Reefs of Life to Reefs of Death: The Political Ecology of Coral Reef Health

by

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Abstract

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This research focuses on the South Pacific region, an area of high global coral diversity. I examine reef health surrounding two islands in Fiji, Vatulele and Ovalau, and two Cook Islands, Aitutaki and Rarotonga. Each island has distinct differences based not only on reef type, environment, and ecology, but also upon social institutions. I will compare four islands with barrier and fringing reefs that have different levels of economic development, population pressure, land-use practices, and marine management practices. This research will assess coral health in areas that have not been previously surveyed.

This interdisciplinary research methodology includes both ecological and social data collection to further understanding of human environment interactions. I do this by identifying and describing the presence of certain social institutions and some historical reasons as to why they exist. I then assess the impact they probably are having on the reef, and finally I present data on the ecological condition correlated with certain social institutions. In comparing the reefs with these social conditions and institutions, I argue that certain institutions have greater or lesser impact upon coral reef health based upon

correlation. Correlative research is useful to point out areas of future research, and to provide data to make estimates as to the level of causality, which could in turn be information used for policy making and activism.

Through the examination of four island case studies I will argue that:

1. The commodification of the reef and reef resources is one of the primary factors causing the decline of coral reef health.
2. The loss of traditional marine social institutions has affected coral reef health. Specifically, the transformation of common property resources from communally owned property to state owned with open access status has primarily influenced ecological change on the reef.
3. The implementation of traditional marine social institutions as exemplified in a case study in Rarotonga, Cook Islands is improving coral reef health.
4. The image of the South Pacific as having "healthy" reefs shapes and forms policy and practices of global, regional, and local institutions and organizations.

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The Political Ecology of Coral Reef Health: The Approach and Theoretical Framework

Coral reefs contain 25 percent of all known marine species (Paulay 1997). They are important because they contain high biological diversity and abundant economic and ecosystem services for millions of people (Costanza 1997). All around the world, coral reefs - underwater communities of biological diversity and life - are changing (Grigg 2000). The various faces of the devastation are well known - loss of diversity, fish life, tourist dollars - but the rush to the rescue has not yet determined one crucial factor: what caused and is still causing the the decline of the reefs? This dissertation attempts to answer that question using a political ecology approach that integrates both human and biological geography (Zimmerer 1994).

This research focuses on the South Pacific region, an area of high global coral diversity. I examine reef health surrounding two islands in Fiji, Vatulele and Ovalau, and two Cook Islands, Aitutaki and Rarotonga. Each island has distinct differences based not only on reef type, environment, and ecology, but also upon the level of commodification[1] of the reef. I will compare four islands with barrier and fringing reefs that have different levels of economic development, population pressure, land-use practices, and marine management practices.

Based upon these case studies I argue that contrary to many scientific claims, coral reef environmental change is connected with human geographic factors, such as changes in such social institutions such as marine property regimes. Natural processes such as hurricanes and sea surface temperature changes are important factors in coral reef change, but in the Pacific region, I will argue that the commodification of the reef and reef resources as well as the transformation of certain marine institutions have contributed to the decline of coral reef health. I present four case studies that document the changes in the social, economic, political, and environmental conditions, which have altered the pattern of indigenous resource use, and management, leading to the commodification of the reef and common access to the reef and surrounding environment. As the marine resources become more commodified, the externalities associated with commercial development of each business sector developing the marine resources also increase, thus potentially increasing the degradation to the reef environment. Furthermore, the change from private or communal property systems to one of open access may also lead to deterioration of the reef through the exploitation of reef resources. Clearly there are no easy solutions to developing coastal environments without harming the delicate marine ecosystems.

Throughout the world there has been a growing concern about the decline in coral reef health. Many governments, communities and organizations are trying to decide which management strategies are the most effective in improving the state or conserving the coral reef. However, there are few successful models of coral reef conservation and management. This study also explores how ecological change is perceived and analyzes one case, in more detail, on the island of Rarotonga, Cook Islands, where the local

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[1] The commodification of the reef is the transformation of the reef environment from one with a use value to one with an exchange value, and thus is the development of indirect and direct markets from coral reefs

communities are attempting to re-instate indigenous access institutions. This community-based model illustrates how one island is successful protecting their marine environment. The case of Rarotonga shows and argues that reef health has improved through the re-introduction of a traditional system of marine resource management. Policy recommendations follow from a better understanding of how the problem of coral reef deterioration emerged. But now that reef health has become a popular conservation target, the question remains: is it too late?

Political Ecology

This research traces the interaction of society and the environment through time and between different spatial scales of analysis, specifically focusing on coral reef health in the South Pacific. I examine four island case studies and their inter-island and intra-island linkages, examining the socio-economic variables that may be correlated with differences and variability of coral reef health at a static point in time. The approach used in this project is very similar to "traditional" geographical research that studies the interaction and impacts of people upon the physical environment (Goudie 2000). Other researchers who use a political ecology approach have investigated soil erosion, land degradation, and deforestation (Blaikie 1985; Blaikie and Brookfield 1987; Bryant and Bailey 1997; Hecht and Cockburn 1989). This study, unlike the others, looks at coral reef degradation.

The political ecology approach and geographic perspective used to understand coral reef health examine marine biodiversity emphasizing the patterns of resources use and degradation of species and ecosystems, as well as the competing interests for

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(McLellan 1995). For a more thorough explanation see Chapter 2 and Chapter 3.

ownership, utilization, and access to biological diversity. This approach analyzes the environmental history and transformation of social institutions as well as biodiversity at multiple time and spatial scales, including the local[2], regional, and global levels. There are few examples of political ecology research in marine environments and even fewer incorporating ecological data into their arguments (Trist 2000; White et al. 1994; Zimmerer and Young 1998).

Political ecologists, however, have always had a difficult time integrating ecology into their analyses. Part of this reason is that to collect data on the ecological impacts and on social factors that shape outcomes on the ecology would not only take a long time, but also require highly specific academic training. Only recently have interdisciplinary teams come together to work on such issues (Hviding and Bayliss-Smith 2000). Furthermore, political ecology came out of a tradition of political economy and cultural or human ecology, which were much more culturally oriented in their analytical framework than studies on ecology or the environment (Blaikie 1985; Bryant and Bailey 1997). Thus the focus of political ecology research has been on the social aspects of environmental change. However, while ecology is still valued by political ecologists, it has not been studied in as great a level of detail. Like other research in political ecology, my research framework considers the importance of historical and social processes that have formed the particular social institutions and situations that I am arguing now impact the coral reef. This study does not ask why and how such social institutions formed and who

[2] Local means living and working in the village community and includes fisherpeople, government officials, resource managers as well as business owners.

benefits from it. Instead, this study attempts to provide the ecology basis of the information for political ecology questions.

Fundamental to the political ecology approach to coral reef health is that it uses integrative methodology that synthesizes how people, the physical environment, and biology interact together in a spatial system of disease and health (Mayer 1996). This research focuses upon ecological data, but also includes social data to further understanding of human environment interactions. I do this by identifying and describing the presence of certain social institutions and some historical reasons as to why they exist. I then assess the impact they probably are having on the reef, and finally I present data on the ecological condition correlated with certain social institutions. In comparing the reefs with these social conditions and institutions, I argue that certain institutions have greater or lesser impact upon coral reef health[3] based upon correlation. Correlative research is useful to point out areas of future research, and to provide data to make estimates as to the level of causality, which could in turn be information used for policy making and activism.

Through the examination of four island case studies I will argue that:

5. Coral reef health is complex and has both natural and human influences.
6. The commodification of the reef and reef resources is one of the primary factors causing the decline of coral reef health.
7. The loss of traditional marine social institutions has affected coral reef health. Specifically, the transformation of common property resources from communally

[3] I am really examining the human impact upon short-term change. A more detailed definition of coral reef health is provided later in the chapter.

owned property to state owned with open access status has primarily influenced ecological change on the reef.

8. The implementation of traditional marine social institutions as exemplified in a case study in Rarotonga, Cook Islands is improving coral reef health.
9. The image of the South Pacific as having "healthy" reefs shapes and forms policy and practices of global, regional, and local institutions and organizations.

