this site.

ANTHESIS: No Miconia plants at this site were observed to be in flower and/or fruit.

Rubus spp., Spathodea campanulata

NOTES: Due to dangerous hiking conditions we were unable to observe the area above this site between 250 and 300 m elevation. This area is the highest part of the colluvial slope just below the valley headwall. Based on the observations we did make, we believe that this area is likely to be invaded with *Miconia* as well.

ASSOCIATED SPECIES: Angiopteris spp, Hibiscus tiliaceus, Mangifera indica, Musa troglodytarum, Persea americana, Polypodium spp.,

DATE OBSERVED: 11/4/93

OBSERVERS: JS and TK

SITE NUMBER: 018

SITE AREA: Papeahi River valle

MAP NUMBER: 002

<u>SITE LOCATION DESCRIPTION</u>: This site is the large Papeahi River valley inland from Maharepa on north side of Moorea. It is inland from the main route between PK 5 and PK 4.

LANDFORM: This site is a cliff-face valley headwall..

<u>ELEVATION RANGE</u>: This site ranges in elevation from 300 m to 520 m above sea level.

ASPECT: This site faces northwest.

SLOPE: The site is estimated to have a 85-90° slope.

OBSERVATIONAL METHODS: The observations at this site were made using binoculars from above the canopy.

<u>POPULATION DESCRIPTION</u>: From an elevation of 221 m above sea level, we observed that the northwest facing valley headwall was heavily populated with arborescent *Miconia* plants. This population was not one contiguous cluster of *Miconia*, but rather scattered clumps. Since *Miconia* plants were only observed from above the canopy, no estimate of *Miconia*'s role in the understory community was made.

<u>POPULATION STRUCTURE</u>: The *Miconia* plants observed at this site were canopy-occupying. From a vantage point at 221 m, it was observed that many of the *Miconia* trees were branched.

ESTIMATED % OF CANOPY COVER: Miconia comprises 50-60% of the canopy cover on this headwall.

ESTIMATED DENSITY: Miconia covered 50-60% of the surface of this headwall.

ANTHESIS: No Miconia plants were observed to be in fruit and/or flower at this site.

NOTES:

ASSOCIATED SPECIES: Aleurites moluccana, Spathodea campanulata,

DATE OBSERVED: 11/5/93

OBSERVERS: JS

SITE NUMBER: 019

SITE AREA: Teaharoa highlands

MAP NUMBER: 002

SITE LOCATION DESCRIPTION: This site runs along the main route from PK 2 to PK 4. Observations were made at this site were made along a dirt road which begins 131 m inland from a point on the main route 154 m past PK 3 heading in the direction of PK 2 near Teaharoa, on the northeast corner of Moorea. This road begins behind a *Cocos nucifera* plantation.

<u>LANDFORM</u>: This site is a series of ridges and shallow drainage qullies descending to the ocean.

<u>ELEVATION RANGE</u>: This site is situated in the elevation range of 0 m to 457 m above sea level.

ASPECT: The ridges and valleys descend to the north and the valley walls face east and west.

<u>SLOPE</u>: The ridgeline slope is estimated to be 35-40 °. The valley walls are estimated to slope 30-35 degrees.

OBSERVATIONAL METHODS: Binoculars were used at this site. Below-canopy observations were made along the road. All other observations were made from above the canopy. Observations were made of this site from the main route between PK 5 and PK 2.

Additional observations were made from a dirt road. The road begins at 7 m above sea level and ends at and elevation of 457 m. Along the road there were many locations where unobstructed views of the adjoining ridges were possible.

POPULATION DESCRIPTION: No Miconia was observed.

POPULATION STRUCTURE: n/a

ESTIMATED % OF CANOPY COVER: n/a ESTIMATED ABUNDANCE/DENSITY: n/a

ANTHESIS: n/a

NOTES:

ASSOCIATED SPECIES: Carica papaya, Gleichenia linearis, Hibiscus tiliaceus, Inocarpus fagifera, Mangifera indica, Musa troglodytarum, and others.

DATE OBSERVED: 11/8/93 OBSERVERS: JS and TK

SITE NUMBER: 020 SITE AREA: Vaipohe Valley MAP NUMBER: 002

SITE LOCATION DESCRIPTION: This site is in the Vaipohe Valley which opens up into the Vaiare Bay, where there is a ferryboat station. It can be accessed of the main route between PK 3 and PK 5.

LANDFORM: This site is a wide valley basin bordered by steep ridges used primarily for residential and agricultural purposes. Also, this site includes a riparian corridor.

<u>ELEVATION RANGE</u>: This site ranges in elevation from 0 m to 157 m above sea level

ASPECT: The valley opens up to the north.

SLOPE: The slope of the valley bottom is estimated to be 10°.

OBSERVATIONAL METHODS: The observations at this site were made in from below the canopy two ways. First, a thorough walking tour of all dirt roads the valley was made. Second, a footpath which started at the end of the dirt road at 75 m above sea level was taken. This trail climbed to 157 m above sea level along the Papeare River.

POPULATION DESCRIPTION: No Miconia was observed. The valley is populated with many residential homes, gardens, soccer fields, and agricultural fields. There are several streams running through the valley to the bay. The trail climbs through a Hibiscus tiliaceus dominated forest into an Inocarpus fagifera dominated forest. There are many waterfalls of less than 5 m in height in the river along the trail.

POPULATION STRUCTURE: n/a

ESTIMATED % OF CANOPY COVER: n/a ESTIMATED ABUNDANCE/DENSITY: n/a

ANTHESIS: n/a

NOTES:

ASSOCIATED SPECIES: The species present in this site were Colocasia esculenta, Carica papaya, Inocarpus fagifera, Hibiscus tiliaceus, Mangifera indica, Musa troglodytarum and Plumaria spp.

DATE OBSERVED: 11/8/93
OBSERVERS: JS and TK

SITE NUMBER: 021
SITE AREA: Vaipohe Valley

MAP NUMBER: 002

<u>SITE LOCATION DESCRIPTION</u>: This site is in the Vaipohe Valley which opens up into the Vaiare Bay, where there is a ferryboat station. It can be accessed of the main route between PK 3 and PK 5. <u>LANDFORM</u>: This site is on lower colluvial slopes and valley ridges and headwalls.

<u>ELEVATION RANGE</u>: This site ranges in elevation from 90 m to 450 m above sea level.

<u>ASPECT</u>: There are slopes, ridges, and walls at this site facing all directions except west.

<u>SLOPE</u>: The slope of the slopes, ridges and walls at this site are estimated to vary from 45° to 90°.

OBSERVATIONAL METHODS: The observations for this site were made using a 60 X telescope on a tripod. The scope was positioned at several locations along the main route between PK 3 and PK 5. These methods only provided an opportunity for above canopy observation. The canopy understory was not observed at this site.

POPULATION DESCRIPTION: No Miconia was observed.

POPULATION STRUCTURE: n/a

ESTIMATED % OF CANOPY COVER: n/a ESTIMATED ABUNDANCE/DENSITY: n/a

ANTHESIS: n/a

NOTES:

ASSOCIATED SPECIES: The species present at this site were Aleurites moluccana, Hibiscus tiliaceus, Inocarpus fagifera, Mangifera indica, Pinus carribean, Plumaria spp, and Spathodea campanulata

DATE OBSERVED: 11/8/93
OBSERVERS: JS and TK

SITE NUMBER: 022 SITE AREA: Vaipohe Valley

MAP NUMBER: 002

SITE LOCATION DESCRIPTION: This site is in the Vaipohe Valley which opens up into the Vaiare Bay, where there is a ferryboat station. It can be accessed of the main route between PK 3 and PK 5.

LANDFORM: This site is on upper valley ridges, slopes, and headwalls.

<u>ELEVATION RANGE</u>: This site ranges in elevation from 300 m to 700 m above sea level.

<u>ASPECT</u>: There are slopes, ridges, and walls at this site facing all directions except west.

<u>SLOPE</u>: The slope of the slopes, ridges and walls at this site are estimated to vary from 65° to 90°.

OBSERVATIONAL METHODS: The observations for this site were made using a 60 X telescope on a tripod. The scope was positioned at several locations along the main route between PK 3 and PK 5. These methods only provided an opportunity for above canopy observation. The canopy understory was not observed at this site.

POPULATION DESCRIPTION: The east facing slope of the Farataupoo ridge was the site of several distinct *Miconia* patches growing amongst *Aleurites moluccana* canopy clusters. These were at an elevation range of 300-500 m above sea level. The south facing wall of the ridge dividing this valley from the Papeahi River valley near Maharepa was the site of scattered clumps of *Miconia* amongst the other forest canopy trees. These *Miconia* patches were at an elevation range of 300-500 m above sea level. The areas at this site higher than 500 m above sea level are where *Miconia* has most densely invaded. The trees along the ridge top often appear windstripped of lower leaves and branches. All the *Miconia* plants at this site are growing on steeply sloped terrain.

POPULATION STRUCTURE: All the *Miconia* plants at this site growing between 300 m and 500 m above sea level are in scattered clusters. These clusters are amongst other canopy occupying forest trees. The *Miconia* plants growing above 500 m are situated in denser groves than the *Miconia* at lower elevations. The *Miconia* plants above 600 m elevation were often wind-whipped and stripped of lower leaves and vegetation.

ESTIMATED % OF CANOPY COVER: The Miconia plants observed at this site between 300 m and 500 m above sea level were estimated to make up less than 1% of the forest canopy. However, the canopy areas at this site above 500 m were estimated to 25% covered by Miconia.

<u>ESTIMATED ABUNDANCE/DENSITY</u>: There are 200-500 *Miconia* plants at this site.

ANTHESIS: No plants at this site were observed in fruit and/or flower.

NOTES: This site is of special interest because the upper slopes of the invaded ridge are opposite from the invaded ridge in the BIG Maharepa valley.

ASSOCIATED SPECIES: The species present at this site were Aleurites moluccana, Hibiscus tiliaceus, Inocarpus fagifera, Mangifera indica, Pinus carribean, Plumaria spp., Spathodea campanulata, and others.

DATE OBSERVED: 11/15/93

OBSERVERS: JS

SITE NUMBER: 023
SITE AREA: Mouaputa
MAP NUMBER: 002

SITE LOCATION DESCRIPTION: This site is the NiuroaValley near Afareaitu. It can be accessed by a dirt road off the main route between PK 8 and PK 9. This dirt road follows the Vaioro River up to 94 m above sea level, where a foot trail begins and ascends along the right-hand side of the river. Trail information may be found at the Bureau D'Economie Rurale.

<u>LANDFORM</u>: This site is in a valley with a waterfall and riparian corridor along the valley axis.

<u>ELEVATION RANGE</u>: This site ranges in elevation from 5 m to 460 m above sea level.

<u>ASPECT</u>: The valley headwall faces southeast and the valley sidewalls face southwest and northeast.

<u>SLOPE</u>: The slope of the valley sidewalls is estimated to be 45-50°. The slope of the valley axis is estimated to be 15°. The slope of the Vaioro River waterfall is 90°.

OBSERVATIONAL METHODS: The observations made at this site were made from below the canopy without binoculars. The observations begin along the dirt road heading off the main route. At the end of the road (about 2 km from the main route), a foot trail begins. Observations were made along this trail. 100 m from the end of the dirt road along the trail a new trail begins on the other side of the stream. This trail goes to the top of the waterfall. At 265 m above sea level, this dirt trail merges with the river and the trail ascends along the river to 400 m above sea level. At 400 m, there is a dirt foot trail heading off to the left from the river and this trail goes to the upper valley ridge at 460 m above sea level.

POPULATION DESCRIPTION: No Miconia plants were observed along the dirt road nor along the dirt foot trail heading from the road. Miconia was first observed along the Vaioro River at an elevation of 280 m above sea level. Miconia plants were continually observed along the river banks, valley slopes and small islands in the river up to an elevation of 460 m. This river valley is **extremely** invaded by Miconia!

POPULATION STRUCTURE: 10 Miconia seedlings were observed at 280 m above sea level growing under and beside embedded rocks and roots along the river banks. These plants were under a canopy of Hibiscus tiliaceus and Freycinetia impavida. At 300 m above sea level, two 3 m tall Miconia plants were observed along with 5 Miconia seedlings. At 320 m, a 5 m tall (dbh=5 cm) branching Miconia plant was observed in fruit. At 360 m, 7 Miconia plants 3-

4 m tall were observed along with at least 10 *Miconia* seedlings nearby. Between 400 m and 460 m above sea level, canopy occupying *Miconia* plants and countless *Miconia* seedlings were observed growing along the upper valley slope.

ESTIMATED % OF CANOPY COVER: Miconia is estimated to occupy 10-15% of the canopy at this site. Most Miconia plants observed at this

site are in the forest understory.

ESTIMATED ABUNDANCE/DENSITY: There are estimated to be more than 500 *Miconia* plants growing at this site.

ANTHESIS: No Miconia plants were observed in flower at this site.

One 5 m tall Miconia plant was observed in fruit at 320 m above sea level..

NOTES: As this trail is hiked often, many of the *Miconia* plants growing along the trail showed signs of being chopped above the roots. Observations indicate that this appears to increase the growth rate by allowing the *Miconia* plants to produce multiple apical meristems from the broken trunk shaft.

ASSOCIATED SPECIES: Freycinetia impavida, Gleichenia linearis, Hibiscus tiliaceus, Lantana montevidensis, Spathoglottis plicata, Rubus spp., and others.

DATE OBSERVED: 11/15/93

OBSERVERS: JS

SITE NUMBER: 024 SITE AREA: Mouaputa MAP NUMBER: 002

<u>SITE LOCATION DESCRIPTION</u>: This site begins above the upper valley ridge of the Niuroa Valley near Afareaitu and continues up to the summit of Mouaputa. Trail information may be found at the Bureau D'Economie Rurale.

<u>LANDFORM</u>: This site is composed up upper valleys, "knife-edge" ridges, and vertical summit cliff-faces.

<u>ELEVATION RANGE</u>: This site ranges in elevation from 460 m to 830 above sea level.

ASPECT: The slopes at this face S, E, W, SW, SE, NW, and NE. No north facing slopes were observed.

<u>SLOPE</u>: The slope of the valley sidewalls is estimated to be 45-50°. The slope of the "knife-edge" ridge is estimated to be 45-50°. The slope of the summit cliff-face is estimated to be 85-90°.

OBSERVATIONAL METHODS: The observations made at this site were made from both above and below the canopy with and without the use of binoculars. The observations were made from positions along the trail beginning from the upper valley headwall of the Niuroa Valley and ascending to the summit of Mouaputa.

POPULATION DESCRIPTION: This area appears to be the most severely invaded part of Moorea, with respect to *Miconia*. There are more *Miconia* plants at this site than any other species. The forest can be considered a *Miconia* forest, as the canopy is nearly 55% composed of *Miconia*. As the trail follows the top of a "knife-edge" ridge, below-canopy observation was only possible along the trail. Thus, little is known about the understory at this site. The *Miconia* population at this site appeared to be just as abundant at the lower elevations as at the higher areas. In fact, a *Miconia* plant was observed growing on the vertical cliff-face of Mouaputa at 827 m above sea level.

<u>POPULATION STRUCTURE</u>: *Miconia* plants ranging in size from seedlings to trees up to 7 m tall were observed in great abundance at this site. At least 5 *Miconia* trees were observed to have a dbh of 12-15 cm. The widest *Miconia* stems observed on Moorea are located at this site. The canopy occupying *Miconia* trees were often branched.

ESTIMATED % OF CANOPY COVER: Miconia is estimated to occupy 55-65% of the canopy at this site.

ESTIMATED ABUNDANCE/DENSITY: There are estimated to be more than 2000 *Miconia* plants growing at this site.

ANTHESIS: No Miconia plants were observed in fruit at this site. Two 5 m tall Miconia plants were observed in flower at 520 m above sea level..

<u>NOTES</u>: As this trail is hiked often, many of the *Miconia* plants growing along the trail showed signs of being chopped above the roots. Observations indicate that this appears to increase the growth rate by allowing the *Miconia* plants to produce multiple apical meristems from the broken trunk shaft. This site has both the largest *Miconia* trees and the most dense *Miconia* population observed on Moorea.

ASSOCIATED SPECIES: Aleurites moluccana, Coprosma ernodeoides, Freycinetia impavida, Gleichenia linearis, Hibiscus tiliaceus, Rubus spp., Meterosideros collina, Pandanus tectorius, Spathodea campanulata, and Spathoglottis plicata.

DATE OBSERVED: 11/7/93 OBSERVERS: JS and TK

SITE NUMBER: 025
SITE AREA: Hotutea Valley

MAP NUMBER: 002

SITE LOCATION DESCRIPTION: This valley watershed is due west of the town Afareaitu. The valley is bordered on the south by the steep cliff walls of Mt. Tohiea and on the north by cliff walls of the Tipatiri ridge. The valley can be entered on a dirt road which starts off the main island route between PK 9 and PK 10.

<u>LANDFORM</u>: This site is a valley with a several riparian corridors running down the axis. The valley is bordered by steep ridges and a mountain.

<u>ELEVATION RANGE</u>: This site ranges in elevation from 0 m to 1000 m above sea level.

ASPECT: The valley walls are East, West, and South facing.

<u>SLOPE</u>: The valley bottom slope is estimated to be less than 30° in the 0-200 m elevation range. The cliff walls surrounding the valley are all sloped 80-90°.

OBSERVATIONAL METHODS: Observations were made at this site from above and below the forest canopy. This valley was observed using a 60X scope from the road. The top of the valley, up to 1000 m, was observed. Observations were made using binoculars from many positions on the main dirt road in this valley, until a TABU sign was encountered. A foot-path began at this point which enters the forest and meets up with a stream. Observations were made from several positions along the stream through in the riparian corridor. At an elevation of 200 m, the slope of the stream becomes to steep to climb, however, binocular observations were made of the rear headwall at this point. Observations were also made along a foot-trail which branches off the main road and leads to the base of a tall waterfall flowing into the Putoa river.

POPULATION DESCRIPTION: No Miconia was observed.

POPULATION STRUCTURE: n/a

ESTIMATED % OF CANOPY COVER: n/a ESTIMATED ABUNDANCE/DENSITY: n/a

ANTHESIS: n/a

NOTES: The stream beds observed in this valley contain crustaceans and red algae. Many spider webs were also seen in the riparian corridor.

ASSOCIATED/OTHER SPECIES: In the valley bottom and riparian corridor there were Ceiba pentandra, Colocasia esculenta, Hibiscus tiliaceus, Inocarpus fagiferus, Lantana montevidensis, Musa troglodytarum, flowering and fruiting Rubus spp., flowering

Spathoglottis plicata, and others. On the headwalls Aleurites moluccana and Spathodea campanulata were observed.

DATE OBSERVED: 11/16/93

OBSERVERS: TK, UG

SITE NUMBER: 26

SITE AREA: Mouaputa

MAP NUMBER: 002

SITE LOCATION DESCRIPTION: NW slope of Mouaputa

LANDFORM: Near-vertical montane slope

ELEVATION RANGE: 400-600m

ASPECT: NW SLOPE: 90°

OBSERVATIONAL METHODS: Viewed from above canopy by telescope

from summit of Paopao Valley pineapple plantation road.

POPULATION DESCRIPTION: Extending down two gullies on the nw.

summit of Mouaputa

POPULATION STRUCTURE: Canopy-level trees

ESTIMATED % OF CANOPY COVER: 25%

ESTIMATED ABUNDANCE/DENSITY: >500

ANTHESIS: Several trees flowering

NOTES: Apparently restricted to two gullies on the face of Mouaputa ASSOCIATED SPECIES: Aleurites moluccana, Spathodea campanulata et al.

Data sheet prepared by Tim Krantz

DATE OBSERVED: 11/16/93

OBSERVERS: TK, UG

SITE NUMBER: 27

SITE AREA: Paopao highlands

MAP NUMBER: 2

SITE LOCATION DESCRIPTION: Paopao Valley pineapple plantation

road

LANDFORM: Valley

ELEVATION RANGE: <100m

ASPECT: N SLOPE: 25°

OBSERVATIONAL METHODS: By vehicle

<u>POPULATION DESCRIPTION</u>: Two plants under Hibiscus t. above roadcut. One plant had fallen down roadcut and rerooted laterally,

about 4m long.

POPULATION STRUCTURE: Understory of Hibiscus t.

ESTIMATED % OF CANOPY COVER: NA

ESTIMATED ABUNDANCE/DENSITY: 2 plants

ANTHESIS: no

NOTES:

ASSOCIATED SPECIES: Hibiscus tiliaceus

Data sheet prepared by Tim Krantz

DATE OBSERVED: 11/16/93

OBSERVERS: TK, UG

SITE NUMBER: 28

SITE NAME: Paopao highlands

MAP NUMBER: 2

SITE LOCATION DESCRIPTION: Upper slopes of the Tearai col, slopes

of Upper Paopao Valley and ridge with Vaipohe Valley

LANDFORM: Upper valley slopes and base of montane ridge and

summit

ELEVATION RANGE: 300-500m

ASPECT: SW SLOPE: 45-80°

OBSERVATIONAL METHODS: Viewed from upper Paopao Valley road

facing observed area from above canopy using telescope

POPULATION DESCRIPTION: Canopy-level trees along ridge separating

Vaipohe and Paopao Valleys

POPULATION STRUCTURE: Canopy and understory

ESTIMATED % OF CANOPY COVER: 50% ESTIMATED ABUNDANCE/DENSITY: >500

ANTHESIS: Partial

NOTES:

ASSOCIATED SPECIES: Metrosideros, Aleurites, Spathodea, etc.

Data sheet prepared by Tim Krantz





Invasion Patterns of *Miconia calvescens* on Moorea, French Polynesia

Christina Underwood University of California at Berkeley IDS 158 December 13, 1993

ABSTRACT

Invasion characteristics of Miconia calvescens were recorded describing its location, the surrounding vegetation, topography, seed dispersal, wind direction and availability of light, water and nutrients. The study was conducted to determine if any patterns of invasion exist and what factors influence its distribution. The study site is located in the Opunohu Bay region of Moorea on the slopes of Mount Rotui. The major vectors of seed dispersal are wind, gravity, endozoochory and cyclones. The plant can flower within three years of germination and will then flower three or four times per year producing hundreds of fruits bearing up to 320,000 seeds per plant. Three plots were chosen for studying the invasion of Miconia calvescens, each varying in size, vegetation and topography. Two plots were mapped using a compass traverse, one in a pasture and the other along a river. A point-quarter sampling method was used to characterize the density of vegetation in the plots and was modified to measure the distance, basal diameter and height of the nearest Miconia calvescens plant in each of the four quadrats. The other plot was in the forest and was mapped by establishing 50-meter transects along the fence bordering the pasture The invasive pattern of Miconia calvescens in the pasture does not follow the riparian corridor which indicates that its distribution is not limited by topography, water or light but by the vegetation surrounding the plots. In the river plot, Miconia calvescens does follow the riparian corridor and is limited in growth and development by the presence of Rubus roasaefolius. The highest density of Miconia calvescens plants in the forest is on large boulders, tree stumps and along the steep creek bank. Size and plant density comparisons indicate that Miconia calvescens is established more firmly in pasture and river areas when compared to forest regions. The data collected indicates that vegetation has had the most impact on the patterns of invasion of Miconia calvescens.

INTRODUCTION

Miconia calvescens was introduced into the ecosystem of French Polynesia in 1937 and is now threatening the native forests on several islands. This highly invasive, woody plant species was imported for its visual appeal to a botanical garden located on the southern end of Tahiti (Figure 1). It was later introduced to an agricultural research organization in Taravao for experiments on its possible useful properties (Birnbaum 1989b). It escaped from these two sites and is now covering approximately 60% of the forest habitat of Tahiti (Figure 2).

The original habitat of *Miconia calvescens* (*Miconia*) is in Southern Mexico, Guatemala and parts of South America (Figure 3) where it grows in a monsoonal climate and can tolerate varying levels of precipitation and sunlight and shallow soil environments (Krantz 1993). The native forest of Polynesia, with it's monsoonal weather conditions and shallow volcanic soils, is a perfect environment for this highly adaptable plant. *Miconia* thrives on the steep slopes found on mountainous volcanic islands where leaf litter is limited and light is constantly available. Because this species is exotic, it came to the islands without predators, diseases or fungi to control it's population. The plant can flower within three years of germination and will then flower three or four times per year producing hundreds of fruits bearing up to 320,000 seeds per plant (Birnbaum 1989a). The major vectors of dispersal are wind, gravity, endozoochory and cyclones (Meyer 1993). *Miconia* is deposited on the high mountain slopes by birds or cyclones and then moves down slope by gravity and wind.

Research into the *Miconia* invasion has been centered on Tahiti, covering seed development with water treatments, density at certain key sites, basal diameter and height characteristics, growth stages and patterns, and effects of cyclones on distribution (Birnbaum 1989a, 1989b, 1991, Doumenge 1986, Gaubert 1991, 1992).

J.Y. Meyer of the Organizacion de Recherch Scientifique et Technologique Ouver Mer (ORSTROM) is currently studying the invasion of *Miconia* on Raiatea and Moorea and is focusing his research on the introduction and distribution of the plant, the structure of the populations and the methods of dispersal (1993).

The extent of this invasion warrants more investigation into the interactions of *Miconia* with other species of plants, its environmental limiting factors and its locations and densities on Moorea. Understanding the physical and ecological characteristics of *Miconia* is essential to controlling its growth on Moorea and preventing it from taking over the available forest habitat. It can be found on most steep mountains and has reached more disturbed, lowland areas of the island through transport down river valleys and by wind and gravity (Figure 4).

The area described in this paper is located in the Opunohu Bay region of Moorea at a property owned by Mari Mari Kellum. This property extends from the slopes of Mount Rotui to the bay (Figure 5). The study site includes pasture land, a river section with pasture around it, and the forest area directly above the fence bordering the pasture (Figure 6). This site was chosen for its unusual invasion patterns of Miconia and its location near Mount Rotui, one of the largest invasion sites on Moorea. The pasture section of the plot is generally of a uniform elevation across its width with only a slight gradient moving up toward the forest. The vegetation in the pasture includes Cocos nucifera (coconut), Psidium guajava (guava), Annona muricata (sour sop), Spathodea companulata (African violet), Artocarpus altilis (breadfruit), Wedelia trilobata (pasture grass), Rubus roasaefolius (rubus berries) and a variety of small ferns including Gleichenia linearis. The river section has a very gradual elevation change towards the forest and the vegetation includes Hibiscus tiliaceus (hibiscus), Inocarpus fagifer (inocarpus), P. guajava, R. roasaefolius and G. linearis. The forest includes some areas of H. tiliaceus, but mostly consists of I. fagifer, Colocasia sp. (taro), G. linearis and Angiopteris evecta

(a large fern). The predominant wind direction is from the northeast or down the slope of Mount Rotui.

The invasion pattern of *Miconia* into each of the study site areas is unique because of environmental variables and level of disturbance. The purpose of this study is to record the characteristics of the invasion by describing the location of *Miconia*, the surrounding vegetation, topography, seed dispersal, wind direction and availability of light, water and nutrients and from these observations explain why these invasion patterns exist.

METHODS

Two adjacent areas of dense Miconia in the pasture and river were mapped using compass traverses (Figure 7 and 8). The perimeter of the Miconia front in the pasture and river environments was determined by visually identifying areas that included two or more plants per two square meters (m²). Records were kept of the vegetation and the total number, heights and basal diameters of all Miconia plants found within a two-meter belt at each section of the traverse around the plot. A point-quarter sampling method was used to characterize the density of vegetation in the plots (Krebs 1989). Two of these transects were established outside the plots, one parallel to the fence and one parallel to the riparian corridor (Figure 6). Three more transects were chosen within the pasture plot to represent several lobes of the invasion front. The remaining transect was sampled in the river plot. The pointquarter method was modified to measure the distance, basal diameter and height of the nearest Miconia plant in each of the four quadrats. Each transect was also sampled for the distance, basal diameter and height of the nearest tree of any species including Miconia of height greater than 1.5 meters. The transect intervals were selected based upon the transect length and plant densities. The standard used to select eligible trees for sampling purposes was branching at 1.5 meters above ground. The transect data was then analyzed for the total density per 100 meter square (m²) for all transects (Table 1). The average height of Miconia in each area was computed (Table 2).

To map and describe the forest, a point along the fence dividing the pasture and forest was selected and a fifty meter transect was run perpendicular to the fence from this point (Figure 9). In ten meter intervals along the fence, six perpendicular transects were measured out to various lengths. Because the plot was intersected by a small creek it was necessary to shorten the last three transects from fifty meters in length. Five meter areas were observed along both sides of the transects. Boulders and light gaps of sizes greater than one meter square were noted. The size of the light gap and the presence of *Miconia*, its distance to the transect, location upon the light gap, height and basal diameter were also recorded. The distance along three identifiable legs of the creek was measured and at every ten meters the distance from one bank to the next (at a height of one meter above water level) was measured. The location, heights and basal diameters of *Miconia* plants within the creek environment were also recorded.

RESULTS

The invasion pattern of *Miconia* into the pasture area extends outward along the contour into open pasture and not along the riparian corridor as might be expected (Figure 6). This indicates that the distribution of *Miconia* is not limited by topography, water or light availability but rather by vegetation or some other variable. The number of *Miconia* plants observed within two meters around the plot indicates that some areas are growing outward more rapidly than others (Figure 10). By starting from the benchmark and moving around the perimeter to Section 9, there is a great deal of *R. roasaefolius* and a small number of *Miconia* plants (Table 3). A *Tamarindus indica* (tamarind) tree is located near Sections 8 and

9. It is possibly using allelopathy to exclude all vegetation within its range, including Miconia. Sections 10 through 13 of the plot are bordered by the greatest number of Miconia plants indicating that it is the area of largest growth in this plot. The surrounding vegetation of this area consists mostly of aged P. guajava and W. trilobata grass with some R. roasaefolius and G. linearis. The following sections are surrounded by G. linearis and have few Miconia plants. Moving around the plot towards Section 20 there is a large tangle of H. tiliaceus that appears to be impeding the growth of Miconia. Sections 21 through 28 have a moderate number of Miconia and the vegetation consists mostly of W. trilobata and R. roasaefolius, with the exception of the lobe that extends eastward which has abundant R. roasaefolius and few Miconia.

The invasion of *Miconia* into the river area does follow the riparian corridor in a westward direction, but it is more abundant to the sides of the corridor than within the river itself (Figure 6). Starting from the benchmark the largest number of *Miconia* is along the edge of the lobe that extends down the river (Figure 10). The vegetation in this area consists primarily of *G. linearis* and *W. trilobata* (Table 3). At Sections 6 and 7 there is a grove of *I. fagifer* trees which could account for the lower number of *Miconia* and may impede further growth into this area. Data was not collected for Sections 10 through 12. Along the perimeter of Sections 13 and 15 there is little herbaceous vegetation and a moderate number of *Miconia*. Along Sections 14, 17, 18 and 20 the vegetation consists almost entirely of *R. roasaefolius* with few *Miconia*. These numbers suggest that areas of abundant *R. roasaefolius* may limit the growth of *Miconia*, although the number of plants in Sections 16 and 19 do not support this assumption.

The transects through the pasture plot show *Miconia* densities ranging from 30.61 to 57.80 plants per 100 m² (Table 1) and the river plot has 62.53 plants per

100 m² compared to the surrounding area which has between 6.92 and 9.79 plants per 100 m² (Figure 11). When the transects were sampled for all species the density ranges from 22.17 to 44.67 plants per 100 M² inside the pasture plot, 38.02 plants per 100 M² in the river plot and 14.56 and 9.95 plants per 100 M² outside the plot (Figure 12). Although the density of *Miconia* plants inside the studied areas is much higher than outside the plots, there are areas of significantly lower density within the plots corresponding to areas of dense *R. roasaefolius*.

The map of the forest area shows the location of boulders of size greater than one square meter, the transects, the creek and *Miconia* plants (Figure 9). The vegetation in the plot includes areas of dense *H. tiliaceus* and *I. fagifer* with some *A. evecta* in the creek. The pasture does have some patches of *Miconia* growth that meet the fence on the south end which may explain the large number of *Miconia* at the beginning of the 50-meter transect. With the exception of that area, the largest number of *Miconia* found in the forest is located on boulders, coconut stumps and along the creek bordering the site. The plants within the creek are mostly located along the last segment and are growing high on the bank.

The *Miconia* plants within the forest plot have an average height of 0.35 meters, with the plants in the creek averaging 0.27 meters and in the rest of the plot averaging 0.41 meters (Table 2). The plants in the pasture plot averaged 1.18 meters and 1.65 meters within the river plot. Along the transects outside the study areas the plants averaged 1.35 meters (Figure 13). These patterns suggest that the *Miconia* plants are larger, older and perhaps more established in the pasture and river areas when compared to the forest region.

DISCUSSION

The invasion patterns of *Miconia* into the study area are determined by the environmental variables and level of disturbance. Of all the variables examined,

vegetation has the most impact upon the pattern of the invasion and the growth of Miconia. The amount of water available does appear to effect the distribution of Miconia in the river plot but does not explain the large invasion into the pasture. Light availability may contribute to the growth of Miconia but it is not a limiting factor. Throughout each of the plots the light level is variable and Miconia is highly adapted to growing in low levels of light in the understory of forests (Birnbaum 1989). Topography is an important factor when studying the invasion of mountain slopes but it does not explain the pattern of invasion in the lower elevations. The wind direction and seed dispersal may effect the spread of Miconia on the island, but seed rain in this area is most likely uniform, abundant and not a limiting factor for Miconia. Nutrient availability may contribute to the growth and size of Miconia in areas of disturbance such as pasture land. But the most important limiting factor in the pasture and river areas for Miconia is the vegetation in the surrounding region. The comparison between the amount of R. roasaefolius and number of Miconia plants demonstrates that the existence of certain plants can slow or prevent the growth of Miconia while other plants, such as W. trilobata, might actually encourage growth. In the forest plot Miconia is also not limited by light availability even though the largest number of plants are found in light gaps and along the creek. This is explained by the fact that I. fagifer trees produce large leaves that prevent Miconia seeds from germinating. Miconia is limited to the sides of boulders and stumps and along the steep edges of the creek where I. fagifer leaves are not able to settle.

Further study should focus on measuring additional characteristics of the plant and the spread of the invasion over time. With information that spans years it will become more evident what controls the spread of *Miconia* and how it can be used to prevent further growth. It would also be helpful to collect data in other areas of invasion and compare the patterns of growth to those found in this study.

Miconia is an extremely robust and adaptable plant. Even plants that are cut at the base can be observed resprouting, often in more than one place. It can also be observed growing up through the R. roasaefolius with long, winding stalks and on top of coconuts with its roots surrounding the nut. Miconia is especially adept at putting out large root systems that support it on the steep sides of boulders. Though vegetation may be controlling the spread of the invasion, the amount of seed rain from mountain slopes and the adaptive nature of Miconia ensures that the invasion on Moorea will be difficult to control.

While in the forest environment the invasion is still manageable, the spread of *Miconia* into the pasture environment is rapid and will be difficult to eradicate. To control the spread of *Miconia* on Moorea it will be necessary to better understand the biology of the plant, its interactions with other species, and its environmental limiting factors. It is also important to educate the public of the threat of *Miconia* to the forests and form a task force to remove the plants from the accessible areas.

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Table 1 - Density analysis for Transects 1-6

a militar	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Transect 6
MICONIA Total point-to- individual distances	144.42	124.67	72.3	50.66	39.46	32.88
No. points	38	39	40	37	30	26
Mean point-to- individual distance	3.80	3.20	1.81	1.37	1.32	1.26
Mean area-per- individual	14.44	10.22	3.27	1.87	1.73	1.60
Total density (per hectare)	6.92	9.79	30.61	53.34	57.80	62.53
ALL-SPECIES Total point-to- individual distances	112.7	130	89.2	53.18	38.9	37.3
No. points	43	41	42	34	26	23
Mean point-to- individual distance	2.62	3.17	2.12	1.56	1.50	1.62
Mean area-per- individual	6.87	10.05	4.51	2.45	2.24	2.63
Total density (per hectare)	14.56	9.95	22.17	40.88	44.67	38.02

Table 2 - Average height of Miconia

	Total Height	Number of plants	Average Height
Forest plot	43.58	125	0.35
creek	13.86	52	0.27
all else	29.72	73	0.41
Pasture	164.81	140	1.18
transect 3	59.86	68	0.88
transect 4	73.63	40	1.84
transect 5	31.32	32	0.98
River	46.06	28	1.65
transect 6	46.06	28	1.65
Outside plots	116.33	86	1.35
transect 1	50.68	38	1.33
transect 2	65.65	48	1.37

Table 3 - Vegetation around perimeter of pasture and river plot

Section	Description of vegetation	Number of Miconi
number		
PASTURE		
1	5% R. roasaefolius, C. nucifera, dead/live P. guajava, W. trilobata	0
2	95%R. roasaefolius, dead P. guajava	0
3	95% R. roasaefolius, dead P. guajava	4
4	95% R. roasaefolius, dead P. guajava, H. tiliaceus	4
5	no data	3
6	95% W. trilobata, bare ground, small A. altilis, Colocasia sp.	6
7	50% G. linearis, 50% W. trilobata, large S. companulata	1
8	30% R. roasaefolius, 30% W. trilobata, 20% bare, T. indica	1
9	30% R roasaefolius, 50% W. trilobata	0
10	30% R. roasaefolius, 30% W. trilobata, 30% G. linearis, C. nucifera, A. muricata	19
11	10% G. linearis, W. trilobata, small A. muricata, C. nucifera, old P. guajava	21
12	40% G. linearis, W. trilobata, small A. muricata, M. calvescens	12
13	5% G linearis, 5% W trilobata, old P. guajava	10
14	W. trilobata, dead P. guajava, small A. muricata, A. altilis	0
15	5% G. linearis, W. trilobata, dead P. guajava, large A. altilis	1
16	30% G. linearis, W. trilobata, M. calvescens, small A. muricata	2
17	20% R. roasaefolius, 20% G. linearis, small A. muricata	0
18 19	10% R. roasaefolius, 40% W. trilobata, 10% G. linearis, small A. muricata	2
20	70% R. roasaefolius, G. linearis, lots of A. muricata, Miconia	4
21	40% G. lineariss, 50% W. trilobata, little R. roasaefolius, S. companulata	1
22	80% W. trilobata, little G. lineariss, lots of S. companulata, M. calvescens	5
23	70% W. trilobata, few G. linearis, few R. roasaefolius, A. muricata, old P. guajava 60% R. roasaefolius, 40% W. trilobata, small A. muricata, dead P. guajava	6
24	20% R. roasaefolius, W. trilobata, G. lineariss, P. guajava, A. altilis, A. muricata	4
25	80% R. roasaefolius, G. linearis, W. trilobata, old P. guajava, M. calvescens	8
26	20% R. roasaefolius, 20% W. trilobata, C. nucifera, A. muricata	1
27	20% R. roasaefolius, Colocasia sp., S. companulata, large A. altilis, A. muricata	1
28	10% R. roasaefolius, G. linearis, bare, A. altilis, S. companulata, small A. muricata	8
29	95% R. roasaefolius, medium A. muricata, dead P. guajava, M. calvescens	6
30	100% R. roasaefolius, C. nucifera, A. muricata, Colocasia sp.	inside plots
31	95% R. roasaefolius, 5% W. trilobata, S. companulata, A. muricata, P. guajava	inside plots
32	60% R. roasaefolius, 40% W. trilobata, A. altilis, S. companulata, H. tiliaceus	inside plots inside plots
RIVER	and a second a second and a second a second and a second a second and a second a second a second a second a s	mside piots
1	20° P. massacfalius W. tailabata hara math	
2	20% R. roasaefolius, W. trilobata, bare path 70% R. roasaefolius, W. trilobata, dead P. guajava	2
3	· ·	2
4	90% W. trilobata, 5% rocky, 5% G. linearis, R. roasaefolius, Colocasia sp., 75% W. trilobata, 20% G. linearis, 5% R. roasaefolius, river bed	15
5	10% R. roasaefolius, 50% G. linearis, 40% rocky/bare, Colocasia sp.	6
6	90% W. trilobata, 10% G. linearis, Colocasia sp., rocky	10
7	99% leaves/rocks, 1% G. linearis, L. fagifer	0 5
8	80% mid-sized G. linearis, 20% W. trilobata, dead P. guajava, H. tiliaceus	
9	99% W. trilobata, 1% G. linearis, H. tiliaceus	6 4
10	no data	no data
11	no data	no data
12	no data	no data
13	dense canopy, dead trees, little vegetation	7
14	100% R. roasaefolius	2
15	dead trees, H. tiliaceus, some vines	9
16	60% R. roasaefolius	
17	95% R. masaefolius, 5% G. linearis, C. nucifera, A. muricata, H. tiliaceus	6
18	90% W. trilobata, 5% G. linearis, 5% R. roasaefolius, Colocasia sp., rocky	0
19	80% R roasaefolius, G linearis, Colocasia sp., large A. altilis	7
20	75% R. roasaefolius, few G. linearis, bare ground, C. nucifera, A. altilis	0
21	5% R. roasaefolius, 25% G. linearis, 70% bare, lots of A. muricata	1