This research emerges from a debate surrounding theories and practices of development, sustainability of the environment, and the interaction between the social and natural environment. In 1798, Thomas Malthus published *An Essay on the Principle of Population*, which introduced discussion of population growth and natural resources. Arguing that humans are biological and social beings that essentially have an inherent sexual drive and need for food, he was criticized for being too moralistic and not scientific enough (Malthus et al. 1986). Furthermore, population growth grows at geometric rate, placing pressure on subsistent resources, which grow at an arithmetic rate (Malthus et al. 1986). The issue was again brought to the attention of the world in the 1960s and 1970s, especially when Neo-Malthusian Dr. Paul Ehrlich published *The Population Bomb* (1968). Population pressure was increasing rapidly in the developing world and many, like Erhlich, correlated environmental degradation with this growth. Many environmentalists and scholars argue that population growth is creating more pollution such as acid rain, DDT, and as well as causing loss of soil fertility, environmental degradation, and food scarcity (Ehrlich 1968). The Malthusian and often the Neo-Malthusian model offer an explanation for population growth, which does not take into account social processes such as colonialism and development. Karl Marx criticized Malthus's theories for his omission of the influence of social institutions and capitalism upon the relationship between population growth and resource consumption (McLellan 1995). In keeping with Marx's ideas, political ecologists have challenged the Malthusian and Neo-Malthusian perspective (Blaikie 1985; Peet and Watts 1996). This research shows that, population is but one factor leading to environmental degradation. Researchers must also examine the local and regional political economy to assess the complexity of reef changes.

Common property literature as well as studies of traditional marine tenure systems is another body of literature that provides useful theories and models for analyzing these case studies. Furthermore, this dissertation will contribute to our understanding of how changing property regimes affect coastal environments. Through the examination of the different marine property institutions found in the four case studies this research investigates and documents, from both western and traditional ideologies, the changing approaches to marine conservation and protection in the South Pacific. Island and coastal people throughout the Pacific Ocean use many approaches to manage, protect, and conserve the coral reefs (Cordell 1989; Hviding 1989; Johannes 1981; Nietschmann 1997). There are essentially three techniques for the management and protection of coral reefs and the surrounding fisheries: 1) regulation of fish catch by placing restrictions upon size, species, gear, season, amounts; 2) regulation of people who can and cannot fish; and 3) the restriction of access to fishing and harvesting areas through customary marine tenure (Nietschmann 1997). Conservation of marine biodiversity in tropical marine environments is rooted in western ideologies and practices that in many instances were developed or exported to the tropical developing countries as part of colonial expansion. Some scholars attribute the origins of western environmentalism with French and British scientists protecting biodiversity by establishing botanical gardens and forest preserves (Grove 1995). The state began to protect natural resources as well as destroy community tenure systems. The importation of western ideologies and governance has created a long history of exploitation and resistance to the commodification of nature and redefinition of property. Colonization and changes in marine property laws caused the erosion of traditional knowledge and the demise of traditional systems of marine management in many regions (Hviding and Baines 1992). The commodification of marine resources resulted.

Traditional systems of coral reef management have been supported or re-established in some islands. One notable example is the revival of the Ra'ui system in Rarotonga, Cook Islands, as well as other similar systems in Vanuatu, Japan, and the Philippines (White et al. 1994). These traditional methods were used for centuries before Western conservation practices existed and were generally successful throughout the Indo-West Pacific (Nietschmann 1997). Local community support and participation based upon community consensus are necessary for community-based conservation, which is based upon ownership of the reef. When communities are committed and actively involved in natural resource management it can be more effective for creating promoting sustainable coral reef management.

In order to understand coral reef health I must examine the recent history of development, and geography of each coral reef and use a whole reef perspective. In the remainder of this chapter I discuss the issues and debates surrounding coral reef health and conservation in the South Pacific. First, I will determine whether or not coral reefs in the South Pacific are at risk and show how the large-scale studies can inaccurately portray the state of the reef, which in turn can influence policy and conservation practices. Second, I will examine the debates in the scientific community about the factors that affect coral reef health and why this dissertation approach and research furthers our knowledge about coral reef health in the South Pacific. Then I will describe the study sites and methods used for this dissertation research

Coral Reefs in the Pacific: Are They at Risk?

Western coral conservation institutions have inaccurately and incompletely assessed and portrayed coral reef health in the South Pacific. They have done this by not gathering enough data, nor depicting and synthesizing thoroughly the data they do have (Bryant 1998; Wilkinson 1998). While these conservation efforts are valiant attempts at mapping coral reef health, the results have ramifications for Pacific Island reefs that could result in further commercial development in the region.

In this section I consider the main point that the “low” risk status of Pacific corals imports a Western “standard view” on environment and development. The ways in which governing bodies, scientific institutions, and multilateral institutions construct environmental health images and conservation practices have consequences. Furthermore, when these organizations develop guidelines and statements, the findings will influence potential funding, implementation, and policy. These reports have implications that are ethical, political, and economic.

Reefs at Risk and the Status of Coral Reefs of the World

There are numerous prestigious publications that fail to accurately address the reality of coral reef health. Prior to the 1990s little research and monitoring at a global scale had been compiled on coral reefs and the health of coral reefs. *Reef at Risk: A Map-Based Indicator of Threats to the World's Coral Reefs* is a joint publication by World Resources Institute (WRI), International Center for Living Aquatic Resources Management (ICLARM), World Conservation Monitoring Centre (WCMC), and the United Nations Environment Programme (UNEP) and funded by The United Nations Environment Programme, The Bay Foundation, The David and Lucille Packard Foundation, The Henry Foundation, The Swedish International Development Cooperation Agency, and the United States Environmental Protection Agency. Hundreds of agencies, institutions, and organizations have referred to and cited this report as a guideline and baseline database on coral reefs, indicators of threats to coral reefs, and marine parks. The Reefbase program has expanded on the internet (http://www.reefbase.org/) into numerous databases and projects funded by a wide range of multilateral and bilaterial funding agencies, international organizations, and private foundations.

Reefs at Risk is the first ever map-based database of coral reef threats and is the "first systematic and data-driven global assessment of these habitats". It clearly states that the Reefs at Risk Database indicates the problems facing the world's coral reefs (Bryant 1998: 7). The analysis measures potential threats created by humans but does not look at any specific problems such as disease, bleaching, climate change, and other threats natural in origin.

Nine Key Findings are highlighted on the first page of the report findings, two of which state the following:

> 1). The Pacific, which houses more reef area than any other region, is also the least threatened. About 60 percent of reefs here are at low risk.
>
> 2). Outside of the Pacific, 70 percent of all reefs are at risk (Bryant 1998: 6).

I discuss what "low risk" means and furthermore how the researchers came up with these results. The report focuses upon four main threat factors 1) coastal development, 2) overexploitation and destructive fishing practices, 3) the impact of inland pollution and erosion, and 4) marine pollution. The data and results are based upon correlating mapped statistical data. Draft data maps were presented and edited at a workshop where numerous coral reef experts reviewed and contributed to the accuracy of the maps. This process was then repeated. The quantification of the threat factors are all based on a location of the threat at a certain point-source. This is a problem for two reasons. First, water is fluid and threat factors can impact areas tens of miles away. Second, with a four kilometer resolution for the map grid loses much of the detail on the small islands. The authors believe the model actually fails to include at least one-third of all of the activities causing degradation (Bryant 1998: 50). In addition, the authors claim in the report to have 80 percent accuracy of sites known to be degraded by humans. But they also state, not in the key findings section, but in the sixth paragraph of the introduction, that "in the Pacific, for example, 90 percent of the coral reefs have never been assessed" (Bryant 1998: 7). Furthermore, the majority of coral reef research, coral disease research, and long-term monitoring has been in the Caribbean, not in the Indo-

Pacific although, the Indo-Pacific[4] region comprises 85 percent of the reefs in the world and extends over an area six times as large as the west Atlantic (Connell 1997).

> More than a quarter of the world's reefs are at high risk, and just under a third of these habitats are at moderate risk, from human disturbances. Of the four broad categories of potential threats to coral reefs evaluated, overexploitation of marine resources, including destructive fishing practices, and coastal development present the greatest threat. Globally, 36 percent of all reefs are classified as threatened by over exploitation, 30 percent by coastal development, 22 by inland pollution and erosion, and 12 percent by marine pollution. When these threats are combined, 58 percent of the world's reefs are at risk (defined as medium and high risk). These figures are tempered by the relatively low threat faced by coral reefs in the Pacific – home to more reefs than any other part of the world. Forty-one percent of the reefs in the Pacific are estimated to be at risk. Outside of this region, 70 percent of all reefs are at risk (almost 40 percent at high risk)…… (Bryant 1998: 20).

In this statement 41 percent of the reefs in the Pacific are classified as at risk, but this number seems unimportant when it is compared to 70 percent at risk and 40 percent at "high" risk in other regions.