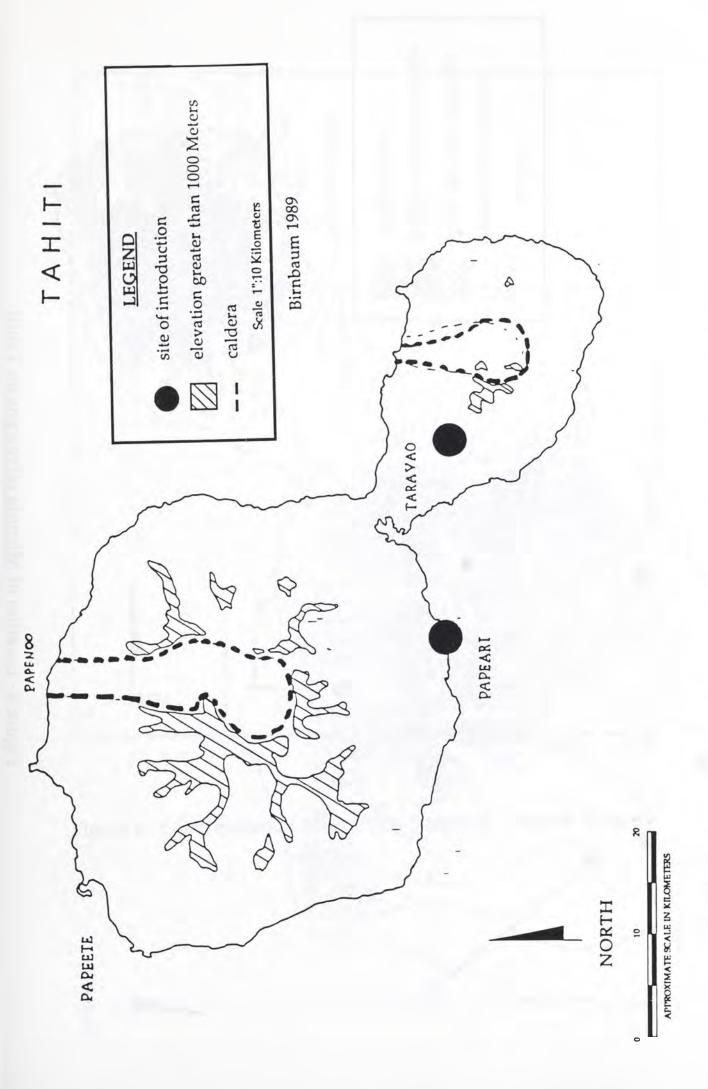


Figure 1 - Sites of introduction of Miconia calvescens on Tahiti

Figure 2 - Location of Miconia calvescens on Tahiti



Figure 3 - Distribution of Miconia calvescens in Tropical America

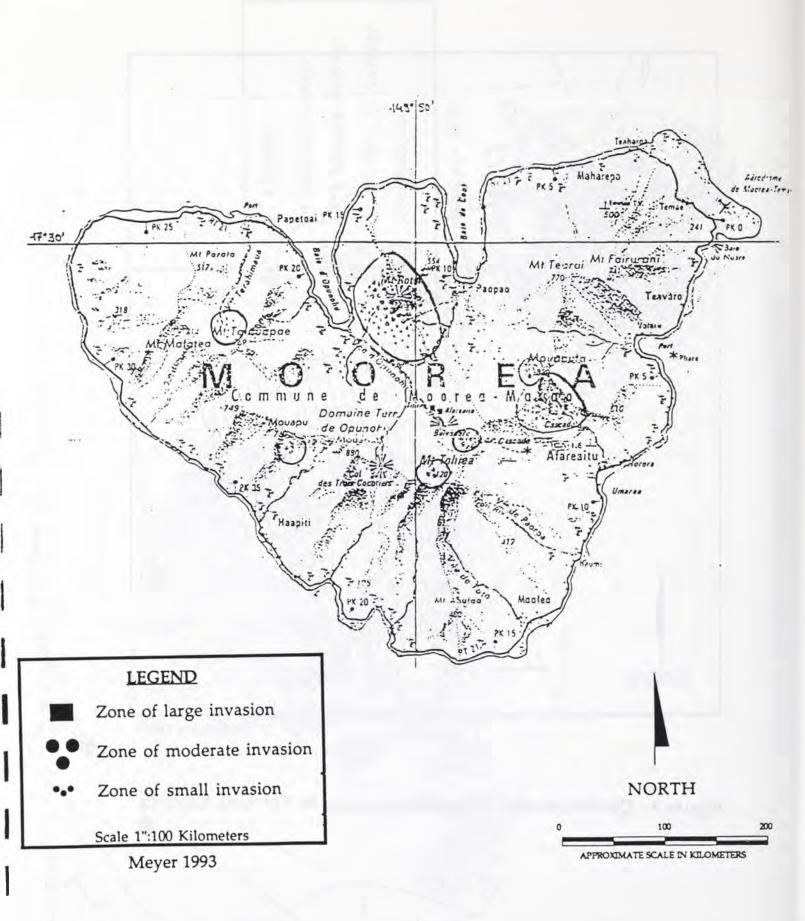


Figure 4 - Location of Miconia calvescens on Moorea

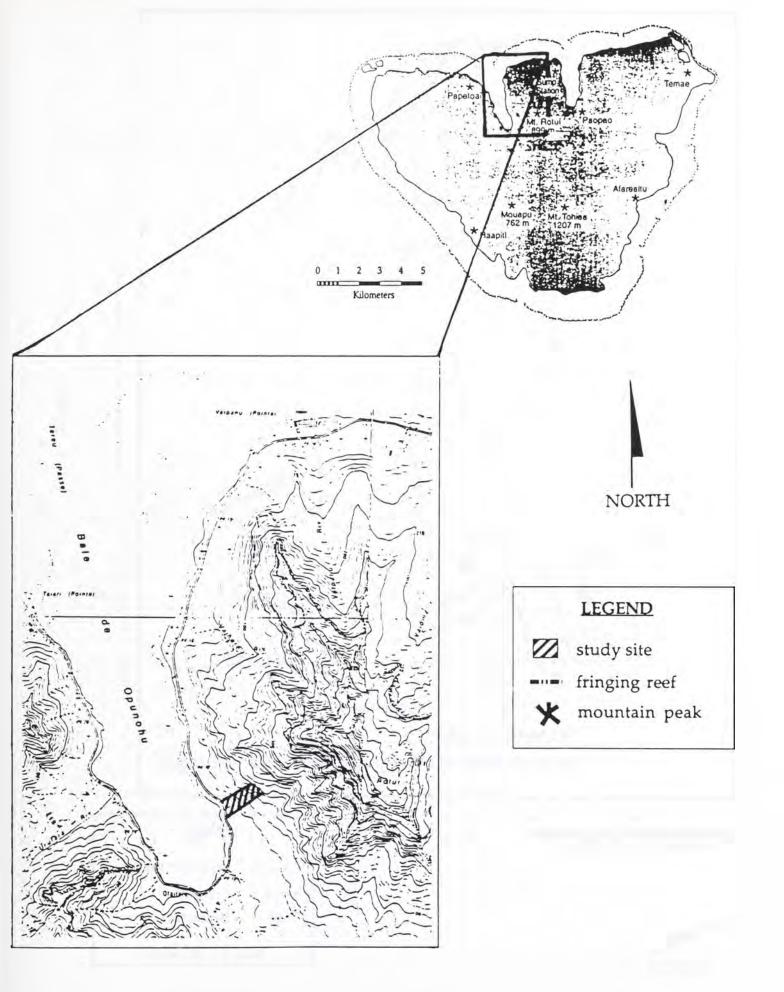


Figure 5 - Location of study site on Moorea

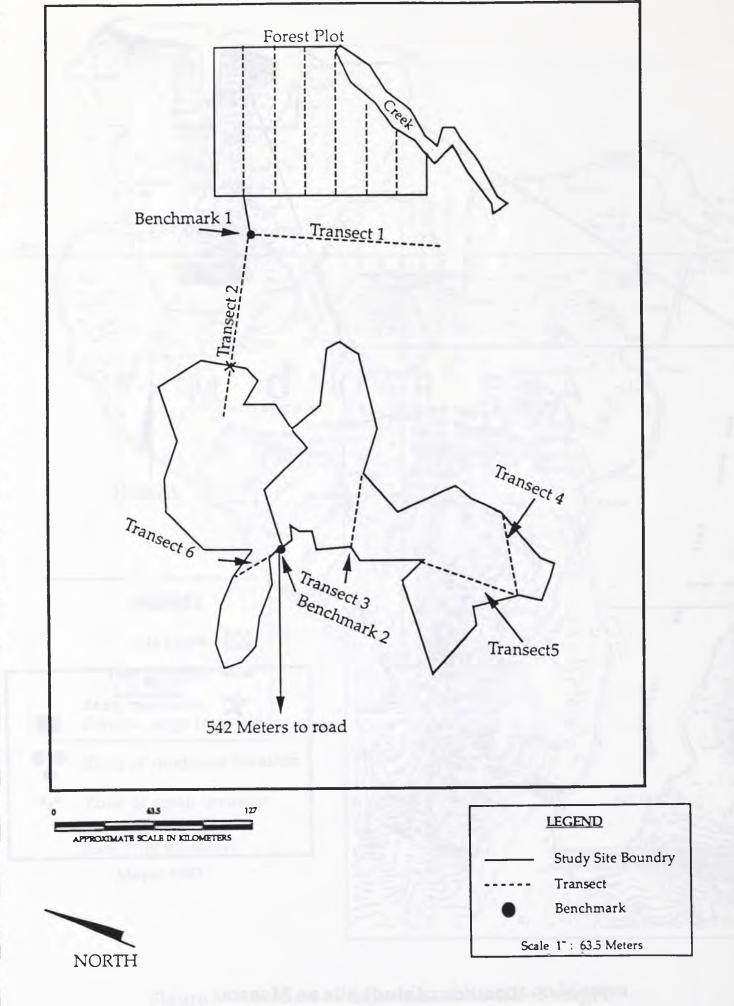


Figure 6 - Map of study site

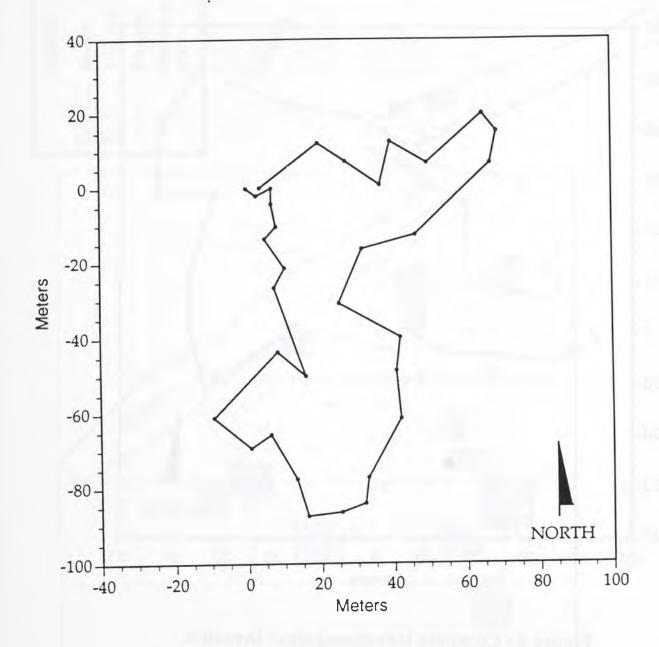


Figure 7 - Compass traverse of pasture invasion

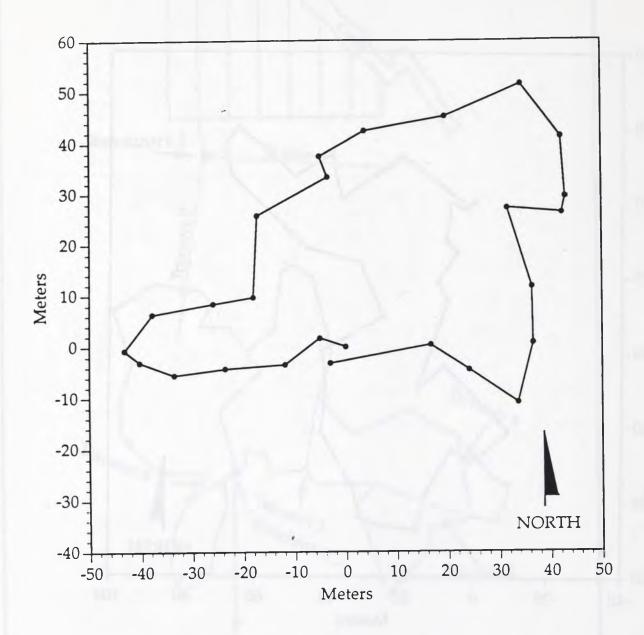


Figure 8 - Compass traverse of river invasion

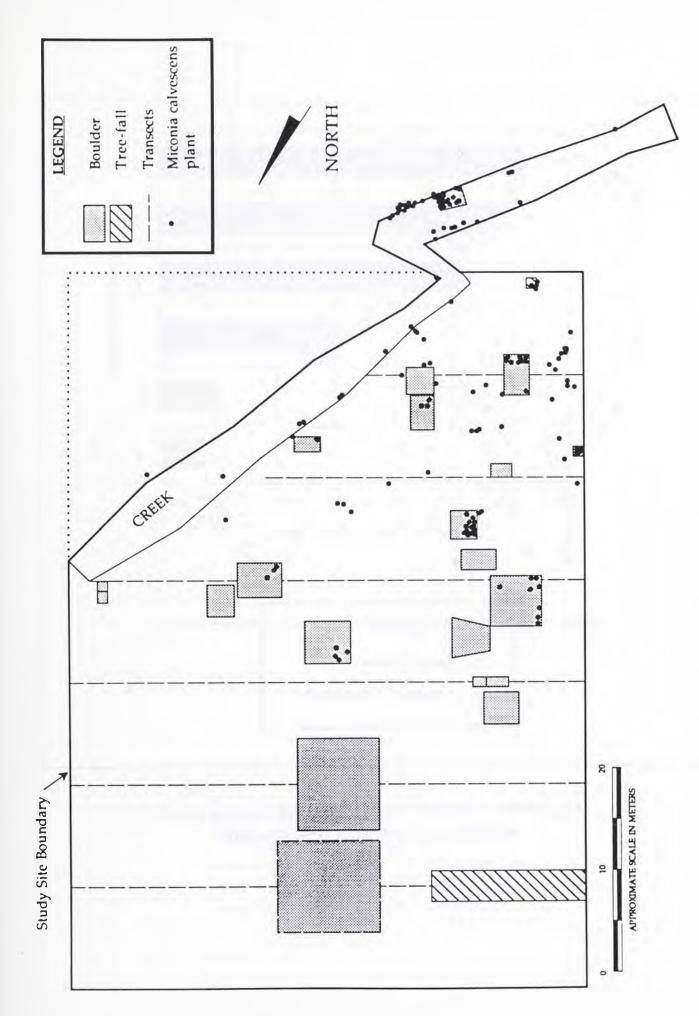


Figure 9 - Map of Forest Environment

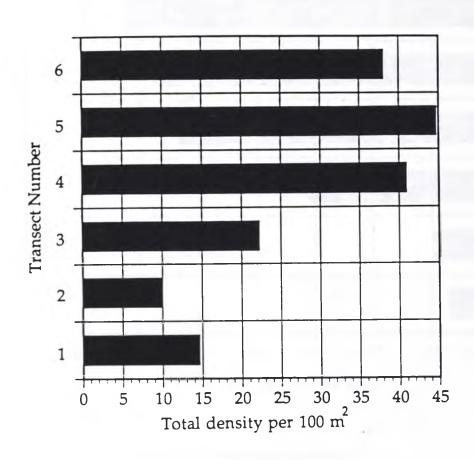


Figure 12 - Density per transect including all tree species

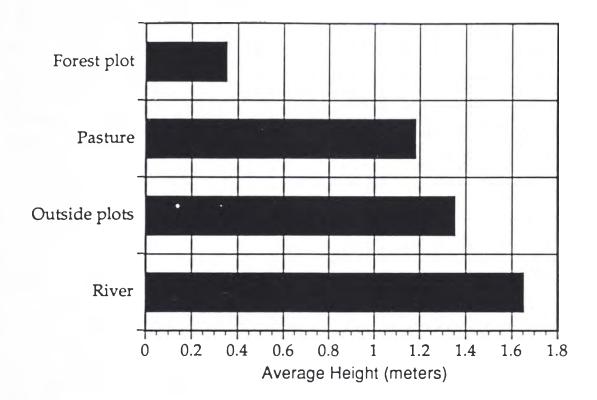
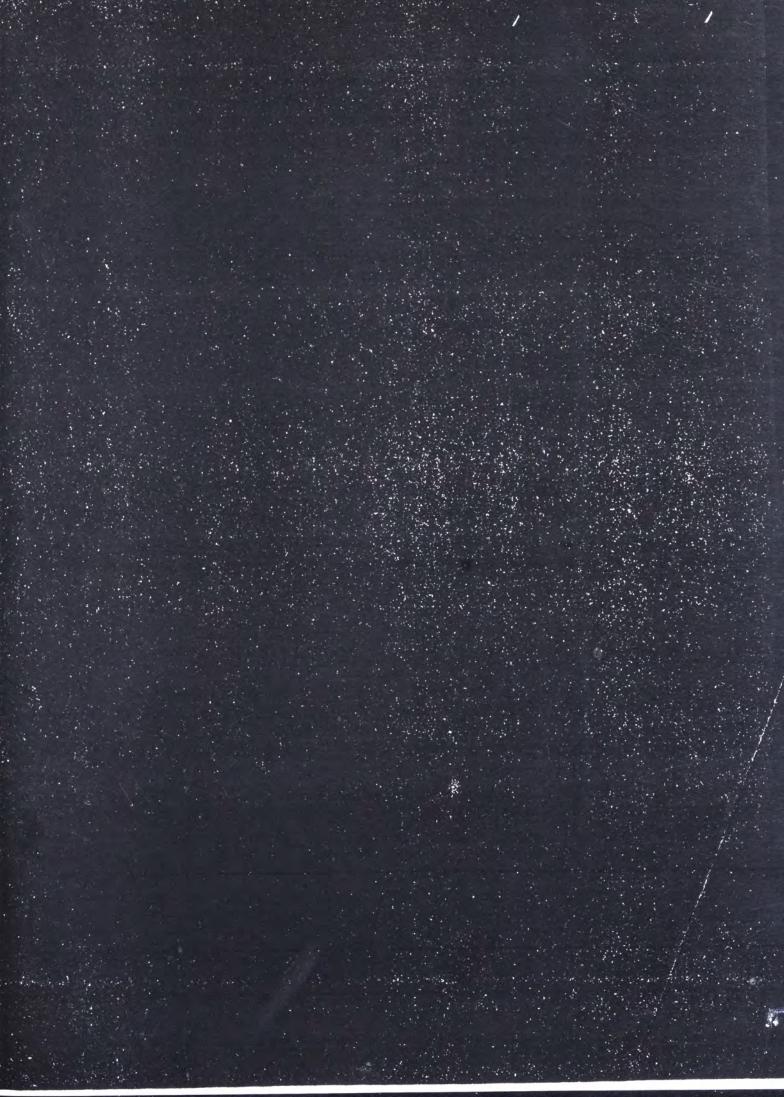


Figure 13 - Average height of Miconia calvescens in each area of the study site

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Factors Influencing the Establishment of Miconia calvescens, an Invasive Weed, on the Island of Moorea, French Polynesia.

by Ute Gigler

1113 10th Street, #15A Albany, CA 94710 IB 158, Fall 1993.

Abstract

A study was conducted analyzing factors influencing the establishment of Miconia calvescens on the island of Moorea (17° 30', 149° 50') (Map 1). Degrees of invasion under *Inocarpus* fagifer aggregations, isolated Inocarpus trees and Hibiscus tiliaceus were examined within a disturbed pasture and in forest dominated by Inocarpus, Hibiscus or Metrosideros collina. Differences in mean distances of Miconia from the center of the canopy under the three tree types suggested a negative association between Miconia and leaf litter. A strong association with litter-free microsites was found under all trees with the highest being under Inocarpus. Two-meter wide belts around the canopy drip lines exhibited a much lower association to litter-free microsites as litter decreased. The difference between association with litter-free microsites under canopies and belt areas was significant with 0.01<p<0.025. No correlation was found between availability of light and density of Miconia. The highest density of Miconia was found under isolated Inocarpus and Hibiscus trees and the lowest under *Inocarpus* aggregations. Association with litter-free microsites of Miconia was found to be 100% in the adjacent forest dominated by Hibiscus or Inocarpus. The degree of invasion in the forest was significantly lower than in the disturbed pasture. Based upon these data isolated Inocarpus and Hibiscus trees are most easily invaded while Inocarpus aggregations are more resistant to invasion. A discussion of the relative invasiveness of *Inocarpus* or *Hibiscus* forest and native Metrosideros is also presented.

Introduction

Harrison Smith introduced Miconia calvescens

(Melastomataceae) from Central America to the botanical garden in Tahiti in 1937. In 56 years the plant has established itself in 75% of the island's forest and comprises 20-25% of the forest canopy (Bernard Boccas, pers. comm., 1993, Medeiros, 1992).

Miconia has also invaded the islands of Moorea and Raiatea (Meyer, pers. comm., 1993) (Map 1). Lacking natural biological controls (pathogens, herbivores) Miconia is capable of invading a wide variety of habitat types at all elevations ranging from mountain ridges to river valleys.

The height of mature Miconia trees ranges from 3-6m. Their bi-colored leaves, green on the adaxial and red on the abaxial surface range from 30-100cm in length and from 15-40cm in width (Picture 1). Dense cover provided by these unusually large leaves may exclude other seedlings from establishing underneath Miconia. The plant has perfect flowers; a mature Miconia tree flowers four times per year and is capable of producing up to 360,000 seeds (<1.0mm) in that period (Birnbaum, 1991), (Illustration 1). Miconia's two principal means of dispersal are endozoochorous transport by birds (Zosterops lateralis) and dispersal by wind (Meyer, 1993). Tropical cyclones in 1982-1983 were responsible for damaging native vegetation and spreading Miconia seeds to previously uninvaded areas (Birnbaum, 1991, Gaubert, 1992).

In the last twenty years *Miconia* has also invaded the island of Moorea and exhibits similarly rapid spreading patterns across a variety of habitats on the island (Kellum, pers. comm. 1993, Meyer, 1993). A disturbed, heavily invaded pasture, cleared of *Inocarpus* and *Hibiscus* with scattered tree islands remaining, was examined during this study (Map 2). *Inocarpus* is a heavily buttressed 15-20m high tree with dense canopy and a high production of sclerophyllous leaf litter. *Hibiscus* is characterized by a fairly tall canopy, 10-14m, with comparatively thin leaves and a low production of leaf litter. *Metrosideros*, a small-statured, 2-6m high tree with small leaves and a low production of leaf litter grows in montane areas and was studied at the Belvedere site and observed on Mt. Rotui (Map 2).

Little is known about Miconia's relationship to other plants and its patterns of invasion into areas dominated by Inocarpus, Hibiscus or Metrosideros. This study documents that patches of Inocarpus and Hibiscus in a disturbed area have different degrees of susceptibility to Miconia invasion depending on their community structure, stature, micro- and macro-topography. Invasion in a disturbed area will be compared to that in forest dominated by Inocarpus, Hibiscus or Metrosideros. This study presents preliminary documentation of factors promoting or retarding Miconia's germination success.

Methods and Materials

A study was conducted on Mari Mari Kellum's property, a pasture of about 1.6 hectares at the foot of Mount Rotui in Opunohu Valley between October 15 and November 16, 1993 (Map 2). Dominant vegetation in the pasture was comprised of Miconia calvescens, Psidium guajava (guava), Annona muricata (sour sop), Annona sp. (coeur de beauf), Cocos nucifera (coconut), Rubus rosaefolius (raspberry) and some isolated Inocarpus fagifer and Hibiscus tiliaceus. The Inocarpus and Hibiscus forest adjacent to this property was analyzed in comparison to the pasture. Miconia populations were also observed in Metrosideros forest at the Belvedere, on Mt. Rotui, in Pao Pao Valley and on the island of Tahiti (Map 2).

A total of 9 study sites were selected in the pasture. sites were of *Inocarpus* aggregations (4-7 trees), 3 were single Inocarpus trees and 3 were single Hibiscus trees. Under each single tree or tree aggregation, the center of the canopy area was determined. The area was then divided into 4 quadrants along two axes and the distance from the center, height and association to litter-free microsite of each Miconia plant was determined. A litter-free microsite (henceforth microsite) was defined as a feature of vertical relief that does not allow for accumulation of leaf litter: rocks, boulders, roots, root crowns (caudices), dead branches, tree trunks and steep stream banks (Picture 2). Litter samples of 1m² within a circular hoop were taken along the axes one meter inside the canopy drip line, and percent canopy cover was measured using a spherical densiometer in the same locations (Diagram 1). Percent microsite was determined by laying 4 transects along the axes and 2 along lines dissecting quadrant 1 and 3 and thereby measuring the size of microsites at each line intercept.

At each site the same parameters as under the canopy were measured within a 2-meter wide belt around the perimeter of the

canopy drip line. Percent canopy cover readings were taken along the axes in the center of the belts (Diagram 1).

In the forest above the pasture two forest associations were selected: one dominated by Hibiscus with Angiopteris evecta and Coffea arabica in the understory and the other dominated by Inocarpus with similar understory. Six single Miconia and six aggregations of 3-9 Miconia plants were chosen haphazardly in each forest type and percent canopy cover and litter deposition were measured at each Miconia site similar to the pasture treatments. Miconia density in a forest dominated by Metrosideros with Angiopteris, Polypodium, Gleichenia and Commelina in the understory, was examined. Litter samples using the 1m² hoop were obtained and percent canopy cover was determined.

In the above described pasture a seedling survivorship study was conducted from October 29- December 3 1993. A total of forty 200ml cups filled with soil taken from a quarry at Pao Pao were distributed at five different insolation levels and buried in the soil leaving 1cm of the top of each cup above soil level. At each insolation level, readings were taken using a spherical densiometer ranging from 0-100% canopy cover. Exact canopy cover readings were: 7.8, 26.6, 50.96, 81.9 and 92.56%. Eight cups, each filled with 10 seeds that had been sun-dried within the fruit, were placed at each insolation level.

Light, moisture, depth of burial and litter were manipulated in order to determine their effects on germination. Every cup was watered once; subsequently only 20 cups received 100ml of water for the first week and 50ml for the following two weeks on alternate days. The last two weeks they received 50ml every 4 days. The other 20 cups were not watered at all after initial irrigation. Fifty percent of the cups had seeds placed on top of the soil, the other 50% 1cm below soil level. Fifty percent of the cups were covered by a layer of broken Inocarpus leaves positioned inside the cups to cover the soil directly.

Results

The mean distance of *Miconia* from the center of the canopy was measured under *Inocarpus* aggregations and compared to that under single *Inocarpus* trees and *Hibiscus* trees (Figure 1a). *Miconia* grew significantly farther away from the center under *Inocarpus* aggregations than under single *Inocarpus* trees (Figure 5a, b). The mean height of *Miconia* plants under *Inocarpus* aggregations was significantly lower than under single *Inocarpus* trees (Figure 1b). Mean height of *Miconia* was greatest under *Hibiscus* trees. Seedling height was not related to distance from the tree center $(r^2 \le 0.13, n \le 101, p < 0.5)$.

The density of *Miconia* was not significantly correlated with canopy cover under *Inocarpus* or *Hibiscus* trees (Figure 2a, 2b). The amount of litter differed significantly under *Inocarpus* aggregates, single trees and *Hibiscus* with respective means of 312.5, 204.6 and 153g/m² (Figure 3). A very significant association of *Miconia* to microsites and negative association to sites covered by litter was found (Figure 4a), (Chi squared goodness of fit; p<<0.001 for all sites) (Table I). Association to microsites by *Miconia* was also studied in the two-meter belt around the canopy drip line (Figure 4b). For the three *Inocarpus* aggregates, the single *Inocarpus* and *Hibiscus* trees the respective probabilities were: p<<0.001, p<0.001 and p<0.001 (Table II). The difference between association to microsites of *Miconia* inside *Inocarpus* canopy and in the belt area was significant (paired t-test; t=3.18, DF=5, 0.01<p<0.025) (Zar, 1984).

Canopy cover in the forest dominated by *Inocarpus* and *Hibiscus* was continuous, although similar to percent canopy cover readings under *Inocarpus* and *Hibiscus* in the pasture. All *Miconia* plants found in the forest were associated with microsites. Mean litter readings, centered on *Miconia* plants, and density of Miconia were much lower than in the pasture. Canopy cover in *Metrosideros* forest was determined to be 58% and litter amounted to 100g/m². *Miconia* density was very low at this location.

Only two seeds out of a potential of 400 germinated 24 days after plantation in two different cups. Both germinated under 50% canopy cover, without irrigation and covered by leaf litter. One of the seeds showing germination had been planted on top of the soil, the other 1cm below soil level.

Discussion

The pattern of Miconia invasion under Inocarpus aggregations in the pasture differed from that of Inocarpus singles and Hibiscus trees (Figures 5a, 5b and 6a, 6b). Inocarpus aggregations have a higher proportion of small sized plants growing farther away from the center than the other two groups. This might suggest that availability of light is limiting Miconia growth under the Inocarpus aggregation. Figure 2, however, shows that percent canopy cover is not related to density of Miconia.

The other potential limiting factor is the amount of litter under the canopies (Figure 3). Hibiscus sheds the least amount of litter and shows a very evenly distributed Miconia invasion under its canopies (Figure 6b). The Inocarpus aggregations, on the other hand, exhibited the highest amount of litter under the canopies. The invasion pattern under the aggregates (Figure 5a) reveals that Miconia prefer to grow farther away from the center of the canopy indicating that litter is a limiting factor.

The strongest indicator that *Miconia* is inhibited by leaf litter is its clear association with microsites. Even though a mean availability of microsites as a percentage of ground cover under *Inocarpus* was 16.9% as opposed to 10.07% under *Hibiscus*, 29.6% of all *Miconia* under *Hibiscus* established at litter sites and only 9.2% of all *Miconia* under *Inocarpus* established at litter-sites. Association with microsites decreases in the belt areas around the canopy dripline of *Hibiscus* as well as *Inocarpus* indicating that less leaf litter in the belt areas allows *Miconia* to germinate in places other than microsites (Figure 4b).

The nine study sites so far described are situated in a highly disturbed pasture that suffers from an extreme degree of

Miconia invasion. These sites could be viewed as islands of Inocarpus and Hibiscus trees in a sea of Miconia. As depicted in figure 5, Inocarpus aggregates exhibit a different pattern of invasion than single Inocarpus or Hibiscus trees. Miconia trees are able to invade more closely to the center of the canopy at singles than at aggregates suggesting that the smaller the tree island, the more vulnerable it is to invasion. Single Hibiscus trees in a sea of Miconia are most vulnerable to invasion (Figure 6b) due to their comparatively open canopy allowing seeds to penetrate and invade more easily and much smaller amounts of persistent leaf litter.

Another study was conducted in the forest above the pasture. The Inocarpus/Hibiscus forest presented the opposite extreme in degree of invasion. In this case individual Miconia plants represented the islands in a sea of forest. All Miconia plants in the forest were associated with microsites (steep stream banks (>45°), large roots, large boulders). Litter samples obtained in the forest were centered on Miconia plants or aggregates. Therefore amounts of litter were found to be lower in the forest than in the pasture. It should not be inferred from these data that amounts of litter in the forest are generally lower than under tree isolates in the pasture. Amounts of litter under lowstatured, small-leaved Metrosideros was found to be lower than under tree isolates in the pasture. The Metrosideros forest examined at the Belvedere still showed a low degree of invasion, perhaps because the surrounding montane ridges have only recently been colonized by Miconia.

Due to time constraints, that did not allow for extended observation of the cups in the seedling survivorship experiment, and with a low germination success rate, the results are inconclusive.

Conclusions

It is very important to note that the forest above the pasture still exhibits an extremely low degree of invasion.

Although sandwiched between Mount Rotui, a heavily invaded mountain, and the densely colonized pasture, the invasion within the *Inocarpus/Hibiscus* forest is occurring at a very slow rate. Important conservation implications can be inferred from these observations. The creation of disturbed areas through human intervention often accelerates invasion by non-native species (Hobbs, 1989, Loope and Mueller-Dombois, 1989, Mooney and Drake, 1989). If forests are left undisturbed, *Miconia* invasion may be slow enough to allow manual eradication. If, however, areas such as pastures continue to be created thereby disturbing native vegetation and creating tree islands, *Miconia* will be able to invade at a much faster rate. Trees such as *Inocarpus* may withstand invasion longer than other species such as *Hibiscus*, but will ultimately succumb to *Miconia's* invasion.

The native Metrosideros forest presents a special case, since it is only found in montane areas, which have largely been spared from invasions by non-native plants (Loope and Mueller-Dombois, 1989). Miconia, however, often establishes first on steep mountain ridges thereby potentially threatening the existence of Metrosideros. Metrosideros' habitat preferences combined with its low stature and low production of leaf litter make it very susceptible to Miconia invasion.

It is essential that more studies be done on Miconia's influence and relationship to other plant species (Birnbaum, 1991, Vitousek et al., 1987). Furthermore it is very important to conduct additional seedling survivorship studies of Miconia (in the field as well as the lab) to determine the parameters that govern Miconia's germination and growth rate (Birnbaum, 1991). Several studies have been done on different Miconia species in Central and South America documenting their growth in treefall areas, responses to light and nutrients (Denslow et al., 1990, Brokaw, 1987) and their association with dead logs as substrate (Lack, 1991). Miconia calvescens also has to be studied in Central America, where potential biological controls limiting the plant in its native habitat can be examined and possibly applied

in French Polynesia to avoid severe degradation of the native forests on the affected islands.

Acknowledgments

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Zar, J.H. 1984. Biostatistical Analysis. Prentice-Hall, Inc., New Jersey, USA. Table I
Chi-Square Results of *Miconia* Association to Microsites vs. Litter-Sites under Canopies
Mean availability of microsites as a percentage of total area under *Inocarpus* and *Hibiscus* were 16.9 and
10.07% respectively.

Inocarpus/Hibiscus	Microsit	conia at e (MS.)/ site(LS.)	Observed # Miconia	Expected # Miconia	Chi-Square	p
Inocarpus Aggregation		MS	94	18.88	367.5	p<<0.001
modalpas nggrogane		LS.	7	82.11		
	2	MS	21	4.38	79.6	p<<0.001
		LS	0	16.6		
	3	MS.	55	9.42	261.07	p<<0.001
		LS	5	50.58		
Inocarpus Singles	1	MS.	75	9 46	510.1	p<<0 001
		LS.	11	76.54		
	2	MS.	11	2.04	46 66	p<<0 001
		LS.	2	10 95		
	3	MS.	26	4.8	113,87	p<<0 001
		LS.	1	22 2		
Hibiscus Singles	1a	MS.	55	9 42	261.07	p<<0.001
		LS	5	50.58		
	2a	MS.	27	1.83	368 66	p<<0.001
		LS.	3	28.16		
	3a	MS.	68	12.94	257.76	p<<0.001
		LS	18	73 05		

Table 11
Chi-Square Results of *Miconia* Association to Microsites vs. Litter-Sites in 2m-Belts around Canopies Mean availability of microsites as a percentage of total area in belts around *Inocarpus* and *Hibiscus* were 21.33 and 20.21% respectively.

Inocarpus/Hibiscus Belts	Microsite	conia at e (MS.)/ hte(LS.)	Observed # Miconia	Expected # Miconia	Chi-Square	р
Inocarpus Aggregati		MS	42	11 98	98 3	p<<0 001
33 3		LS	9	39 01		
	2	MS	12	3.65	25 82	p<0 001
	_	LS.	2	10 34		p 10 00 1
	3	MS.	44	9.79	145	p<<0 001
	Ü	LS	5	50,58		p 4 0 00 1
Inocarpus Singles	1	MS	14	4.55	19.88	p<0 001
		LS	12	21 45		
	2	MS	1	2	15 62	p<0 001
		LS	3	8		p 10 00 1
	3	MS.	11	2.99	24 13	p<0 001
	Ü	LS	9	15 44	2	p 10 00 1
Hibiscus Singles	1a	MS.	24	8 28	38 74	p<0 001
		LS	12	27 72		p 10 00 .
	2a	MS.	9	3 97	8 46	0 001 <p<0 005<="" td=""></p<0>
		LS	7	12.03		2 00 · ·p ·0 000
	3a	MS	12	2 66	37 52	p<0.001
	Ju	LS	9	18 31	0, 32	p<0.001

Plan View of Tree Canopy and 2m-Belt

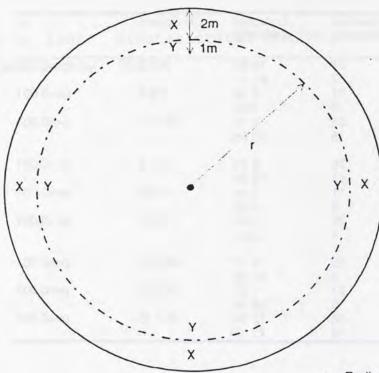


Diagram 1

r = Radius of Tree Canopy X = Spherical Densiometer Sampling Location Y = Litter and Spherical Densiometer Sampling Location

Mean Distance of Miconia from Center of Canopy

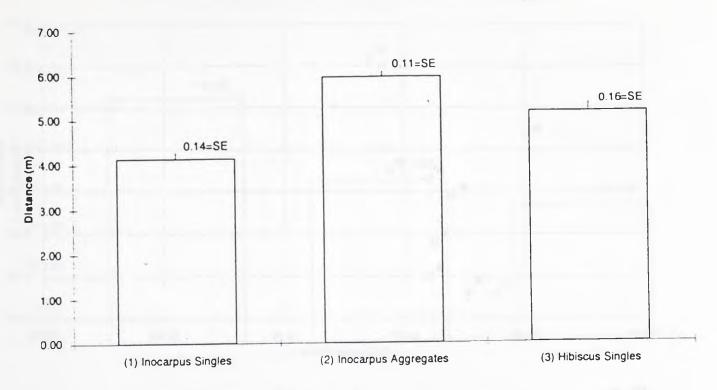


Fig. 1a.