The four threat factors were quantified by gathering subnational statistics on population density, size of urban areas, land cover type, rainfall, and topography. The coastal development component factors included such variables as city size and proximity to the reef, type of sewage treatment, settlement size, airport and military base, mines, and tourist resorts. However, the analysis does not include data on military nuclear testing and waste disposal, a threat to south and east Pacific coral reefs (Maragos 1997). Threat factor one, population pressure, is highlighted as a major factor of coral reef decline, but this can be misleading. For example, on most Pacific Islands population

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[4] Connell uses Indo-Pacific to include Southeast Asia and all of the Pacific coral reefs, whereas the Reefs at Risk report have Southeast Asia and the Pacific as separate geographic regions.

pressure is low compared to other places in the world. While these islands have unique and fragile ecosystems and may have low population pressure, thousands of tourists visit the islands in the Pacific and produce ten times as much waste as locals. Therefore, conservationists and managers really need to look at each coral reefs' unique history of natural events and anthropogenic impacts. Threat factor two, overexploitation and destructive fishing practices, was compiled by gathering data on population density and proximity to the reef and "expert defined areas where blast fishing or cyanide fishing occur" (Bryant 1998: 18). As mentioned earlier, it would be difficult to define the destructive fishing methods for the Pacific region since 90 percent of the reefs have not been surveyed. Through my research I discovered from informal interviews that destructive methods such as bleach fishing, *duva*[5], blast fishing, and cyanide fishing are methods of fishing in the South Pacific. Threat factor three, inland pollution and erosion data, was based upon a hydrologic model incorporating slope, erosion rate and precipitation. Finally, threat factor four, was based upon marine-based pollution compiled by collecting data on proxies. The selected proxies were oil rigs, tanks, wells and ports. The data were primarily collected from sources in the 1970s and 1980s and recently developed oil wells and mines are missing from the data.

In the regional assessment the report describes quantitatively and qualitatively the reef condition in the Pacific. It concludes that reefs in the South Pacific are much healthier than elsewhere.

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[5] *Duva* is a plant that contains rotenone in the root. It is used by the Fijians to stupefy fish.

> Pacific: Reefs here appear to be in the best shape of any region: almost 60 percent were assessed at low risk. About 40 percent of the world's mapped reefs are found in the Pacific, many of which are located around remote atolls and within the Great Barrier Reef tract. Although, reef communities in many uninhabited areas remain in good condition, others have been affected by the long-term impacts of historic nuclear testing and other military activities and poaching of rare species. Several areas, particularly those near population centers, face significant human pressures. These include many of the reef communities off southeastern Papua New Guinea, the Solomon Islands, Vanuatu, Fiji, and Hawaii. Almost half of the Hawaiian and Solomon Island reefs are potentially threatened. Two-thirds of the reefs off Fiji are at risk. Overfishing, coastal development, logging, and agricultural erosion are documented threats to these ecosystems. Fiji's reefs are an important tourist draw and, according to a 1992 estimate, a major source of food for local people, generating close to $200 million annually in fisheries and tourism revenues alone (Bryant 1998: 27).

The *Reefs at Risk* report is not the only report written on world-wide coral reef health. The same year another report was published by the Global Coral Reef Monitoring Network (GCRMN). The GCRMN was established in 1994 when the United States government formed the International Coral Reef Initiative (ICRI). What followed was a *Framework for Action,* which in turn established the GCRMN. The World Bank is a co-sponsor of the GCRMN and the report *Status of Coral Reefs of the World: 1998* published on behalf of the Global Coral Reef Monitoring Network by the Australian Institute of Marine Sciences. In the most recent report produced by The Global Coral Reef Monitoring Network, *Status of Coral Reefs of the World: 2000,* the major supporters are the United States Department of State and National Oceanic and Atmospheric Administration, the United Kingdom Department for International Development, Swedish International Development Agency (SIDA), Swedish Agency for Research Cooperation (SAREC), Governments of France, Australia and Japan. The Co-sponsors are the Intergovernmental Oceanographic Commission of United Nations

Educational, Scientific, and Cultural Organization (UNESCO), United Nations Environment Programme (UNEP), International Union for Conservation of Nature (IUCN), The World Bank, Australian Institute of Marine Science, and International Center for Living Aquatic Resource Management (ICLARM). The GCRMN is an arm of the ICRI and the leading international organization and network for research and monitoring coral reefs. Furthermore, The ICRI has three action units: The GCRMN, The International Coral Reef Information Network (ICRIN), and the International Coral Reef Action Network (ICRAN). These three international agencies are all working together under the guidance of the ICRI with support for all from bilateral and multilateral aid organizations, national agencies, and with the ICRAN having full endorsement from ICLARM, UNEP, World Resources Institute (WRI), World Conservation Monitoring Centre (WCMC), GCRMN, ICRI, and the Coral Reef Alliance.

Status of Coral Reefs of the World: 1998 qualitatively describes the condition of the reefs and also claims, like the *Reefs at Risk* report, that reefs are in good condition in the Pacific. The report fails to create a definition and set of criteria for a coral reef in good condition that is utilized throughout the report. Unlike the *Reefs at Risk Report*, this report does discuss some of the natural phenomena affecting coral reefs. When combined with chronic anthropogenic influences, coral health and recovery from natural events such as hurricanes and increasing sea surface temperature is greatly affected (Connell 1997).

> Status of southwest and east Pacific reefs:
> About 99 percent of all southwest and east Pacific reefs are remote from urban pollution and sediment degradation, and structurally they remain in good to excellent condition. Reefs near large towns provide benefits in subsistence fishing, recreation, tourism, and shoreline protection, but these reefs are being chronically degraded. There is often significant

> overfishing, and giant clams, sea cucumbers, and trochus shells are now rare. Sharks and lobsters have been removed from most remote reefs. This is an increasing trend, and involves cyanide and dynamite fishing for Asian markets. The largest natural threats are from storms and strong wave action, along with crown-of-thorns starfish. Concern is rising about global climate change, coral bleaching, and stronger El Niño events. Rising sea levels will damage the shores of high islands that are rapidly subsiding, and may destroy low coral islands and jeopardize their island cultures. Management is required to reduce or divert increasing population pressures, and integrate traditional management of reef resources into 'modern' methods (Wilkinson 1998: 9).

Although the reports differ, the most recent report produced by the Global Coral Reef Monitoring Network (2000), the status of reefs in the Pacific continues to be at low risk.

> ….the extensive reefs in the Pacific and Australia are in reasonably good health with a positive outlook; unless global climate change events like those of 1998 strike these areas. Indications are that bleaching may recur with severe localized bleaching mortality near Fiji and the Solomon Islands in early 2000 (Wilkinson 2000: 1).

The very organizations writing the *Reefs at Risk Report* and the *Status of Coral Reefs of the World: 1998* are intimately connected. Prior to the publishing of the *Reefs at Risk* report, a less detailed report was written by the same authors as a background paper for the International Coral Reef Initiative (ICRI). The authors, Jameson, McManus, and Spalding, were also leaders in the *Reefs at Risk* Report. And again, reefs in the Pacific were described as being in better health than other regions in the world.

> Overall, the condition of coral reefs in the Pacific was rated to be about 70 percent excellent to good and about 30 percent fair to poor (Jameson 1995: 20).

This may be a difficult claim to prove since there is no documentation of how the authors reached this number, or how the reef health was assessed. What they did state was that the data were collected during the beginning stages of the mapping project for the Reefbase database, otherwise known as *Reef at Risks.* In the latest report out by the GCRMN, *Status of Coral Reefs of the World: 2000*, the report actually quotes the *Reefs at Risk* report:

> The global *Reefs at Risk* analysis from the World Resource Institute suggested that 27 percent of the world's existing reefs were under immediate threat of significant damage and further 31 percent under medium level risk (Wilkinson 2000: 1).

Furthermore, in a table listing coral reef destruction, the Pacific is listed as the least threatened area, with 4 percent of the reef destroyed prior to 1998, 5 percent destroyed in 1998, 9 percent of the reef in critical stage and loss and 14 percent loss in the past 10-30 years. This is compared with 30 percent loss of reef in the past 10-30 years in Southeast Asia and 22 percent in the Caribbean (see table below) (Wilkinson 2000: 1). Again, how can these numbers be accurate when numerous scientists claim that only 10 percent of the reefs in the Pacific have been surveyed? And how can loss be detected and claimed with no baseline data for comparison, let alone current data? This dissertation research fills in the gap in the existing research and literature by thoroughly surveying coral reef health on four Pacific Islands and examining the human impacts potentially affecting the coral reefs.