Mean with one Standard Error n₁ = 126 n₂ = 183 n₃ = 189

Mean Height of Miconia

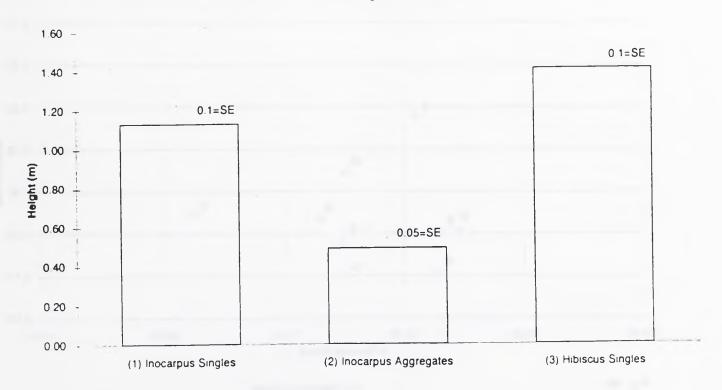


Fig. 1b

Mean with one Standard Error $n_1 = 126$ $n_2 = 183$

00 - 180

Miconia Density vs. % Canopy Cover

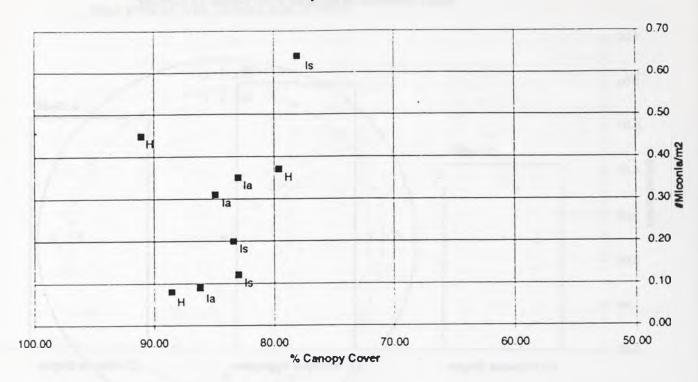


Fig. 2a.

ls = Inocarpus Single la = Inocarpus Aggregation Hib= Hibiscus

Miconia Density vs. % Canopy Cover in Belts

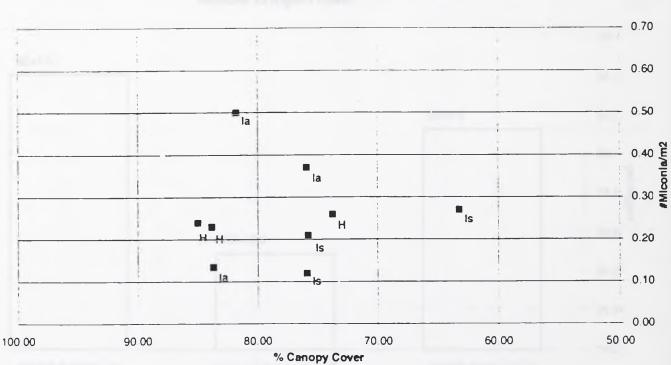
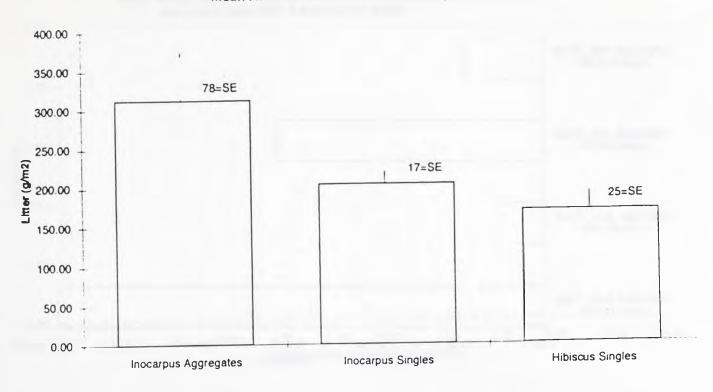


Fig. 2b.

Is = Inocarpus Single Ia = Inocarpus Aggregation Hib= Hibiscus

Mean Amount of Litter Under Inocarpus and Hibiscus



Flg. 3.

Mean with one Standard Error n = 3 for each bar

Association of Miconia to Microsites vs. Litter-Sites Under Inocarpus & Hibiscus Canopies

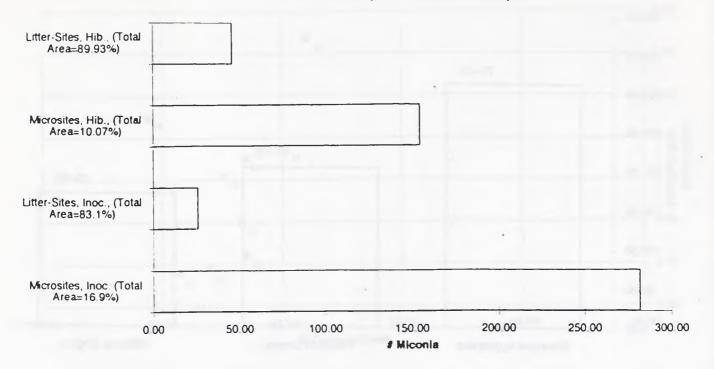


Fig. 4a.

Inoc. = Inocarpus Hib. = Hibiscus

Association of Miconia to Microsites vs. Litter-Sites in 2m-Belt Around Inocarpus & Hibiscus Canopy Drip Lines

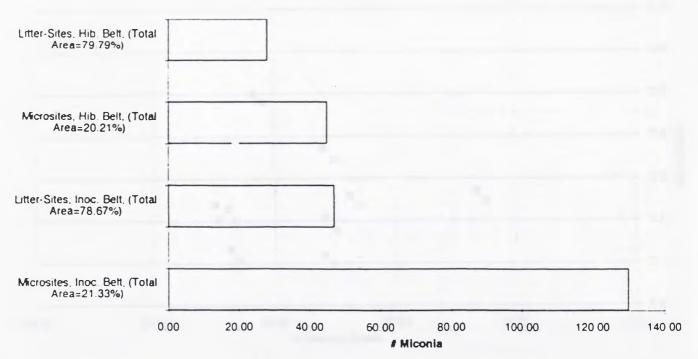
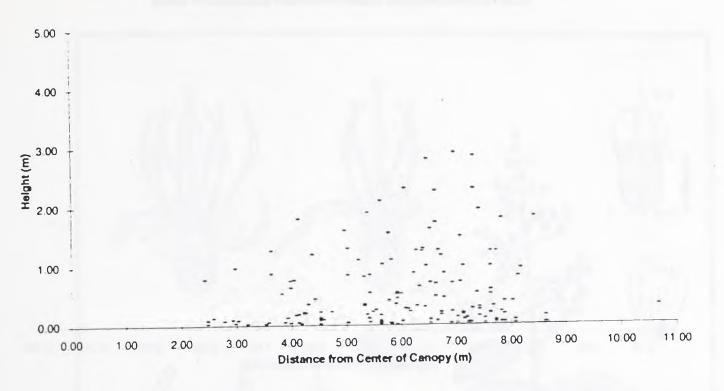


Fig. 4b.

Inoc. = Inocarpus Hib. = Hibiscus

Distribution of Miconia Under Inocarpus Aggregations (3 Sites)



Flg. 5a.



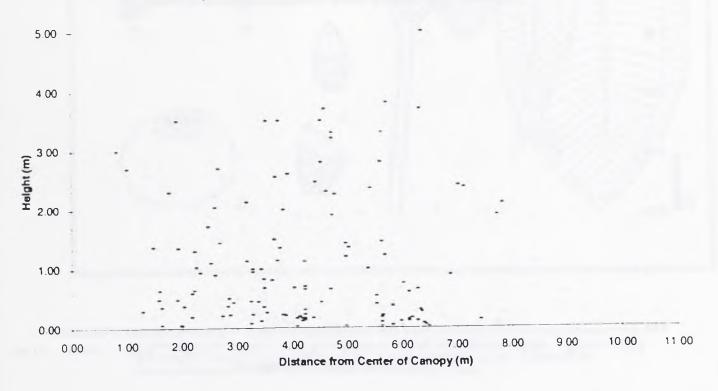


Fig. 5b.

Distribution of Miconia Under Inocarpus Canopies (6 Sites)

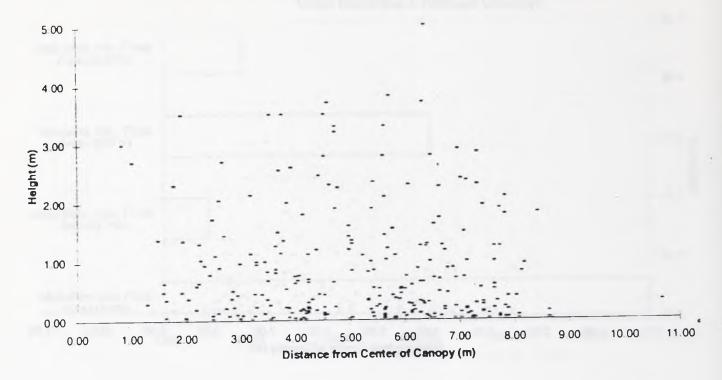


Fig. 6a.

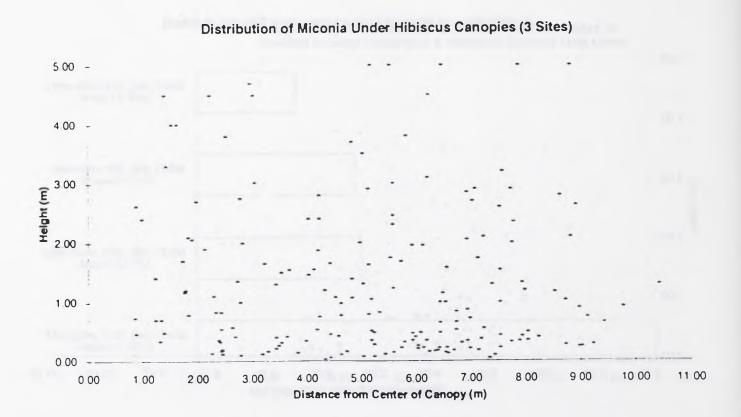


Fig. 6b.

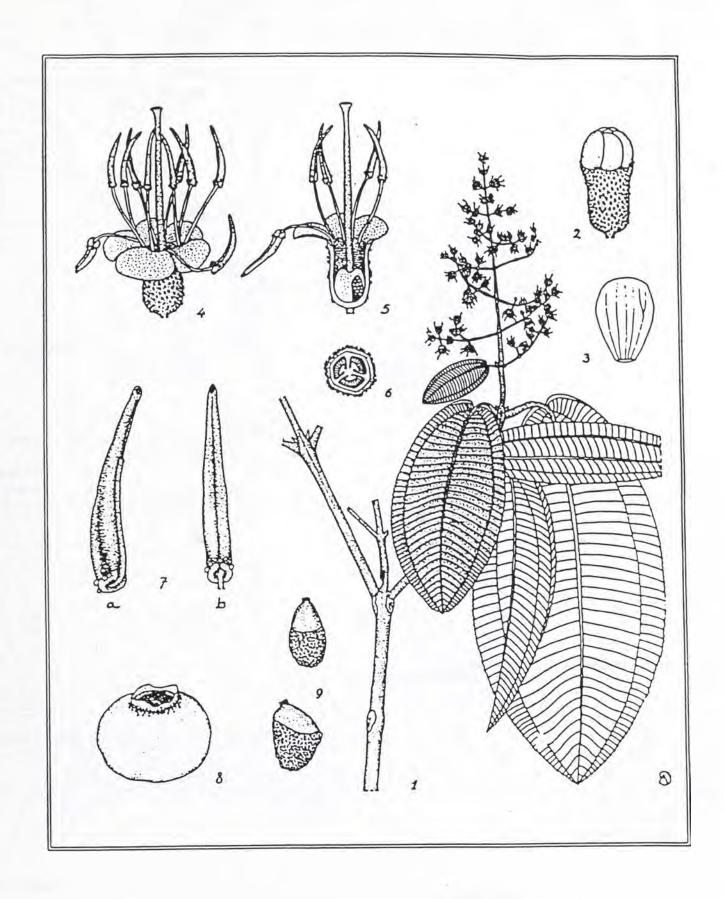
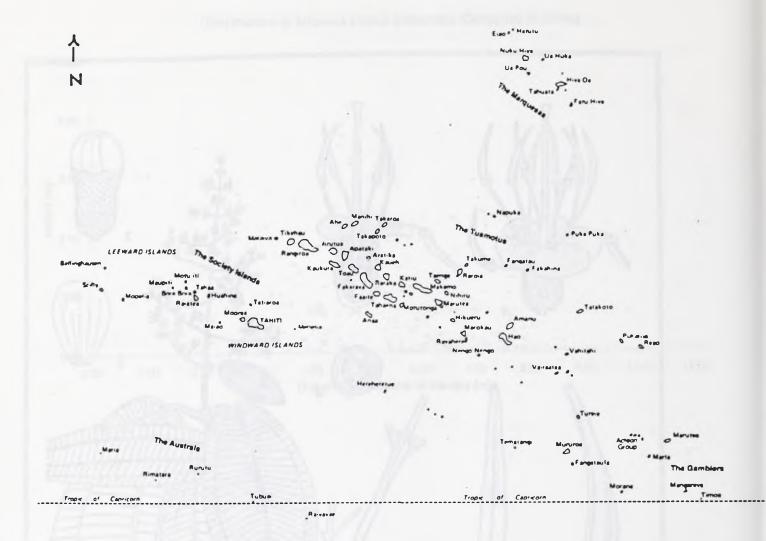
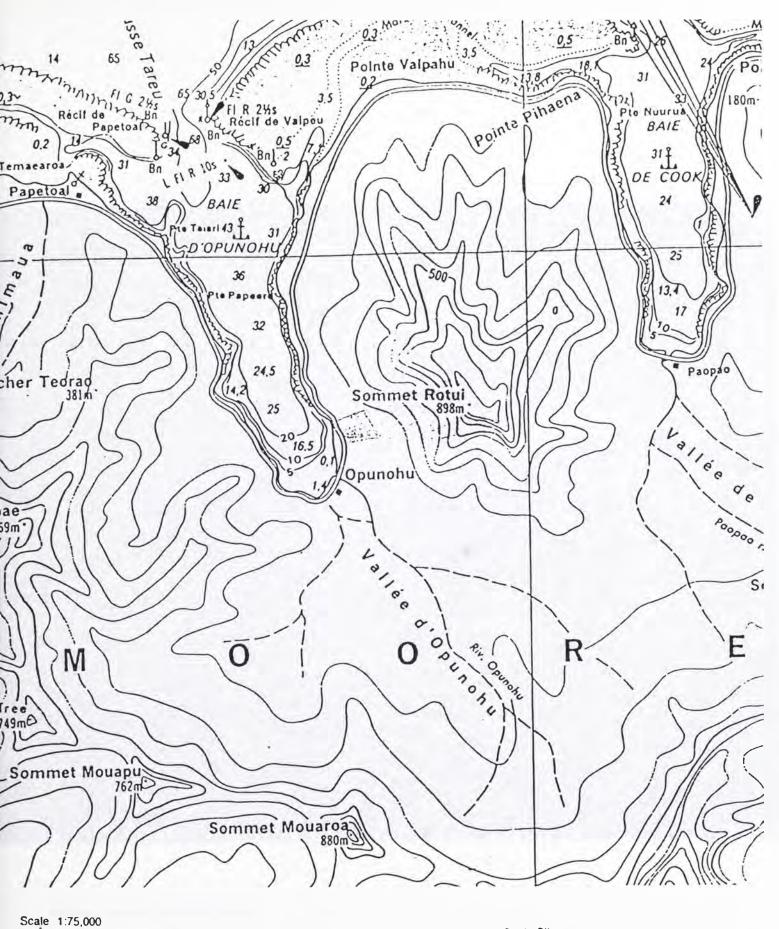


Illustration 1. Miconia calvescens: 1. Before the floral stage (X 1/3). 2. Floral bud ((X 13). 3. Individual petal (X 13). 4. Blossom in full bloom (X 13). 5. Longitudinal cut through flower blossom (X 13). 6. Transverse cut through the ovary (X 13): 7. Stamen (X 33). 8. Black fruit (berry) (X 10). 9. Seeds (X 65). Source: Birnbaum, Ph. 1991. Le cas de Miconia calvescens a Tahiti.



Map 1. Society Islands, French Polynesia. Source: Kay, R. F. 1992. Tahiti and French Polynesia.



Map 2. Pasture, Inocarpus/Hibiscus forest, Mount Rotui.
Moorea, French Polynesia

Study Sites:

- Pasture
- Inocarpus/Hibiscus forest
- Mount Rotui





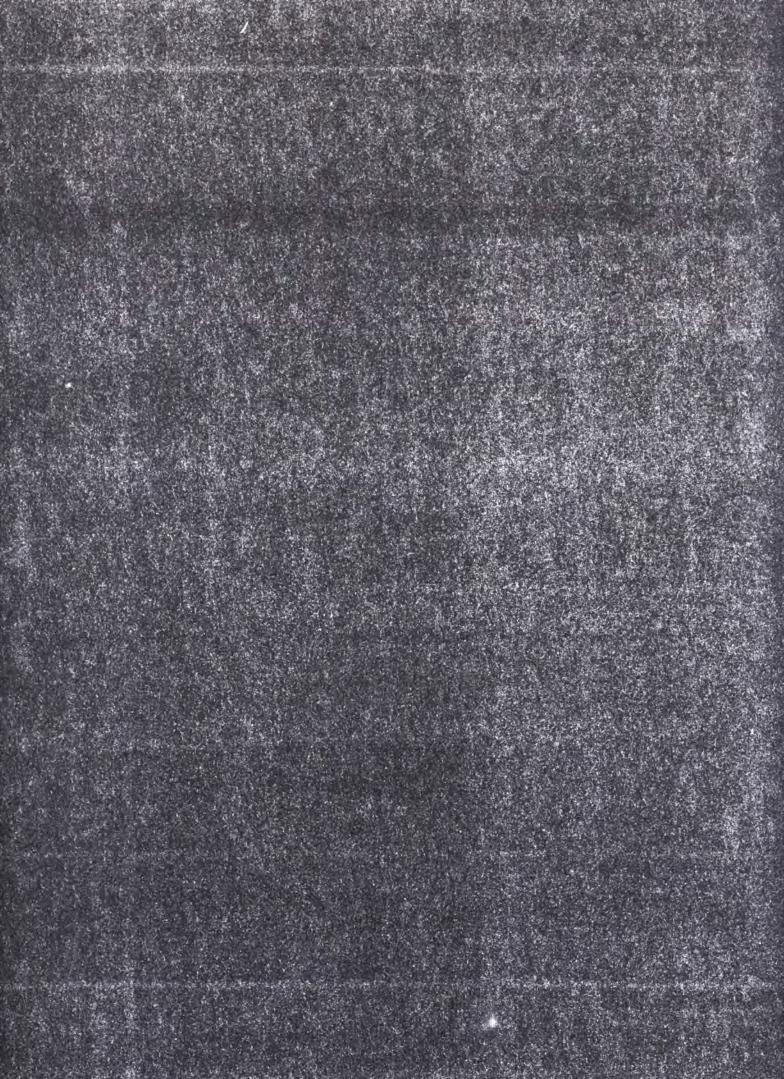
Picture 1 Miconia calvescens leaves

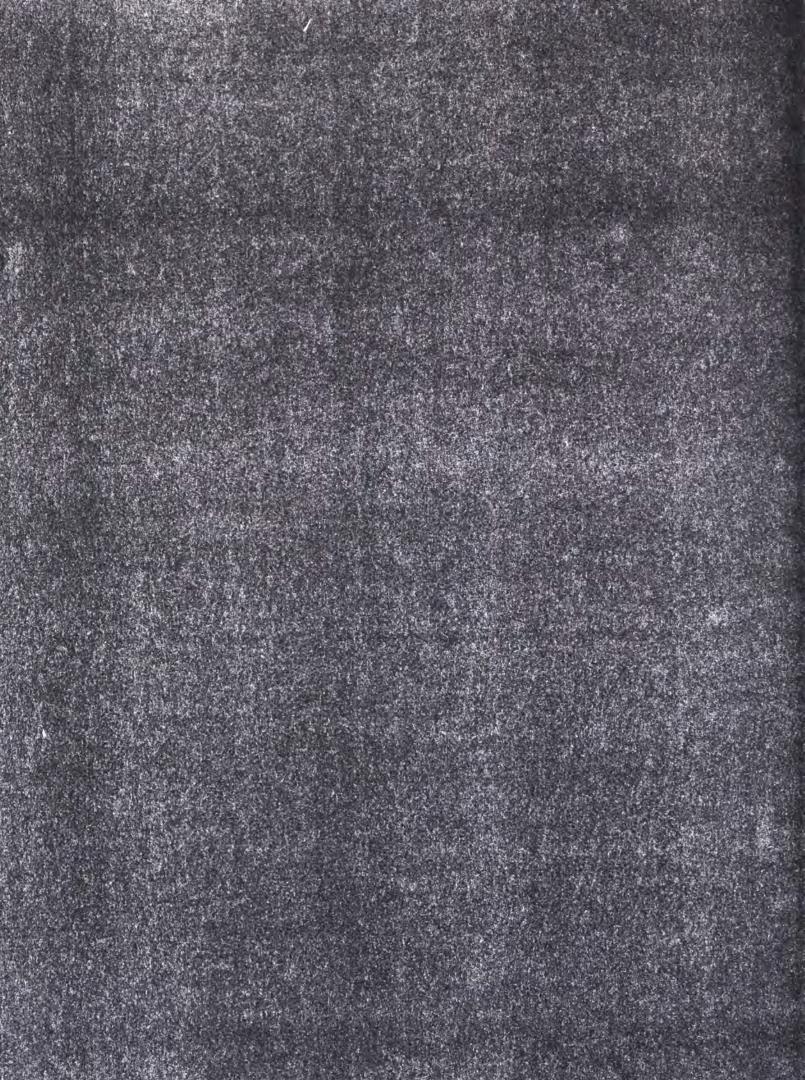




Picture 2. Miconia plants growing on and around boulder.