Table 1.1: Coral Reef Loss

Regions of the World	% reef destroyed pre 1998	% reef destroyed in 1998	% reef in critical stage, loss 2-10 years	% reef threatened, loss 10-30 years
Arabian Region	2	33	6	6
Wider Indian Ocean	13	46	12	11
Australia, Papua New	1	3	3	6
Guinea	16	18	24	30
Southeast and East Asia	4	5	9	14
Wider Pacific Ocean	21	1	11	22
Caribbean Atlantic	11	16	14	18
Status 2000 Global				

(Wilkinson 2000: 1)

The Scientific Debates

This decline in health incorporates coral disease epidemics, outbreaks of coral predators, which results in death of the reef, as well as mass bleaching events. This research project will examine the relationship between local impacts, -- such as tourism development, marine resource exploitation, and agricultural/industrial runoff [6], and marine social institutions. Unlike the reports that are generated by governing bodies and non-governmental organizations, the scientific community is making some different claims about coral reef health in the Pacific. In addition to writing reports that target similar threat factors, scientists have also focused upon climatic change and natural predators, which have significant impacts upon the coral reef environment. The purpose here is to show that the South Pacific region has been greatly affected by these events and the full extent is unknown because so little research has been done in this region. Some researchers would argue that natural environmental factors, such as storms, hurricanes,

[6] For example, coastal communities in eastern Indonesia are being converted rapidly from subsistence fishing villages along the coastal lowlands to rice farms and aquaculture farms for production of shrimp and fish Edinger, E. N., Jompa, J., Limmon, G. V., Widjatmoko, W., and Risk, M. J. (1998). "Reef

and sea surface temperature changes are first and second order events in the level of importance and impact to reefs in the Pacific. Glynn reports coral reef bleaching events as early as 1979-1980 from the Great Barrier Reef in Australia, Ryukyus Islands in Japan, and the Caribbean, which were very localized events (Glynn 1990; Glynn 1993). The 1982-1983 El Niño event stirred the scientific community into action because bleaching was reported from the Arabian region, the southwest Indian Ocean, West and Central Java Sea, Japan, central Pacific, Pacific coast and the Caribbean. The flow of warm water from the western Pacific into cooler eastern Pacific waters created a significant seas surface temperature rise that had immediate effect in the eastern Pacific during peak sea surface temperature. The rise in temperature resulted in mass mortality of corals - Galapagos Islands 97 percent, Panama 75-85 percent, Costa Rica 50 percent coral mortality (Glynn 1990). The 1986-1988 event was even more extensive than the 1982-1983 event. Bleaching[7] occurred world-wide and reported from a number of new sites from western and central Indian Ocean, western Australia, and Taiwan. The 1991-1992 event was associated with the Society Islands, French Polynesia where above average temperatures caused bleaching in 53 percent of the corals, including 17 percent mortality (Brown 1997). Moorea, Society Islands has a history of coral reef disturbance. Previous mass coral reef bleaching occurred in 1983-84, 1986-87, 1991 and a few cases were reported in 1993 (Gleason 1993). Mortality from bleaching events is increasing. Mortalities in 1991-1994 were as high as 30-50 percent in the Central and Western

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Degradation and Coral Biodiversity in Indonesia: Effects of Land-Based Pollution, Destructive Fishing Practices and Changes Over Time." *Marine Pollution Bulletin*, 36(8), 617-630..

[7] Bleaching is the "collapse of the algal symbiosis in corals and other invertebrates, causing the mass expulsion or *in-situ* degradation of photosymbiotic algae" Wood, R. (1999). *Reef Evolution*, Oxford University Press, Oxford; New York..

Pacific and 80-90 percent in the certain parts of the Great Barrier Reef (Gleason 1993; Hoegh-Guldberg 1999).

In addition to bleaching, Crown of Thorns Starfish (COTS), *Acanthaster planci*, a coral predator, has also greatly affected coral reefs throughout the Pacific. Population booms of the starfish have many reefs. People have attributed increases in the starfish to increases in freshwater and nutrients as well as the decrease of its main predator, the giant triton, which is reported to feed on juveniles and small adults. The extent of the damage has only been documented upon a fraction of the reefs in the Pacific (Birkeland and Lucas 1990). Bleaching events and outbreaks of COTS have been changing the coral reefs in the Pacific.

In *Coral Reef Ecology*, Y.I. Sorokin's reviewed the coral scientific literature and has a different interpretation of coral reef health in the South Pacific based upon anthropogenic impacts (Sorokin 1993). Even if one takes an average of the five areas in Sorokins table below, Polynesia and Melanesia, GBR, Australia, Hawaii, and the east Pacific, which is the area that Reefs at Risk classifies as the Pacific, the Pacific has a higher level of anthropogenic stresses than the Red Sea. The average for the Pacific is 19 and for the Red Sea is 10. There are many other analyses of the degradation to the reefs and not all agree with the *Reefs at Risk* interpretation (Connell 1997; Maragos 1997).

Table 1.2: Level of Various Types of Anthropogenic Stress in Different Reef Regions as Evaluated Within a 0-4 Grade Scale with 4 as the highest

Types of Stress	Asia	Micro nesia	Polynesia and Melanesia	GBR, Australia	Hawaii	E. Pacific	Red Sea	W. Atlantic	Sum of grades in all region
Destructive Fisheries	3	2	1	1	0	1	1	0	9
Overfishing	3	4	4	1	4	2	1	4	23
Excavation of sand and lime for construction	4	1	3	0	0	0	2	3	13
Tourism	4	2	2	4	3	2	2	4	22
Collection of corals and shells	4	4	2	3	1	3	2	3	22
Discharge of Industrial Waste waters	2	1	2	1	2	2	1	2	13
Discharge of man-made waste-waters	3	2	3	1	2	3	1	3	20
Discharge of fertilizers and pesticides from fields	3	2	2	3	2	3	0	2	17
Pollution connected with construction and intensive agriculture	4	2	3	2	2	4	1	2	20
Sum of grades for all kinds of stress	30	20	22	16	15	20	10	23	

(Sorokin 1993: 413)

There is little scientific evidence and information on the causation of the decline of coral reef health throughout the world, let alone the South Pacific (Birkeland 1997). Coral reef organisms are classified as stenotypic organisms and therefore exhibit relatively low tolerance to changes in environmental conditions (Sorokin 1993). Reproduction, recruitment, as well as other crucial biological processes are influenced by changes in the environmental conditions (Richmond 1993). Since the 1970s, scientists have challenged the notion that coral reefs evolved under limited changes in physical and chemical variables (Brown 1997). As a result, new research has focused on theories and models pertaining to the relationship between high biodiversity and intermediary disturbance (Brown 1997; Connell 1997). This has led to an enormous amount of research on the effects of disturbance upon coral reefs. There is growing evidence that coral reefs are disturbance-adapted ecosystems, especially natural disturbances (Karlson and Hurd 1993). Coral reefs have adapted to their environment through genetic variability, life history strategies, or climatizing. Between species, within species, and within the coral colony there are different environmental tolerances to changing environmental variables such temperature, salinity, and sedimentation (Brown 1997). In recent years, environmental variables affecting the coral reef ecosystem are both natural variables and indirect and direct human disturbance, such as an increase of nutrients in the water from sewage (Connell 1997; Ginsburg 1997; Richmond 1993). As more threats are introduced by humans into the coral reef ecosystem, coral species will have difficulty adjusting to new environmental conditions. Several researchers have argued that long-term geological changes such as oceanographic patterns, temperature, sea level, sedimentation patterns, tectonic ups and downs, subsidence, slumping and crumbling as well as short-term natural disturbances such as El Niño events, seasonal changes in sea surface temperature, hurricanes, big waves, disease, and predator outbreaks have devastated coral reefs and are largely responsible for deleterious impacts on coral reef ecosystems, and yet corals have survived and adapted to these natural fluctuations through geologic time (Gleason 1993; Glynn 1993; Goreau and Hayes 1994; Grigg 2000; Hughes and Connell 1999; Meehan and Ostrander 1997). A report written by Hoegh-Guldberg (2000) states that climate change will be the main catalyst for the removal of corals as the dominant organism on reefs in the next 20 to 50 years (Hoegh-Guldberg 2000). Another group of researchers argues that anthropogenic stress is threatening the stability of the coral reef system with short-term and chronic disturbance such as destructive fishing practices, radiation, dredging, oil spills, pollution, coastal development, tourism, and sedimentation (Birkeland and Lucas 1990; Richmond 1993). Others suggest changes in coral reef health are attributable to both natural factors and anthropogenic impacts (Grigg 2000).

I will argue that the death of the coral reefs in my case study areas in recent years is strongly correlated with the increased direct and indirect human impacts imposed on these ecosystems. Furthermore, each reef has a unique geography and environmental history that will explain the state of the particular reef. Thus large-scale studies such as *Reefs at Risk* and *The Status of Coral Reefs of the World* can misrepresent the state of coral reef health. My geographic case study approach focuses upon human factors that may cause reef decline at varying spatial scales. Based upon my finding this research will suggest ways to properly manage the coastal ocean.

Building upon past coral reef research, new questions will be investigated in this project that further the understanding and knowledge of this complex ecosystem. This research will assess coral health in areas that have not been previously surveyed and will also attempt to link the variation in coral reef health with marine resource development and impacts on property regimes through the reconstruction of environmental history of marine resource commodification, marine social institutions, and the examination of human use and natural disturbance in the coastal environment (Glynn 1993; Hughes 1994). Through the examination of these variables at different spatial scales I will be able to provide some insight toward the successful management of coral reef ecosystems. Spatial analysis provides a powerful means to identify, suggest, and explain the geographical distribution of the changes in coral reef health (Gatrell and Bailey 1996; Kitron et al. 1991; Stone et al. 1996).

Island Study Sites and Selection

Island study sites were selected in two different South Pacific countries, Fiji and the Cook Islands. Islands were selected based upon their different human and physical geography, levels of economic development, and systems of marine tenure.

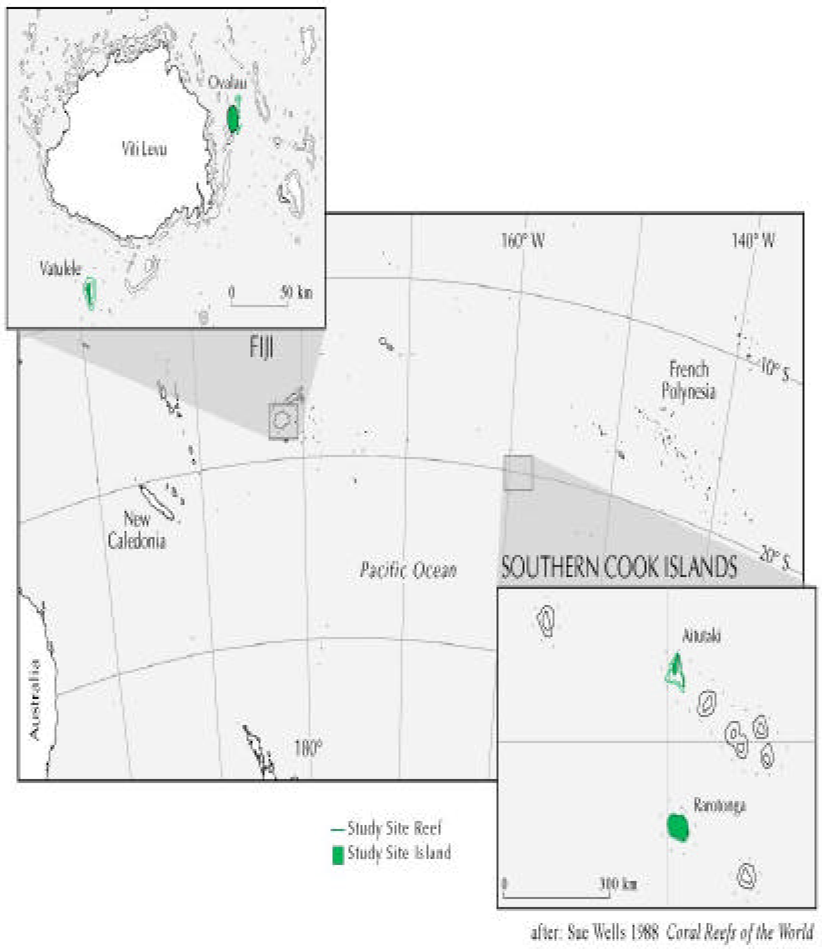
Table 1.3: Island Study Site Characterization

Island	Island Land Area	Present Population	Average Geometric Population Growth Rate 1966 -1996	Level of Tourism Development	Level of Harvesting Marine Resources	Level of Agro/ Industrialization
Aitutaki, Cook Islands	16.8 square kilometers	2,389	-.3%	Mid-size	Subsistence , mariculture industry & commercial harvesting	Commercial Agriculture Heavy Industry
Rarotonga, Cook Islands	67 square kilometers	11,225	.4%	Mass tourism	Subsistence , mariculture industry & commercial harvesting	Commercial Agriculture
Ovalau, Fiji	103 square kilometers	8,647	.8%	Small scale	Subsistence & commercial harvesting	Heavy Industry & Commercial Agriculture
Vatulele, Fiji	31.6 square kilometers	914	2.3%	Small scale	Subsidence & Small-scale commericial fishing	No agro/industry

(Bureau of Statistics 1996; Cook Islands Statistics Office 1999; Turva 1988)

These variables will be explained in detail in Chapter 2 and 3. Furthermore I selected islands with two types of coral reefs - fringing and barrier reefs. Different islands and sites around the islands have various levels of wave energy intensity as well as different natural events that have affected the reefs, such as sea surface temperature (SST) anomalies. All of the islands have had storms and hurricanes that have physically damaged the reef, as well as SST changes. Events may vary between islands as well as between island study sites. This will be explained in more detail in Chapter 4.

Map 1.1: The Cook Island and Fiji Study Sites in The South Pacific



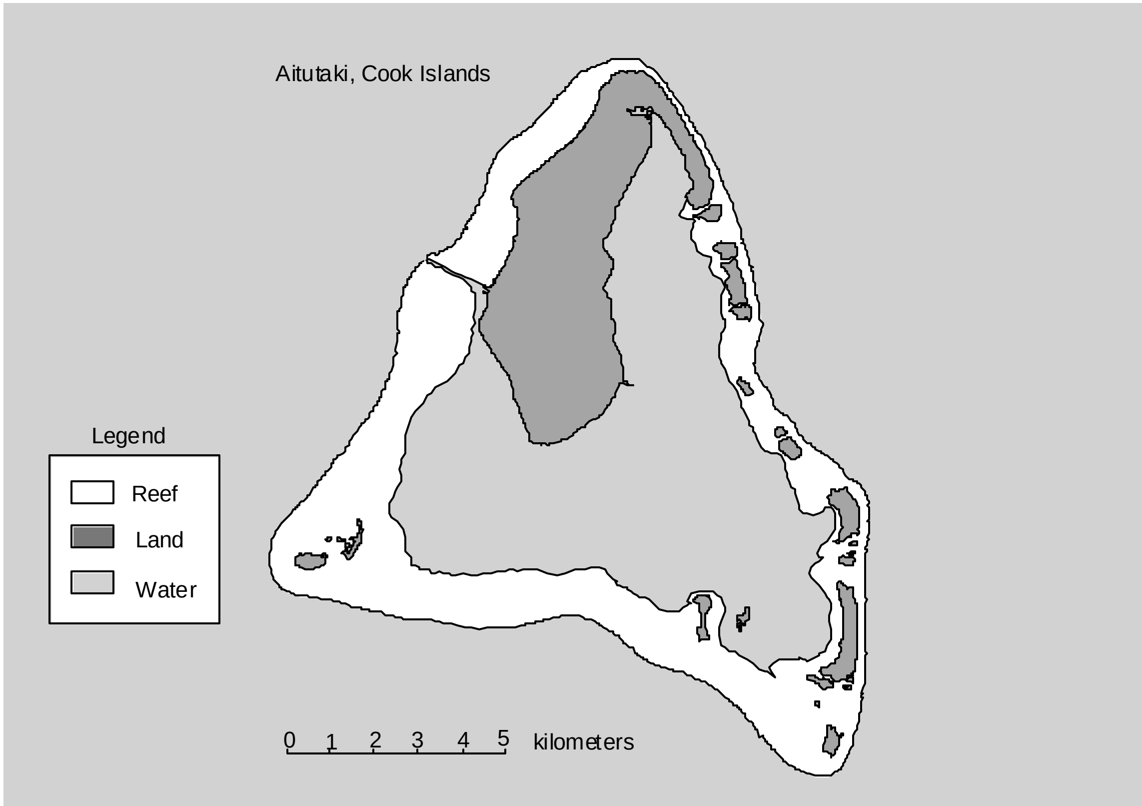
The Cook Islands

The fifteen Cook Islands are spread over an area of 8°-23°S, 156°-167°W. They are divided into two main groups - the Southern and Northern Cook Islands. The Northern Cook Islands are composed of six atolls with only 25 square kilometers of land area. The Southern Cook Islands are composed of nine volcanic and uplifted limestone islands of different ages. Northeast, east, and southeast trade winds blow around this linear island group and rainfall ranges from 1500-2800 mm (Anon 1985). With the northeast winds come major hurricanes from January to March. The mean SST varies from 27.3°C in January to 25.5°C in June. Tides are semi-diurnal and have a small amplitude. For example, on Rarotonga the spring tidal ranges is .85m and neap range is .33m (Stoddart 1972). I selected two islands, Aitutaki and Rarontonga, in the Cook Islands for this study.