Comparison of Leaf Tissue Losses by Riparian Trees and an Invading Plant in a Tropical Island Stream

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Abstract:

Loss of leaf tissue in three species of trees were studied in two pools in the Opunohu River (17°31'S, 149°S 50'W), Moorea, French Polynesia. Two species, Inocarpus fagiferus and Hibiscus tiliaceus, currently dominate the riparian corridor. The third, Miconia calvescens, is an introduced species invading Tahiti and Moorea. Loss of leaf tissue is assumed to be due to shredding by palaemonid shrimp. Fresh leaves lost more area and weight than dead leaves, presumably due to higher nutrient concentration and water content. Leaves in a pool where most ambient litter was inocarpus lost more tissue than leaves in a hibiscus-dominated pool. Hibiscus and miconia leaves were preferred over the more heavily lignified inocarpus leaves. This evidence suggests that stream organisms might survive if miconia overtook the riparian corridor.

Introduction:

Tropical island streams are probably the least studied of all island habitats. Little is known about community structure or functional feeding groups. Covich (1988) states that functional feeding groupings (i.e. shredders, scrapers, filterers, collectors, predators) have not been well studied in the tropics. Some studies suggest that tropical island streams have fewer shredders than temperate streams (Resh and de Szalay, in press, Winterbourn, et al., 1981). Other studies suggest that food webs in small tropical streams are dominated by generalized consumers (Covich, 1988).

Irons et al. (1988) found that certain leaves are preferred by shredders depending on their nutritional quality. The quality is influenced by both microbial conditioning of the leaves and inherent properties of different species. Strong et al. (1984) gave three species properties that influence shredder preference, which included 1) physical deterrents, such as toughness or lignification, 2) chemical deterrents, such as tannins and other defense chemicals, and 3) differences in nutrient content, such as nitrogen and protein.

The Society Islands are threatened by the invasion of an alien plant species, *Miconia calvescens*. Miconia was introduced into a botanical garden on Tahiti in 1937. Since that time, over 60% of the island has been invaded by miconia, which replaces the native forest by outcompeting the natural

vegetation. In some areas, most native vegetation has been replaced by groves of miconia (Gagne and Montgomery, 1993). Miconia is now beginning to invade the island of Moorea (Schwartz, this report), which is located 18 km west of Tahiti. Miconia has been found in the Opunohu River watershed (personal observation).

The purpose of this study was to determine whether fallen leaves are utilized as a food source by organisms in the Opunohu River, and whether there is any preference among the *Hibiscus tiliaceus* (hibiscus) and *Inocarpus fagiferus* (inocarpus) leaves, which currently dominate the riparian vegetation, and the leaves of the invading plant *Miconia calvescens*.

Methods and Materials:

The study took place in the Opunohu River catchment, Moorea, French Polynesia (Figure 1), between October 29 and November 15, 1993. This time frame coincides with the beginning of the hot and rainy season, which lasts from November to April. The river level increased noticeably between November 11 and 13. In the Opunohu Valley the annual average rainfall is 325 cm.

The riparian vegetation is dominated by two types of trees, inocarpus and hibiscus. Leaves of three types (hibiscus, inocarpus and miconia) were placed into two pools, one dominated by inocarpus canopy cover and the other dominated by hibiscus. Table 1 summarizes characteristics of each pool. Both pools had similar maximum depths and percent canopy cover (although different types of trees). The inocarpus-dominated pool was only 35% as large as the hibiscus pool, and the shrimp density in the inocarpus pool was almost three times that of the other pool. The substrates of both pools were similar except that fallen hibiscus leaves were three times as common in the hibiscus-dominated pool.

Both fresh and dead leaves of each species were used in the study. Fresh leaves of similar sizes were picked one day prior to being placed into the stream. Dead leaves of similar sizes and colors (to help standardize length of time since falling) were selected from the ground under the same trees the

fresh leaves came from. Because the miconia leaves were much larger than the other two species, they were cut down on three sides in order to fit on the tiles, leaving a rectangle with one original leaf edge. The stem edge of each inocarpus and hibiscus leaf was cut off in order to control for preference of cut edges by the shredding organisms.

Each leaf was traced and weighed, then secured onto a tile with two rubber bands. Half of the tiles were enclosed in 1 mm² screen mesh to serve as a control for stream decomposition processes carried out by microorganisms. The tiles were then placed into the two pools in the same arrangement, a 3 X 12 square grid in which all treatments were systematically interspersed. The experimental design is shown in Table 2.

On Day 2 of the experiment, the exposed leaves were examined and no damage had occurred, so they were not traced. On Days 4/5, 8/9, and 16, all leaves with visible damage were traced and sediment was tipped off of all tiles. Each tile was removed from the water, the leaf was placed between two pieces of 0.25 inch thick Plexiglas, and the outline and any interior holes in the leaf were traced with the aid of a flashlight shone from underneath the Plexiglas, creating a sort of light table. Figure 2 shows examples of leaf tracings.

When the leaves were removed from the stream on Day 16, all exposed leaves were gently washed in the stream to remove dirt and traced, then placed into zip lock baggies until they were pressed and dried. The mesh covered tiles were also washed to remove accumulated dirt and brought back still covered. They were later opened, and each control leaf was washed in tap water before being pressed and dried. All leaves were weighed (to 0.01 gram precision) two weeks later after they had dried completely.

The area of each leaf tracing was measured using 4 mm² graph paper and counting squares. Once the original area was calculated, missing area was measured on successive days and subtracted to give area remaining.

Results:

During the course of the study, six leaves were completely lost from their tiles, and two others lost so much area that their post-experiment weights did not register when weighed. In calculating area remaining for the charts and statistics, two methods were used: 1) the zero values were left in, giving the lowest possible area remaining, and 2) the last previous areas of the lost six leaves were used in place of the zero values, giving the most conservative estimate possible for area remaining. In calculating weight remaining for charts and statistical purposes, two methods were also used: 1) the zero values were left in, as above, and 2) the zero values for the lost leaves were left out of the calculation to give a conservative estimate for weight remaining. The conservative values from day 16 were used for all statistical analyses unless otherwise noted.

Figure 3 shows that fresh hibiscus and miconia leaves lost similar percentages of area, while very little area was lost by fresh inocarpus leaves. The difference in the medians of the three samples was significant (Kruskal-Wallis test; H = 7.97, df = 2, P < 0.05; Gibbons, 1985). A multiple comparison test showed that fresh inocarpus leaves had a significantly different area loss than hibiscus and miconia (Dunn Multiple Comparison test; RI-RM = 6.17, RI-RH = 7, RM-RH = 0.833, 0.15 > z > 0.10; Gibbons, 1985). Figure 3 also illustrates the higher leaf area loss by fresh hibiscus and miconia in the inocarpus-dominated pool than in the hibiscus-dominated pool. (Mann-Whitney test; U = 31, n = 6, P = 0.05; Brower et al., 1990).

Comparison of Figures 3 and 4 shows that fresh hibiscus and miconia leaves lost more area than dead leaves of the same species. Hibiscus leaves showed a nearly significant difference between fresh and dead in both pools (Mann-Whitney test, U = 30, P < 0.10, Brower et al, 1990). Miconia leaves also had a nearly significant difference between fresh and dead in the inocarpus-dominated pool only, using day 16 data with the zero values (Mann-Whitney test, U = 9, P = 0.10, Brower et al, 1990). There was not a significant difference between area lost in fresh and dead inocarpus leaves (Mann-Whitney test; U = 21, P > 0.10; Brower et al., 1990).

Figure 5 illustrates weight remaining for both exposed and control (mesh covered) fresh leaves of all three species. The control leaves did not lose any area during the experiment. There was not a significant difference in percent weight lost among the three species of exposed fresh leaves (Kruskal-Wallis test; $H_C = 4.32$, df = 2, P > 0.10; Gibbons, 1985). There was a significant difference in weight loss among the three species of control fresh leaves (Kruskal-Wallis test; H = 6.47, df = 2, P < 0.05; Gibbons, 1985). A multiple comparison test confirmed that control fresh inocarpus leaves had a significantly different (lower) percent weight loss than the hibiscus. Control fresh hibiscus and miconia leaves did not have significantly different percentages of weight loss (Dunn Multiple Comparison test; RI-RM = 3.67, RI- $R_{H} = 7.83$, R_{M} - $R_{H} = 4.16$, z = 0.05; Gibbons, 1985). Figure 5 also shows the significant difference in weight lost by exposed fresh hibiscus and miconia leaves in the two pools. The leaves in the inocarpus-dominated pool lost more weight than those in the hibiscus-dominated pool (Mann-Whitney test; U = 37, n = 6, P < 0.05; Brower et al., 1990). The control fresh leaves did not have a significant difference in weight lost between the two pools (Mann-Whitney test; U = 47, n = 9, P > 0.10; Brower et al., 1990).

Figure 6 shows weight remaining for exposed and control dead leaves of each species. There was not a significant difference in percent weight lost among the three species in either the exposed (Kruskal-Wallis test; H = -8.79, df = 2, P > 0.99; Gibbons, 1985) or control dead leaves (Kruskal-Wallis test; H = 0.63, df = 2, P > 0.95; Gibbons, 1985). Dead leaves did not show a significant difference in weight lost between the two pools for either the exposed leaves (Mann-Whitney test; U' = 54.5, n = 9, P > 0.10; Brower et al., 1990) or the control leaves (Mann-Whitney test; U' = 55.5, n = 9, P > 0.10; Brower et al., 1990).

Comparison of Figures 5 and 6 shows that both exposed and control fresh leaves of all species, except exposed inocarpus leaves, lost a significantly greater percentage of their original weight than the corresponding dead leaves did. Table 3 gives the Mann-Whitney test results for these leaves.

Discussion:

Fresh leaves have a higher concentration of nutrients and a higher water content than fallen leaves do (Boulton and Boon, 1991). My results showed that there was more area and weight lost by fresh hibiscus and miconia leaves than by dead leaves of the same species. Most tissue loss began with small holes in the edges or interiors of the leaves. When large amounts of tissue were lost, the veins were often left intact, with the surrounding tissue missing, as shown by Figure 2. This pattern suggests that tissue was lost due to herbivory by shredding organisms. The fact that fresh leaves lost more tissue is consistent with the findings of Irons et al. (1988) and Strong et al. (1984) that leaves containing more nutrients may be preferred by shredders. The larger percentage of weight lost by fresh leaves than dead leaves is due to the greater water content of fresh leaves than fallen leaves at the beginning of the experiment as well as the larger amount of tissue lost by the fresh leaves.

The preference for hibiscus and miconia leaves over inocarpus is due to inherent physical characteristics of the three species. Inocarpus leaves are much more heavily lignified than those of the hibiscus and miconia species. Increased leaf lignification or toughness decreases the usefulness of a species as a food source (Harrison and Rankin, 1975, Irons et al., 1988, Strong et al., 1984). Inocarpus leaves may also contain a secondary defense compound that deters macro- and/or microorganisms from breaking them down. The fact that the fresh control inocarpus leaves lost significantly less weight than the other fresh control leaves, while there was not a significant weight loss difference among the three species for the other treatments suggests that fresh inocarpus may have a chemical deterrent as well as the physical deterrent of lignification. More slowly decomposing leaves may be used as attachment sites by some organisms (Harrison and Rankin, 1975).

There are at least two possible explanations for the greater loss of tissue by fresh hibiscus and miconia leaves in the inocarpus-dominated pool than in the hibiscus-dominated pool. Shrimp census data in Table 1 shows that there was a greater shrimp density in the inocarpus-dominated pool than in the hibiscus-dominated pool. A higher number of shrimp were observed on the tiles in the inocarpus pool (15-20) than on those in the hibiscus pool (0-2) on three different occasions. Resh et al. (1990) collected shrimp from two

different families in the Opunohu catchment: the Atyidae and Palaemonidae families. According to Resh et al. (1990), the atyid shrimp are filter feeders and the palaemonid shrimp are predator-omnivores. Two individuals of the palaemonid family were observed shredding inocarpus fruit which had fallen into a pool, and are the most likely leaf shredders in the stream. The higher density of shrimp in the inocarpus-dominated pool is one possible reason for the higher loss of leaf tissue. A second possible explanation is that less hibiscus is available to the shredders in the inocarpus-dominated pool, increasing the likelihood of their shredding the experimental leaves.

There are three possible sources of error in my results. The first is the loss of complete leaves due to the increase in the level of the river. The two leaves lost in the inocarpus-dominated pool on day 8 were a fresh miconia and a fresh hibiscus which were located the closest to the shrimp microhabitat in the roots of the inocarpus tree. Another fresh hibiscus leaf was missing at day 16. All three were probably shredded to the point that they were no longer secured to the tiles. Small fragments of each were recovered. three leaves that were lost in the hibiscus dominated pool had shown less than 2% loss of area before they disappeared on day 16. They were probably lost in the faster current due to the rise in the river level between November 11 and 13. This would result in an overestimate of tissue lost, which I tried to correct for by using the conservative estimate of area and weight lost for those leaves which had disappeared. Use of the 0.25 inch Plexiglas for tracing the leaves produced a small amount of distortion when tracing the leaves due to light refraction through the plastic. This distortion was fairly consistent for each leaf, so using percent area lost reduced the possible error somewhat. The last source of possible error came from cutting the miconia leaves slightly larger than the tiles they were secured to. This increased the chance of the current ripping the edges, and possibly exposed the edges to more shredding than the hibiscus and inocarpus leaves which did not extend over the edges of the tiles.

The methods used in this study could be improved in some ways. One way would be to cut the miconia leaves into smaller sizes, closer to that of the other leaves. Use of thinner Plexiglas would reduce the distortion due to refraction. Weighing the leaves to one hundredth or thousandth of a

milligram would give more precise data on weight lost. Controlling for water loss by fresh leaves by not placing some in the river and recording their weight before and after the experiment would clarify how much weight loss was due to decomposition, rather than desiccation. Finally, changing the design to place the leaves into several different pools would avoid pseudoreplication, giving more significant results on pool differences.

It is clear that shredding organisms exist in the Opunohu River. Whether these organisms always feed by shredding is not known. Covich (1988) states that the low predictability of food resources in unretentive tropical streams tends to result in little specialization of organisms on one food source. The next step would be to positively identify the shredding organisms and conduct further study on their feeding habits.

The fact that miconia leaves lost tissue at a rate similar to that of the hibiscus leaves suggests that stream organisms might be able to survive if miconia invaded and crowded out the current riparian vegetation. Further study on whether organisms can survive on a diet of miconia alone would be helpful. The loss of inocarpus leaves could change the habitat in that slow-decomposing leaves, such as inocarpus, may be used as attachment sites (Stout, 1980), but at least miconia leaves might provide a food source if hibiscus trees were lost from the riparian habitat.

Acknowledgments:

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Table 1. Characteristics of the two pools used in the study.

	Inocarpus Pool	Hibiscus Pool
Surface Area (m ²)	57.9	164.7
Maximum Depth (m)	1.15	1.10
Canopy Cover (% Covered)	76.6%	66.6%
Shrimp Density (#/m²)	2.56	0.90
Sediment (% Substrate)	20.2%	24.1%
Pebbles (% Substrate)	16.7%	7.6%
Cobbles (% Substrate)	43.8%	40.0%
Boulders (% Substrate)	14.0%	15.3%
Hibiscus Leaves (% Substrate)	3.5%	10.6%
Weeds/Twigs (% Substrate)	1.8%	2.4%

Table 2. Experiment design. Exposed leaves were secured to tiles with rubber bands. Control leaves were secured to tiles, then enclosed in 1 mm² mesh.

	Inocarpus Pool					Hibiscu	Hibiscus Pool			
	Fresh		Dead		Fresh		Dead			
	Control	Exposed	Control	Exposed	Control	Exposed	Control	Exposed		
Hibiscus tiliaceus	3	3	3	3	3	3	3	3		
Miconia calvescens	3	3	3	3	3	3	3	3		
Inocarpus fagiferus	3	3	3	3	3	3	3	3		

Table 3. Mann-Whitney test results for comparison of weight loss between fresh and dead leaves.

From Brower et al. (1990).

Leaf Type	n value	U statistic	P value
Exposed Hibiscus	6	31.5	<0.05
Control Hibiscus	6	36.0	<0.01
Exposed Miconia	6	36.0	< 0.01
Control Miconia	6	35.0	< 0.01
Exposed Inocarpus	6	30.5	<0.10
Control Inocarpus	6	36.0	< 0.01

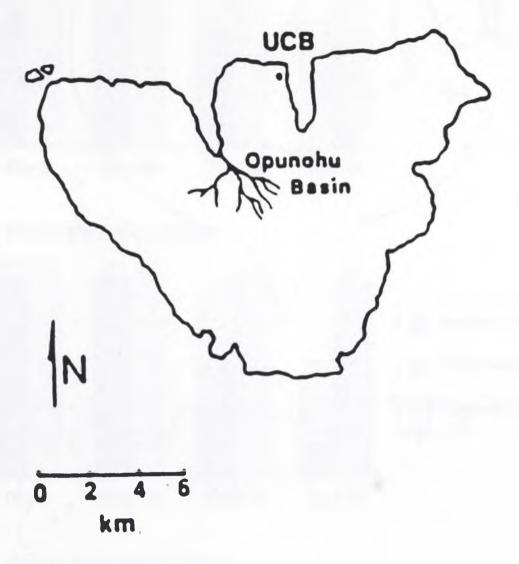


Figure 1. Map of Moorea and the Opunohu catchment. UCB = University of California Biological Station. (Resh et al., 1990)

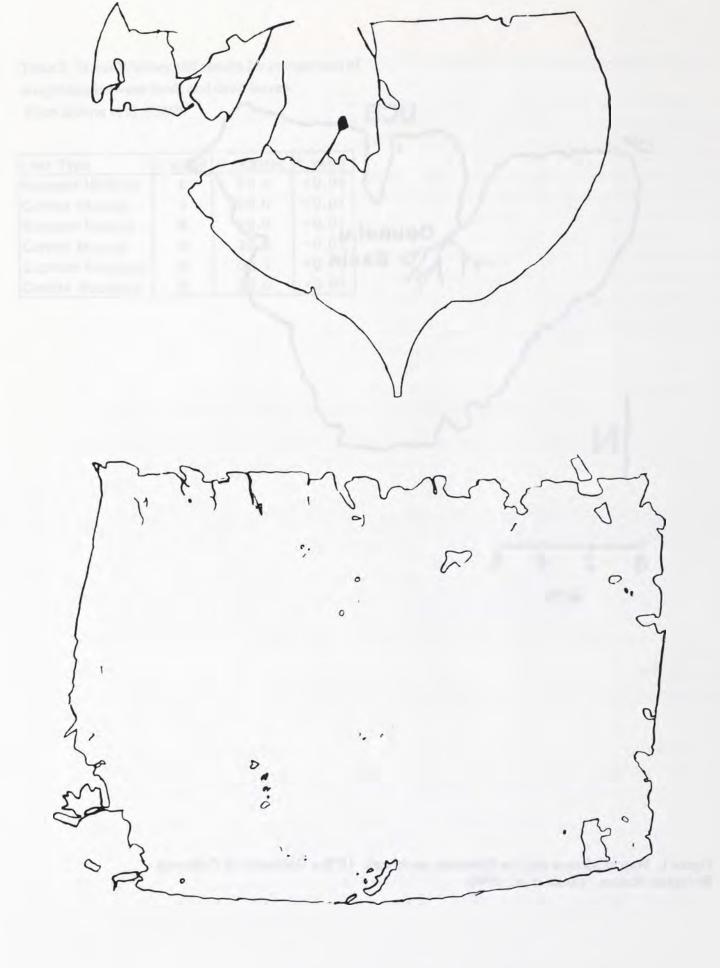
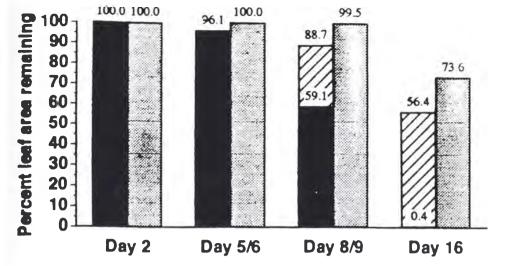
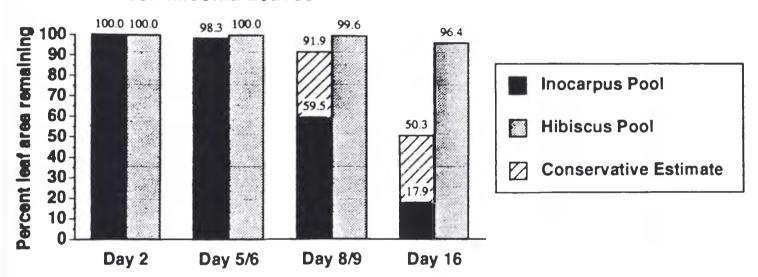


Figure 2. Tracing of a hibiscus (top) and a miconia leaf. The pattern of tissue loss suggests shredding by stream organisms.