Aitutaki

On the island of Aiutaki, people have always depended upon the ocean and its resources for their livelihood. Aitutaki has a large lagoon and barrier reef. It is triangular shaped, with a deeply eroded volcanic cone, and has a surface land area totaling 16.8 square kilometers (Wells and Jenkins 1988). Described as an almost-atoll, Aitutaki is the main island on the north-west rim and has 12 motus (reef islands) on the eastern and western reefs (Stoddart 1975).

Map 1.2: Aitutaki, Cook Islands



From 1966 to the present the population had remained constant at approximately 2500 people. The chart below shows the population data gathered by the Cook Islands Bureau of Statistics and it illustrates the slight changes in population. Therefore, pressure on the marine resources is not a direct result of the increased or growth in population.

Table 1.4: Aitutaki Population Data

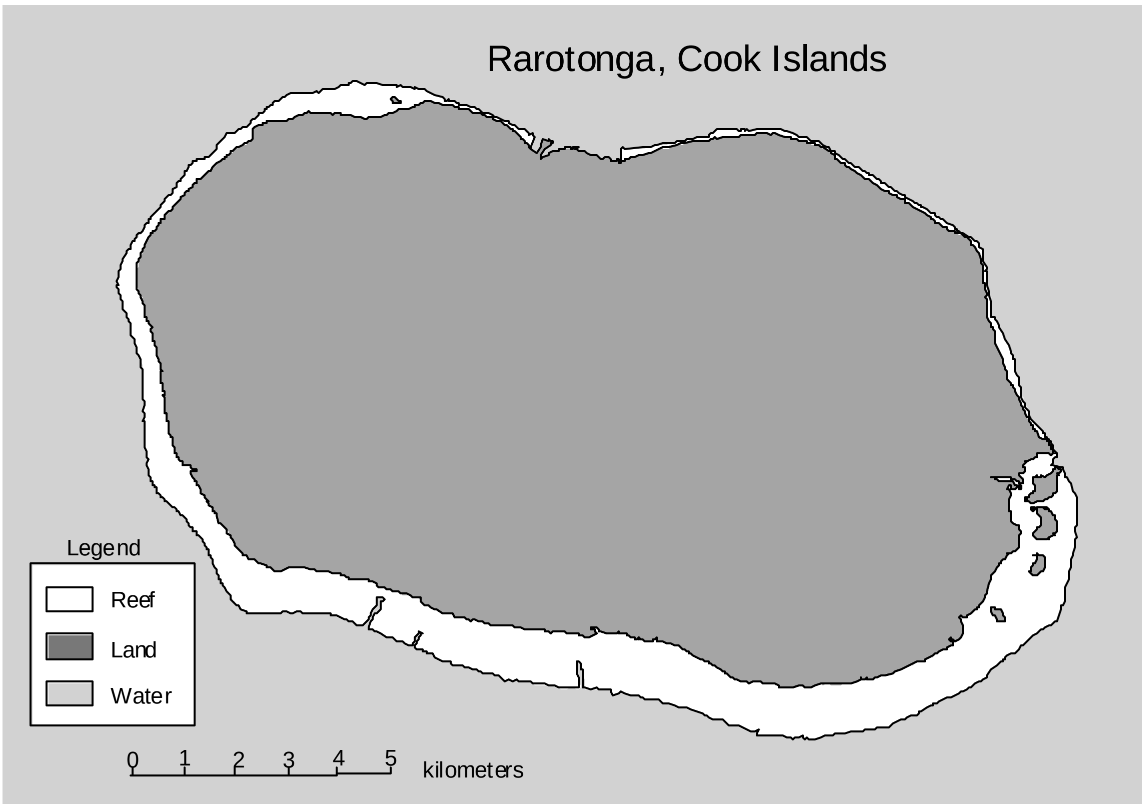
Year	Aitutaki
1966	2,594
1971	2,857
1976	2,473
1981	2,347
1986	2,391
1991	2,357
1996	2,389

(Cook Islands Statistics Office 1999; Turva 1988)

Rarotonga

Rarotonga is the main island in the Cook Islands. This high volcanic island has an area of 67 square kilometers, and the rich, fertile soil supports an intensive cash crop economy. Agriculture was once the main source of income for the islanders, but this has changed and now tourism has become the biggest source of revenue.

Map 1.3: Rarotonga, Cook Islands



Cook Islanders have migrated to New Zealand during times of recession and returned to the Cook Islands during periods of economic growth. The population changes reflect these departures to and from New Zealand.

Table 1.2: Rarotonga Population Data

Year	Rarotonga
1966	9,971
1971	11,478
1976	9,802
1981	9,539
1986	9,826
1991	10,886
1996	11,225

(Cook Islands Statistics Office 1999; Turva 1988)

Fiji

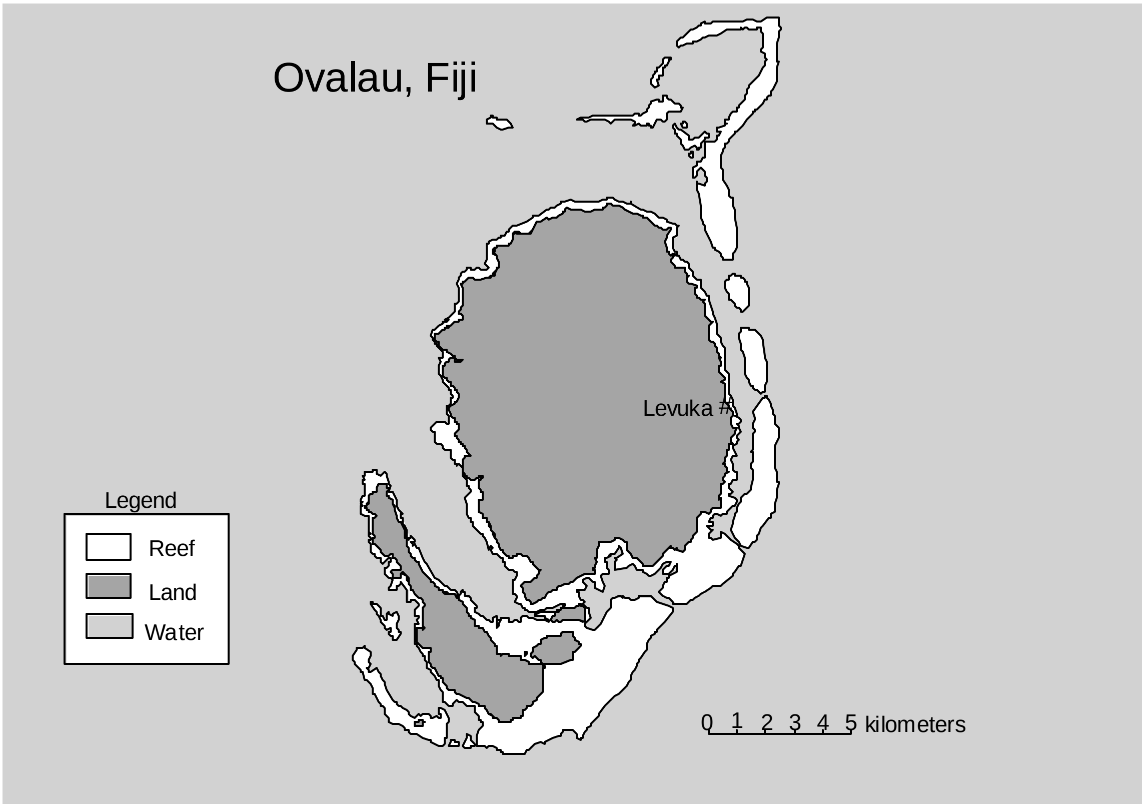
Fiji has over 844 islands and islets across an area 15°-23° S, 177°-178° W. The surface currents flow south-westerly through the islands. Water temperature is always above 20°C with the summer maximum approximately 30°C and a mean variation of 6°C (Wells and Jenkins 1988). The summer, November – May, is hot and wet with numerous tropical cyclones. Annual rainfall varies due to rain shadow produced by the central mountains (1200+m). In general, the mean is 3000mm annually on the east coast and 1650mm on the west coast (Guinea 1981). Tides are semi-diurnal and the range is small. The mean range for neap tides is 0.9m and spring tides is 1.3m (Ryland 1981).

Ovalau

Ovalau is a high island with both a fringing and barrier reef. This large volcanic island covers 103 square kilometers with a central basin surrounded by peaks reaching 626 meters. Approximately 8,000 people live on the island and the population has steadily increased during the past forty years in the 22 communities around the island (Nunn in press 2000). This island is famous because of Levuka, the main town, port and trading post, which was once the capital of Fiji and the entire South Pacific in the late

1800s, when it was settled by merchants, missionaries, traders, as well as sailors, whalers and businessmen.

Map 1.4: Ovalau, Fiji



In the 1830s, Levuka was known as an Anglo whaling settlement, and the non-native population numbered about 400. By the 1840s the people of Lovani from central Ovalau began fighting with the coastal townspeople. Growth increased in the 1860s as there was speculation that Fiji was to become part of the British Empire. Settlers from Australia and New Zealand came to the town to take part in the cotton trade. The capital (1874? –1881) became famous for its social scene, but there was continuous strife between Anglo settlers and with the local population. In the 1840s, the population was recorded at 8000 but it fell to 3345 by 1936 (Naval Intelligence Division 1944; Wilkes 1845).

Levuka was not only the first capital of Fiji, but also the first town in Fiji to have a bank, post-office, school, newspaper, hospital, and running electricity by 1927. Many of the original buildings are still intact. Due to this unique cultural history and biological community the island is seeking to become an UNESCO World Heritage site.

Table 1.3: Population on Ovalau

Year	Total Number of People
1966	4,396
1976	5,146
1996 [8]	8,647

(Bureau of Statistics 1966; Bureau of Statistics 1976; Bureau of Statistics 1996)

Vatulele

Vatulele is a low limestone island with an area of 31.6 square kilometers (Wells and Jenkins 1988). Approximately 900 people live on the island in four villages: Ekuba, Lomanikaya, Taunovo, and Bouwaqa. The population has fluctuated the past four decades (see chart below). According to the Ekuba village chief, the population in the 1900s use to be 1200 people, but hundreds died during a measles epidemic and the population never recovered (Vatulele, Interview #10).

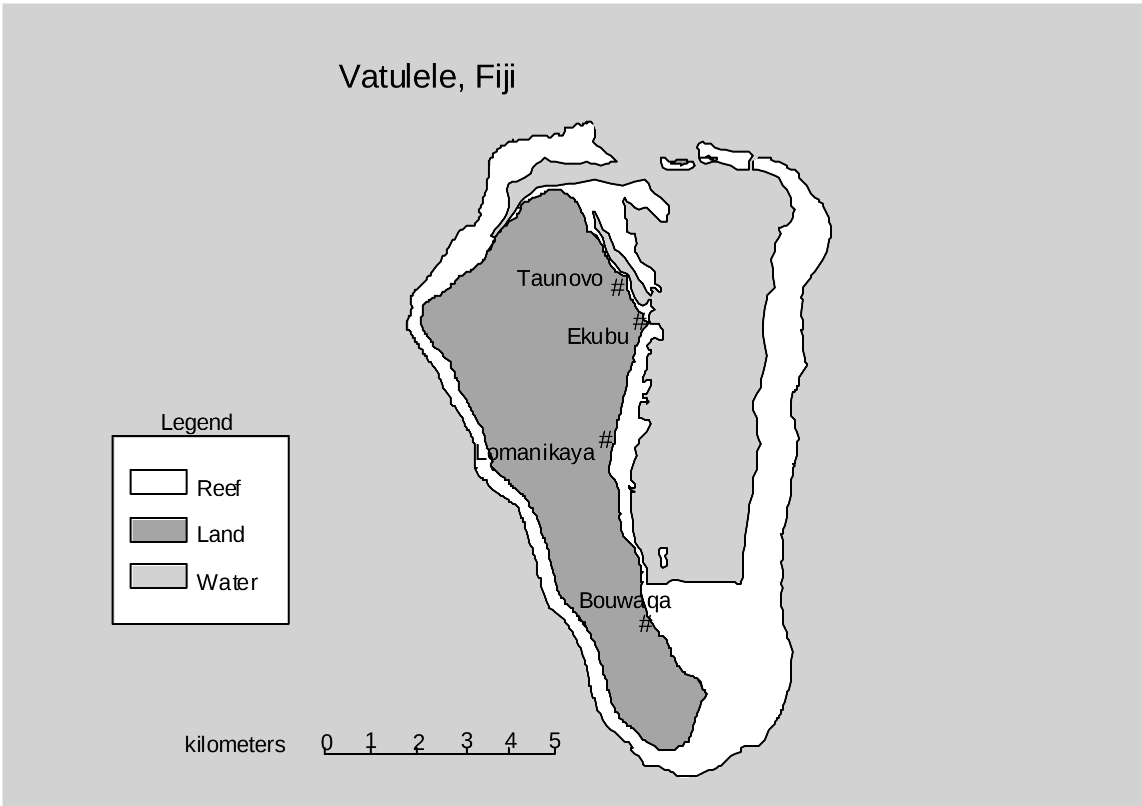
Table 1.4: Population on Vatulele

Year	Total Number of People
1966	729
1976	729
1986	653
1996	914

(Bureau of Statistics 1966; Bureau of Statistics 1976; Bureau of Statistics 1986; Bureau of Statistics 1996)

[8] Department of Statistics could not find 1986 data for Ovalau

Map 1.5: Vatulele, Fiji



The local villages are composed of subsistence fishers and farmers who sometimes do contract work on the mainland in plantations and construction. The women are known for their *tapa*[9] cloths which are sold to the tourists who visit the island and main island, Viti Levu.

Determining Coral Health

Defining and examining coral reef health is essential to understanding environmental changes and assessing reef conditions, as well as providing insight for conservation purposes and coral reef management decisions (Done 1995). In this section,

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[9] Bark paintings

I will present a problem that has been unexamined and argue that coral reef health can be defined, but only as a normative concept based upon human values. As a result of this difficulty in defining coral reef health, trying to measure and quantify coral reef health with a set of criteria is extremely subjective. Therefore, I must take an entire reef approach: a qualitative and quantitative approach at various spatial scales and within the reef itself.

Coral reef health has been an undefined topic within the coral reef scientific community. This may be because it is difficult to accurately characterize the health of the reef. In the past few decades scientists have examined aspects of coral reef health by describing the state of the reef, the susceptibility of reefs to degradation, or the conservation value of reefs. Many papers have been written on disturbance to the reef, diseases among reef organisms, and whether or not reefs are geologically robust or biologically fragile and vice versa (Done 1997; Gomez 1994). Scientists have described reefs as more or less disturbed based upon percent live coral coverage, a mortality index, coral growth rates, and the presence or absence of certain bioindicators, such as corals and fish (Edinger et al. 2000; Gomez 1994). Researchers state the reef is healthy or unhealthy based upon these proxies, but little has been written on what actually is the "health" of a coral reef. The "health" of the reef is what many are seeking to determine and compare when describing the conditions mentioned above. For the purpose of defining reef health I will assume that researchers discussing the reef and using the words status, state, risk, and disturbance are discussing reef health.

Health is the present state of a system with respect to optimal functioning, reproduction, stability, disease, and abnormality. Like many organisms and natural systems, a coral reef has a natural equilibrium position that will fluctuate above and below this healthy state. When trying to define coral reef health one must try to measure it or compare it to a baseline of optimal coral reef health. This notion of reef health is almost hypothetical because one is creating an ideal reef system of optimal health. The question remains at what time and at what scale did this reef exist? Two geographic factors, space and time, make defining and determining health of the reef unclear. Did this "healthy" system exist prior to the 1960s when the scientific literature began to document degradation of the reef and outbreaks of Crown of Thorn Starfish for example, or rather was it before industrialization in the 1800s, or did it exist prior to 15,000 years ago changes in sea level due to deglaciation? The issue of scale complicates the question of coral reef health. When discussing coral reef health, are scientists talking about coral health at the organism level, or the entire reef, or does the reef also include the other ecosystems surrounding it such as seagrass beds?

How can I assess and quantify coral reef health based upon the geographical factors discussed above? I suggest that in order to accurately examine coral reef health and adaptability to short-term natural or human environmental change one must take a whole reef perspective. A coral reef is an organic structure along tropical coasts and islands in the photic zone made from living corals and other reef-building organisms and their calcareous remains. The whole coral reef perspective includes the coral reef and surrounding community, which encompasses all of the species populations living together and interacting in this habitat.