Fresh Miconia Leaves



Fresh Inocarpus Leaves

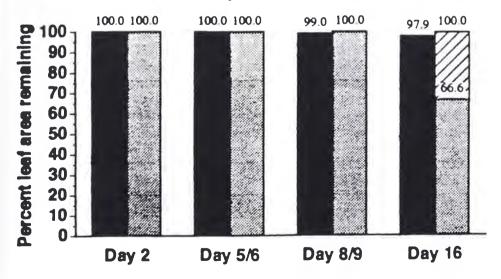
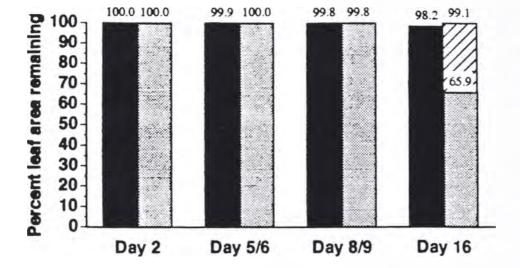
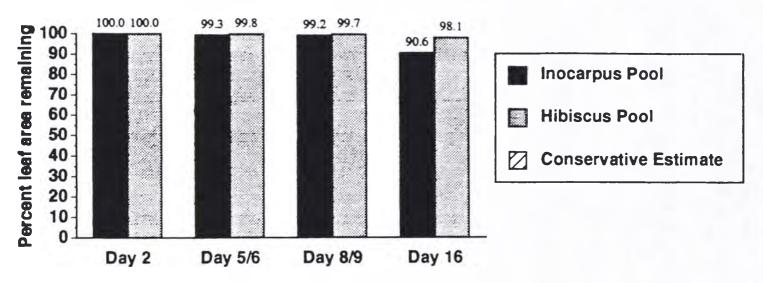


Figure 3. Percent leaf area remaining for fresh hibiscus, miconia and inocarpus leaves. Conservative estimate of area remaining calculated using the last previous area for leaves that were lost completely.



Dead Miconia Leaves



Dead Inocarpus Leaves

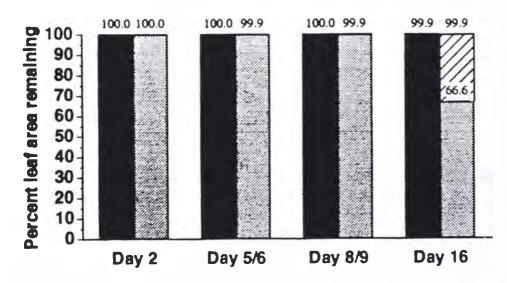
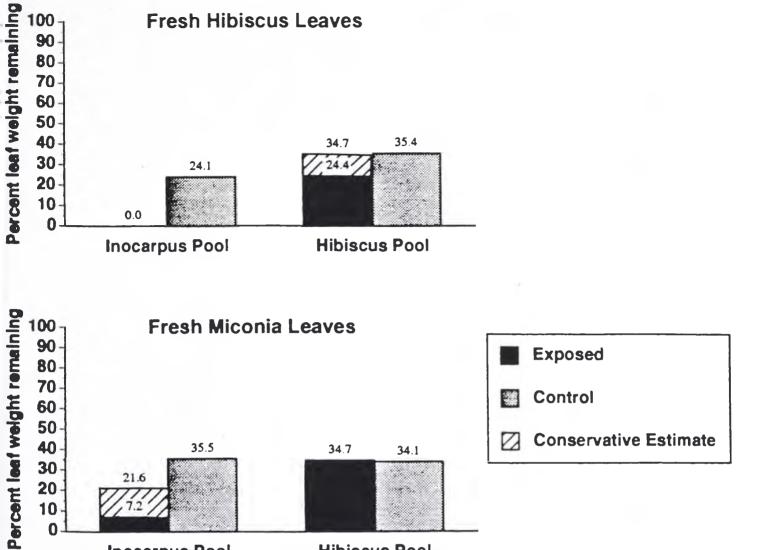
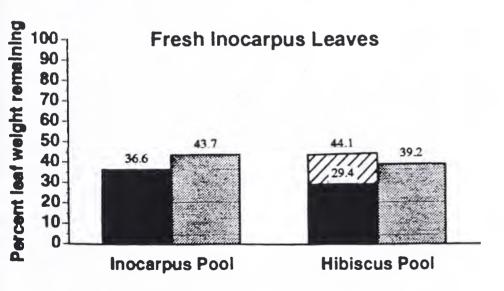


Figure 4. Percent leaf area remaining for dead hibiscus, miconia and inocarpus leaves. Conservative estimate of area remaining calculated using the last previous area for leaves that were lost completely.



Hibiscus Pool



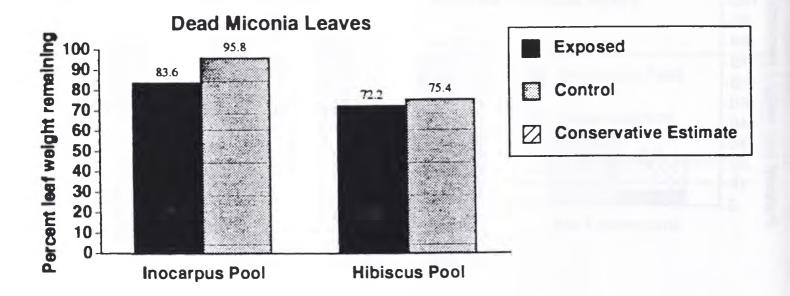
30

20 10 0 21.6

Inocarpus Pool

Figure 5. Percent leaf weight remaining for fresh hibiscus, miconia and inocarpus leaves. Conservative estimate of weight remaining calculated by leaving out values for leaves that were lost completely.

Dead Hibiscus Leaves 100.0 100.0 Percent leaf weight remaining 100 95.2 93.3 90 80 66.7 70 60 50 40 30 20 10 0 **Inocarpus Pool Hibiscus Pool**



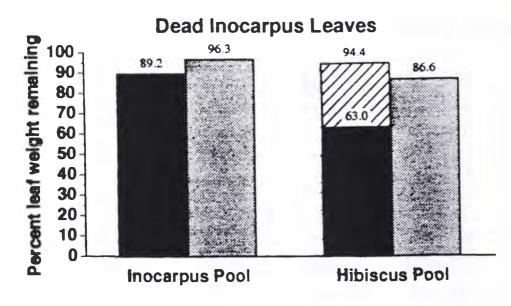
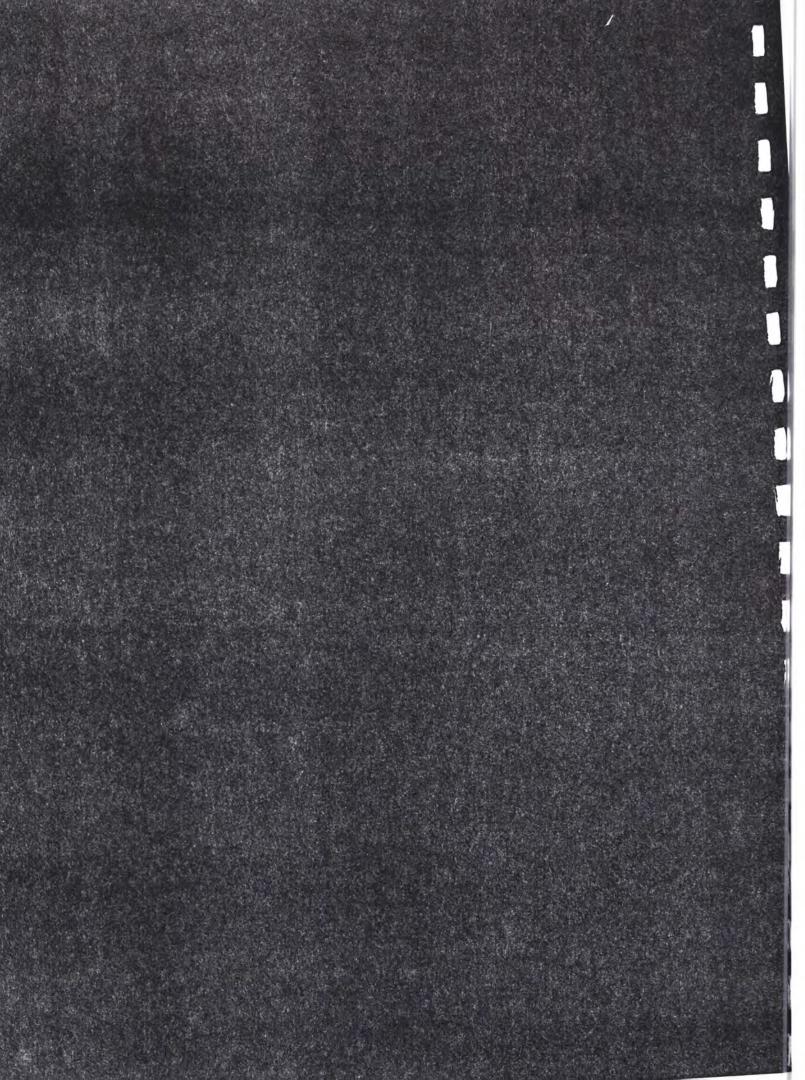


Figure 6. Percent leaf weight remaining for dead hibiscus, miconia and inocarpus leaves. Conservative estimate of weight remaining calculated by leaving out values for leaves that were lost completely.



LIMITING FACTORS IN THE DENSITY AND DISTRIBUTION OF GOBIIDS IN A TROPICAL STREAM IN THE OPUNOHU VALLEY, MOOREA, FRENCH POLYNESIA

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ABSTRACT.

- (1) Densities of algae-eating gobies correlate positively to open canopy in pool habitats along the course of the stream. Algal growth rates are higher in sunny pools and have a highly positive correlation to open canopy.
- (2) Species within the gobiidae family may be distributed across a gradient related to substrate cover. Observation of Awaous occillaris suggests this species grazes fine sediments. Awaous has a positive correlation with percent sand substrata in pools censused.
- (3) Gobies of the Opunohu have few sparsely-distributed predators. Observations of Anguilla, the freshwater eels that occupy the streams of French Polynesia, suggest that these animals are poor hunters and are probably not a limiting factor in the density of gobies.

INTRODUCTION

Little is known about the gobiid fish that are characteristic of a French Polynesian freshwater stream. Gobies are spawned in the marine environment and migrate to the streams of tropical islands where they remain until they return to the sea to reproduce. What factors, if any, influence their settlement in pools? Does predominant substrate composition alter density of all gobiid fish or is distribution specific to species? What role do predators play in the determination of gobiid populations? Does algal growth rate in a pool play a significant role in its settlement by gobiid fish? I examined these questions over the course of two months with observation and quantitative experimentation to learn more about the factors that may affect habitat choice and population viability along a branch of a relatively unperturbed tropical stream.

SPECIES AND SITE DESCRIPTION.

The study sites are located in the Opunohu River catchment (17° 31′ S, 149° S, 50′ W) of Moorea, French Polynesia. Moorea is a volcanic island, 1.2 million years old, with a tropical climate (25–30 degrees C and relative humidity of 80–90%). The island is surrounded by barrier and fringing coral reefs. Most rain occurs between the months of

October and April (Resh et al. 1990) and varies from less than 200 cm to over 400 cm depending on altitude. Study sites ranged in location from about 1.2 km to 2 km from the Opunohu Bay and are bordered by native *Hibiscus tiliaces* and introduced *Inocarpus fageriferus* (the Tahitian chesnut tree). Outlying the surrounding forest is agriculture including grazing livestock and citrus groves.

Gobies of the Opunohu remain localized within pools habitats of the freshwater stream. The most abundant species is Sicyopterus pugans which, upon study of stomach contents, has been determined to feed exclusively upon algae (Marquet 1988). The similar mouth shape of the other Polynesian gobiid species suggests that they are also entirely herbivorous. Neritid snails also inhabit the stream environment and graze on attached algae, or periphyton, but densities were low in the study pools and snail grazing was not considered to be significant. While Marquet(1988) has noted that there are nine Polynesian goby species, only the three most abundant, S. pugans, Stenogobius genivitatus, and Awaous ocellaris, will be addressed specifically although others will be noted. Because so little is known about the gobies of French Polynesia, species determination of the less prevalent fish was difficult and will often be referred to as unknowns.

METHODS

Selection and Description of Pools

Fourteen pools were selected along a branch of the Opunohu River catchment representative of various degrees of canopy cover, ranging from native *Hibiscus* at the lower reaches of the study site to dense *Inocarpus* at pools located furthest from the mouth of Opunohu Bay. Pools were selected without regard for size, given that they fall within the minimum requirements for a pool. A pool was defined as the area between two riffles where the surface of the water becomes smooth due to a slowing in flow rate.

Pools were surveyed and mapped by laying a tape measure down the length of the thalweg and taking cross-stream transects at intervals which documented the contours of the bank. Deepest point readings were also taken at each transect. The pools were then sketched by hand and reconfigured by computer using a program which estimates area of a convoluted surface, such as a riverbed. Study pools were surveyed for substrate composition by a simple transect method: a tape was stretched perpendicular to the thalweg and substrate was noted at pre-determined intervals depending on pool size.

Determination of Periphyton Growth Rates

Algal growth curves for two of the fourteen pools, one under dense canopy and another of intermediate cover, and an additional extremely sunny pool were measured. The experiment was established using raised tiles to cultivate an undisturbed crop (Power 1981). Tiles of unglazed terra cota were first seasoned in the river for a minimim of 24 hours to leach impurities and then strapped to the platforms about 10 cm from the water surface. Similar experiments (Power 1981, 1984, Feminella et al. 1989) have proven to effectively mimic periphyton growth on the smooth rock of a riverbed. Using a razor blade to scrape algae from the tiles and a standard laboratory wash bottle to rinse, I collected samples of periphyton at time points of 2, 4, 8, and 16 days on filter paper for later analysis. As each

sample was taken, the corresponding tile was placed on the pool floor. Although snails, who also feed on attached algae were sited in study pools, none were documented on any of the experimental tiles. I opted not to census snail population at this determination as density in the study pools was low and snail grazing was not considered to be significant. Upon returning from the field, samples were weighed on a Mettler H51AR balance to tenths of milligrams, combusted at 510 degrees for two hours, and reweighed to determine ash-free weights.

Canopy cover was estimated using a spherical densioneter (Lemmon 1957). All fourteen censused pools and the additional sunny pool were measured. Regressions were performed on canopy score to correlate percent cover to periphyton growth rate.

Gobiid censuses

Because gobies of French Polynesia are largely sedentary, resting on cobbles and other substrata, censusing of the pool was accoplished by slowly snorkeling the length of the pools from downstream to upstream. This method has been determined to give better estimates of density for relatively motionless fish(Power 1981). When canopy was extremely dense and incident light was low, a dive light was additionally used to census. Pools that were too shallow for snorkeling were censused using two methods in combination: on several occasions I did push-ups along the length of the pools, putting my head in at defined intervals or, alternatively in places were I could not get my head in, I viewed the pool through my mask on the surface of the water. During this phase of the experiment, extensive observations on feeding behavior and apparent preference for substrate were made.

Observations of Gobiid Predators

In the course of snorkeling pools, predators behavior was observed. Although predators were sited, none were observed to feed on the gobies during the two months of the study. An anguillid was monitored for forty-five minutes which was apparently attempting to hunt both gobies and Macrobrachium shrimp; however, the angullid eel was unsuccessful for the duration of its hunt and eventually gave up. Kuhlia spp. were also noted to contain gobiid fish in their guts (Marquet 1988), but I did not observe them to prey on gobies despite their plentiful densities in all of the deeper pools. Electris fusca were documented hiding in rock clefts but similarly were not observed feeding even after 15 to 20 minute intervals.

RESULTS

Periphyton Growth Rates

As previous studies have shown, algae grew fastest in the sunny study pool and, conversely, was very slow growing at the dark study site. Regressions performed on time points in the algae study gave growth rates in mg/cm/day to be 0.026(r=.89), 0.015(r=.98), and 0.0076(r=.78) for sunny, moderately sunny, and dark study pools, respectively. The percent canopy cover for the pools, 31.2% for the sunny site, 76.6% for the moderately sunny pool, and 99.8% for the darkest location, had a strong negative correlation(r=-0.997, $p \ll 0.05$, df = 1) algal growth rates.

Density and Distribution of Gobiids

Combined goby density for all species in the study had a moderately strong negative correlation (r=-.59, p \ll 0.05, df = 12) to percent canopy cover in pools censused. From the correlation established between percent open canopy and periphyton growth rate, it is inferred that goby distribution is related to algal growth rate. In fact, in the darkest pools, goby density(individuals per area squared) was up to fourteen times less that of the sunny section of Centipede pool and about seven times less than moderately sunny pools.

Two species exhibited preferences for habitat within a pool. Upon extensive observation of Awaous, it was observed that they often remain close to sandy, deep parts of the stream. It was later noted that this species apparently feeds by scooping up mouth-fulls of sand and, presumably, cleaning it of algae and detritus before spitting it back out. This feeding behavior seems to be unique to Awaous as other gobiid species of the Opunohu streams scrape attached algae from cobble size and larger substrata. This pattern of feeding may also serve to elucidate the nature of the difference of Awaous mouth shape in comparison to other gobies in the stream. The linear regression of Awaous density to percent sand substrata seems to support this hypothesis with a positive correlation of r=0.61 ($p \ll 0.05$).

This second observed habitat preferrence was that of Sicyopterus for shallow pool tails. During the course of the study it was noted that Sicyopterus are often the dominant genus in pools where depth is less than approximately 15 cm. These pools were largely devoid of predators such as anguillid eels and Eleotris and were much too shallow for Kuhia spp. The relationship between Sicyopterus and its habitat preference may have been obscured by the coincidence that shallow pools were also sunny in the study.

DISCUSSION

The density and distribution of gobiid fish in the Opunohu seems to be influenced by many factors. The relative canopy cover is a primary concern for algae-eating gobies as it correlates directly to periphyton production in stream pools. Animals must seek out habitats that sustain their nutritional needs, as is suggested by the preference of gobiid fish for pools with high percent open canopy and subsequent increased periphyton production.

A secondary factor influencing goby distribution of different species is the type substrate found in a pool. As indicated with observations of Awaous spp. and Sicyopterus spp., fish exploit different parts of the stream environment according to their individual adaptations. In order to make a statistically significant observation about Sicyopterus spp. and an apparent preference for shallow pools, band transects in both sunny and dark pools should be executed in both shallow and deep regions of the stream.

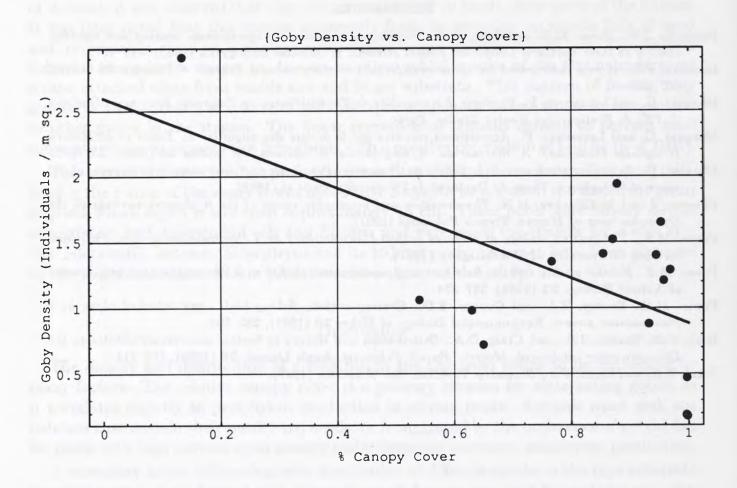
The role of predators on freshwater goby populations is still largely unknown. Studies which more exhaustively observe predation, which may take place largely at night, should be conducted. Because predation on gobiid fish may be difficult to observe, experiments which manipulate the density of predators in relation to goby density would be useful. However, it could be inferred that the success of *Sicyopterus spp.*, which Marquet (1988) estimates to comprise 70% of the individuals in the goby population, is related to their ability to dominate shallow areas of the stream inaccessible to predators.

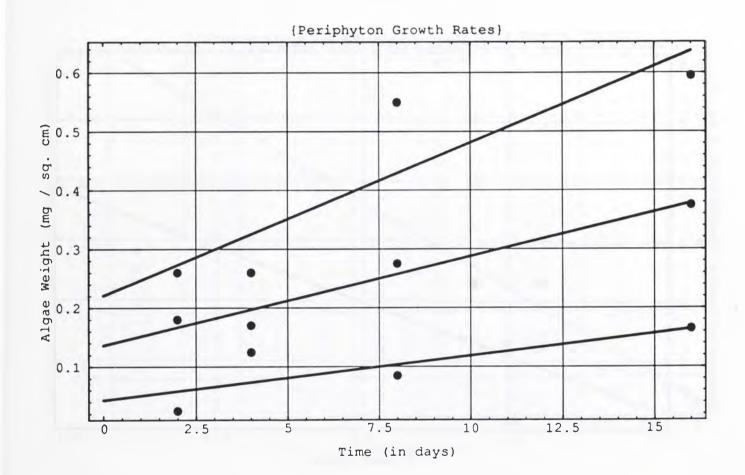
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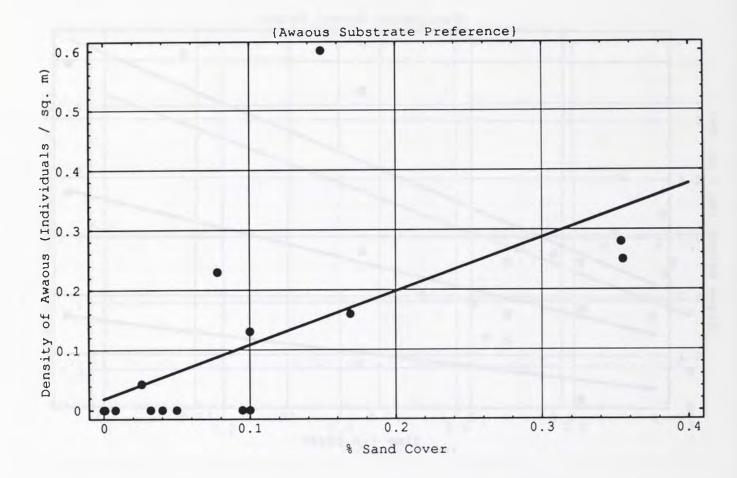
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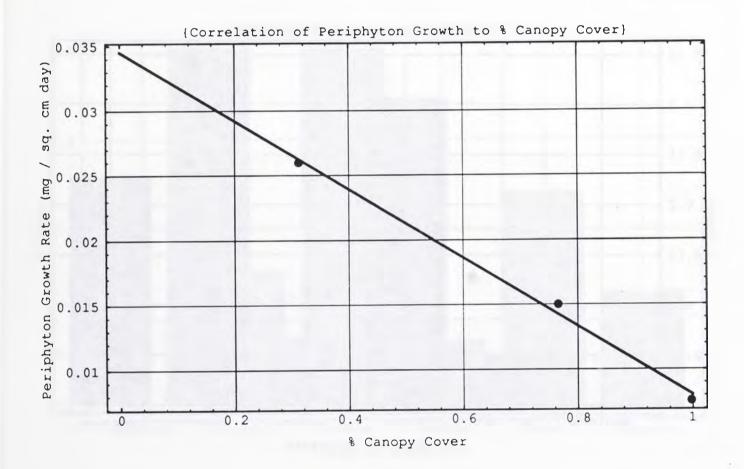
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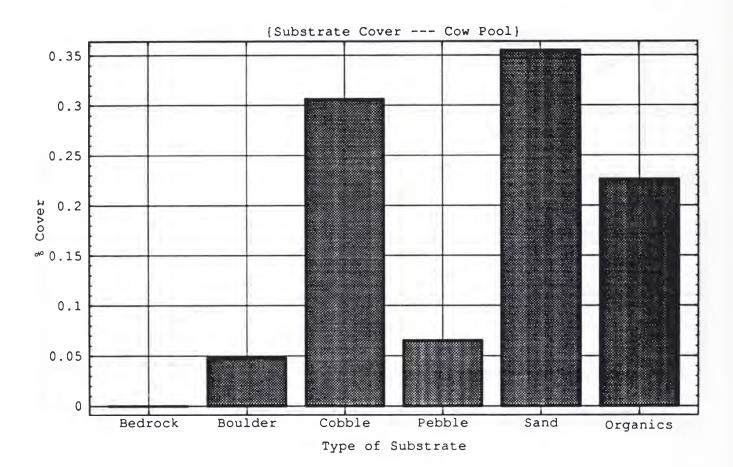
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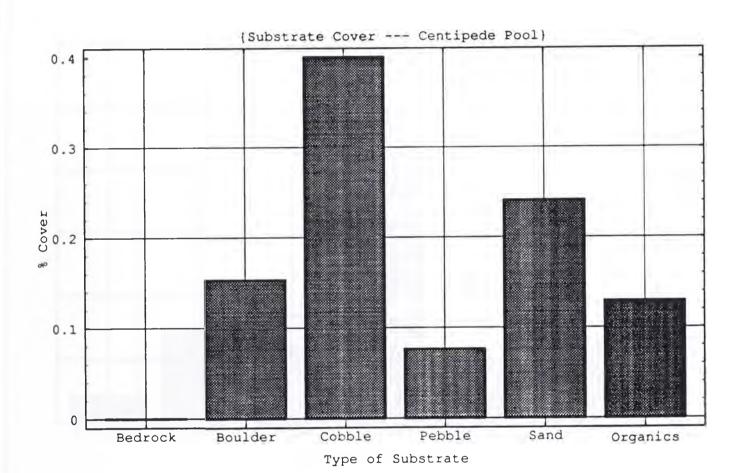


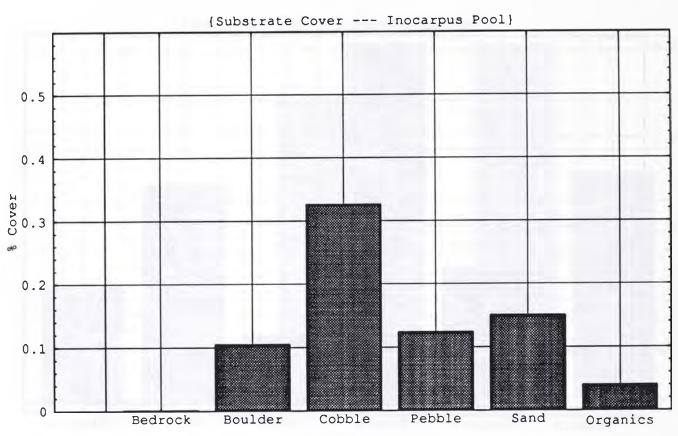




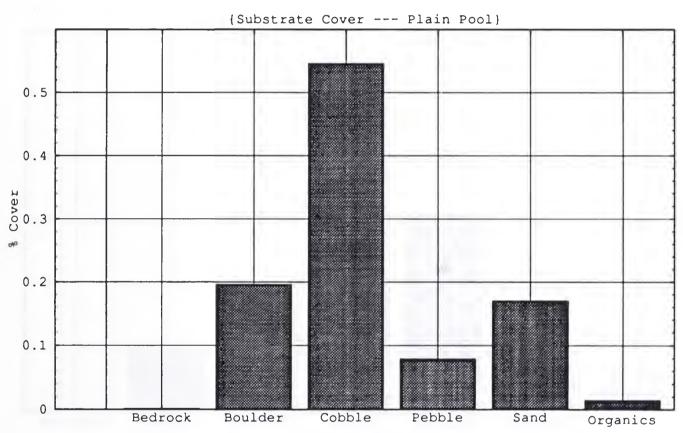




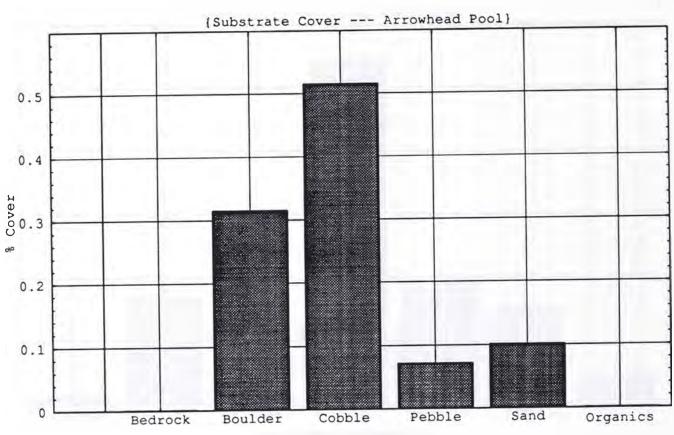




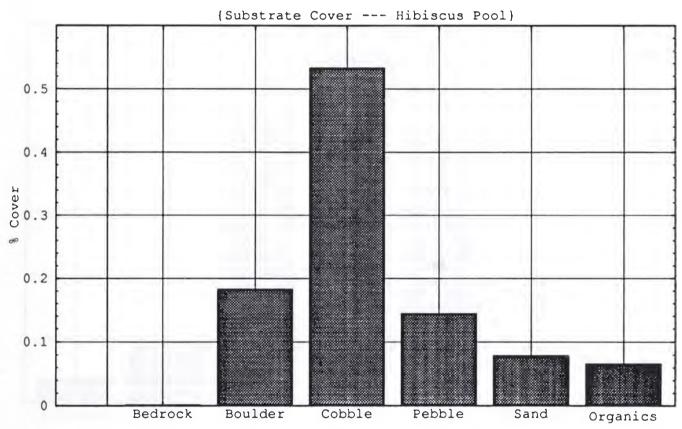
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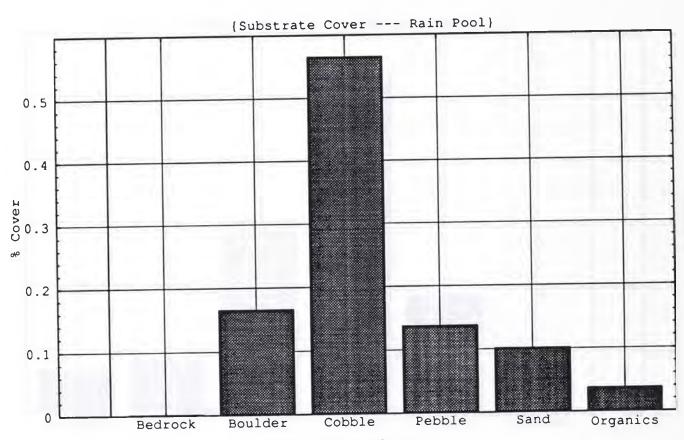
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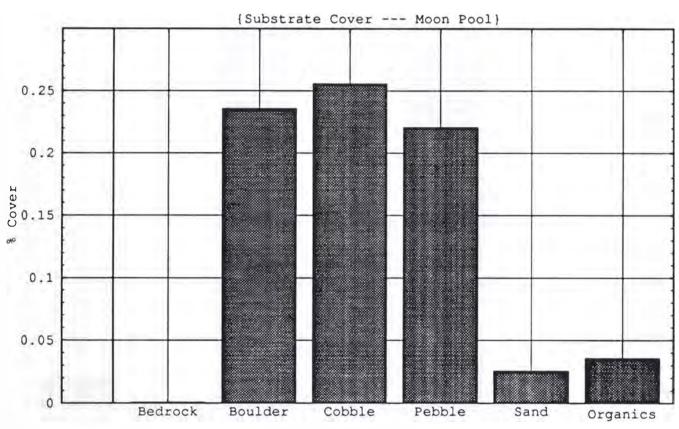
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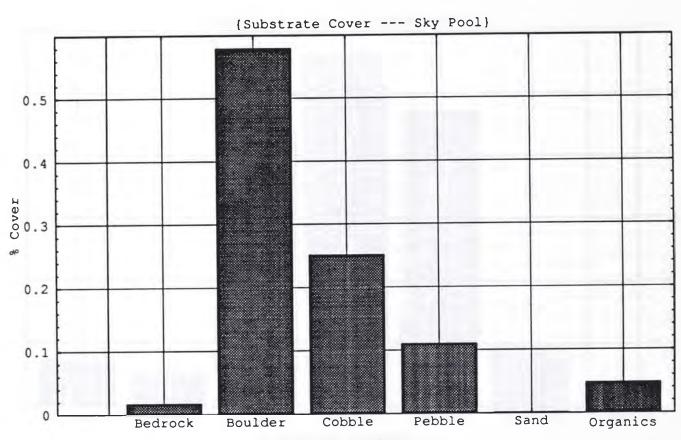
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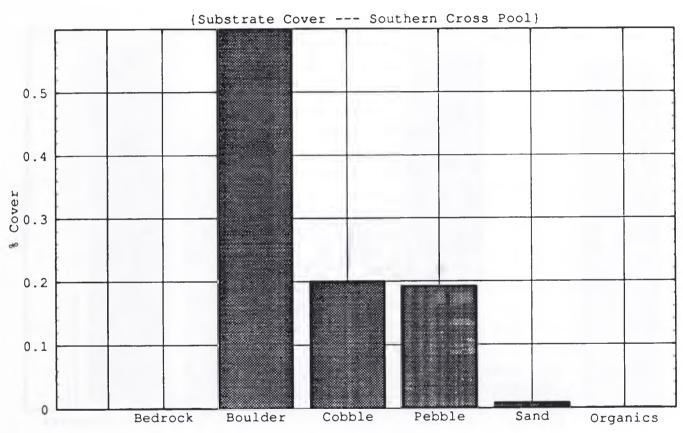
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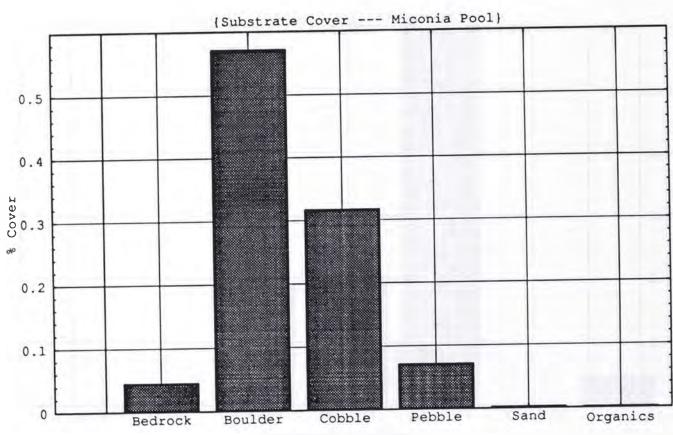
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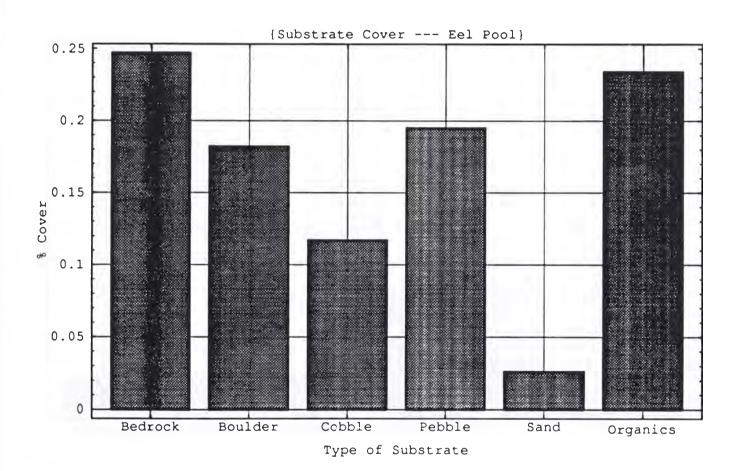
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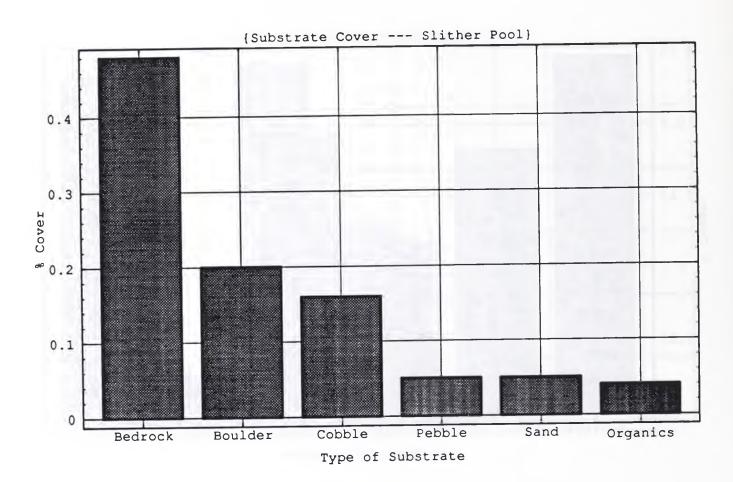


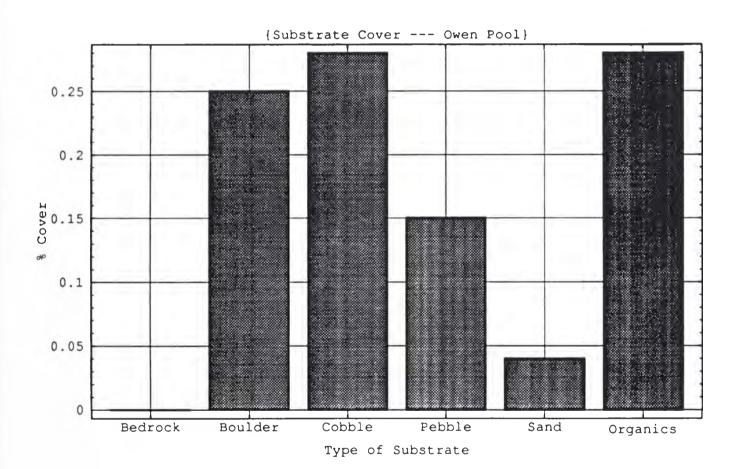
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