In order to apply the whole reef perspective to an understanding of coral reef health, I will first define coral reef health based upon a normative concept of unhealthy reefs, or "degraded state" (Done 1995). Short-term changes in coral health and symptoms of degradation are seen in two services that a healthy reef provides to people. These two services are fisheries production and maintenance of reef structure. To determine what is a healthy or an unhealthy reef, compared to a reef in a former condition, one must see one or both of the two situations. A healthy reef is able to 1) provide for the production of fisheries that it did in the past (especially fish and mollusks), and 2) sustain healthy coral populations that have long-term species diversity in its coral producing zones, which will be neither bare nor invaded by excess populations of non-reef-building organisms such as fleshy algae, soft corals or zoanthids. This set of conditions used to determine reef health is essentially based upon changes in ecological conditions in the past forty to fifty years and ignores long-term geological conditions. It is nonetheless difficult to tease out long-term and short-term ecological trends (Roberts 1993). This dissertation research focuses upon human induced short-term change on the coral reef system and will examine differences between reefs based upon the criteria below that examine the concept of a "healthy" reef.

In order to evaluate reef health based upon this conceptual definition there are a number of criteria to examine. For example, the use of percent live coral coverage ignores the role that indicators of species diversity and species evenness may have in highlighting the role of disturbance and stress in coral ecosystems (Edinger et al. 2000). Coral species diversity is an important component of reef health but this may vary over time because of natural perturbations such as hurricanes and population changes. For example, after an event, a few opportunistic species for various periods may dominate before coral species diversity again increases (Done 1995). Thus, through the examination of live hard and soft coral coverage, number of species of hard and soft corals, indicator species such as certain types of algae, fish, and predators, number of corals affected by parasites and diseases, and clonal condition[10] can a whole reef perspective on the health of the reef be gained. Furthermore, by examining all these factors one can understand how to manage reefs better by gaining insight into the causes and consequences of different types of disturbances.

Methods

This research requires interdisciplinary methods. I will use interviews[11] with local people who live and work in coastal communities, the work of other researchers, and my own fieldwork to determine coral reef health as well as document baseline data on basic ecology of the reef. All ecological data were collected September 1999 – December 2000. September and October were spent on the islands of Ovalau and Vatulele in Fiji, and November and December were spent in Rarotonga and Aitutaki, Cook Islands. Additional interview data was collected in June 2001 in Suva, Fiji and Rarotonga, Cook Islands. A research assistant, Lisa Wedding, was employed to help with data collection and I also collaborated with and employed people on the islands

Significance of Research

This research will contribute to long-term monitoring in the Pacific where little research has been done on coral reef health as well as pinpointing issues of reef health and management. Three methods are used to obtain these data on coral reef health at

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[10] Clonal condition of the coral polyps qualitatively documents the appearance of the coral tissues, colony condition. Comments are documented describing the coloration of the tissue and the appearance of mucus.
[11] List of interviews can be found in the appendix.

varying spatial scales and they are: 1). Local knowledge - I will obtain data from local people who have knowledge of the reef to examine the local history of the environment and identify impacts on the marine habitat; 2). Qualitative ecological data- to assess large-scale patterns of reef health between islands and between island sites; and, 3). Quantitative ecological data - by site specific sampling.

Environmental History

The islands have local communities that use the coral reef every day for subsistence and livelihood. Thus, diving fishermen, as well as dive operators, have considerable knowledge in areas that have no baseline scientific data on coral reefs. Interviews with local people, dive operators, researchers and government employees provided data on the history of coral reef health, use of the reef resources, and exploitation of the reef. I interviewed them about their own first observations and locations of coral disease and change in the coral reef environment (see Appendix A). The questions asked of people were designed as open questions to gain insight on the present reef health. People were asked to describe their views and knowledge concerning the environmental history of the reef and possible changes to coral reef health into the past thirty years. The interviews involved questions about coastal development patterns, environmental practices, and coral diseases. In addition, they were asked to describe changes in fish catch over time and name specific fish that they noticed as having a higher or lower abundance. People often described the environment by telling what the reef was like when they were a child, as a young adult, and at the present time. Some people asked if they could draw maps of the island to show in detail where they saw changes in the seascape. Interviewing local people is a unique method and approach to the investigation of coral diseases. Data obtained from these interviews will be integrated into the text of the dissertation. On some of the islands this is the only information available about the reef. The results of this research will be made available to local communities, government agencies, collaborating institutions, and the scientific community.

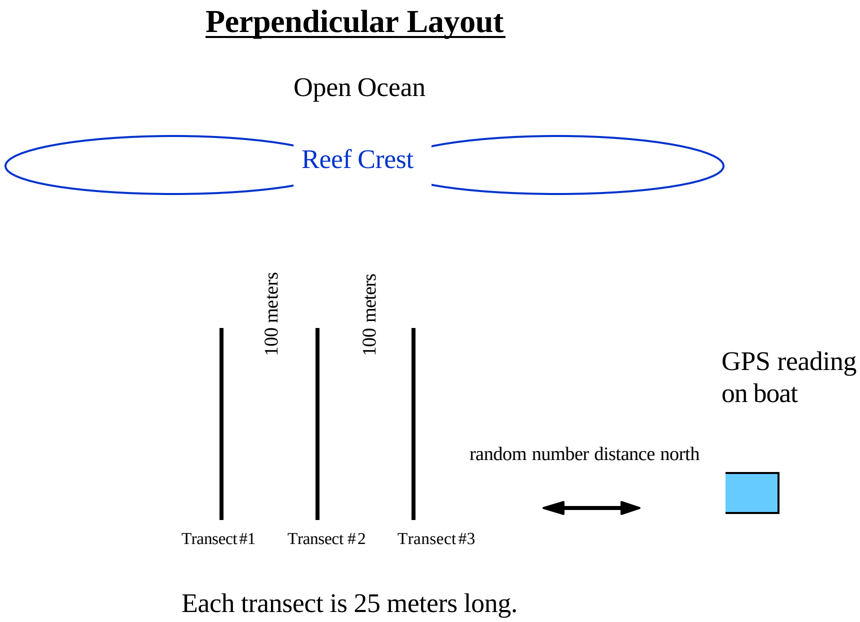
Socio-Economic Data Collection

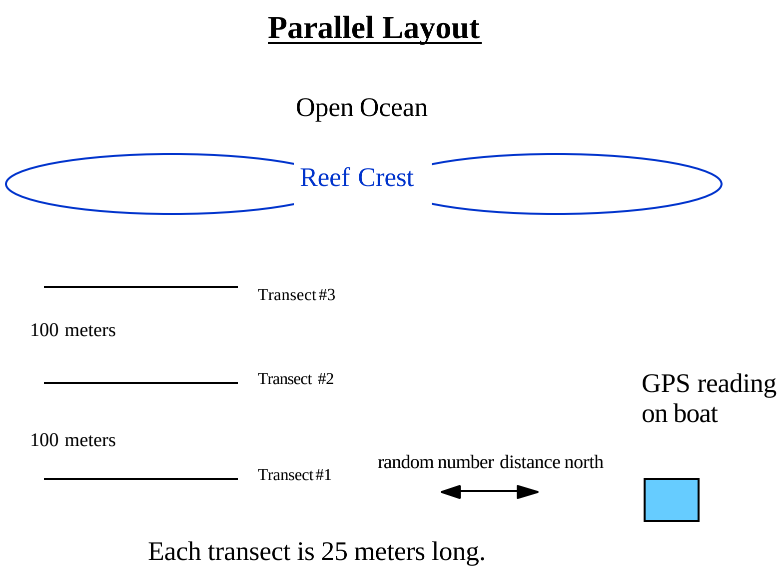
Secondary sources were used to gather socio-economic data. Not all of the island case studies used the same information. Government documents as well as reports, "gray literature" written by consultants, were collected.

Field Surveys

By comparing islands, I will rank and isolate variables such as areas with commercial fishing pressure, the effect of rivers and their sediment inputs, and the role of different marine property institutions. Several methods will be used to monitor the biology and reef health indicators of each site. Islands are characterized and described, specifically documenting information on the recent past and present variables: population, size, isolation, reef zones, species diversity, natural stresses, land use practices, marine exploitation, human disturbances, precipitation, SST, fishing practices, bleaching events, current patterns, and Crown of Thorns starfish outbreaks. These data were collected from a wide range of sources. The islands were surveyed in a range of apparent sub-environments. All quantitative ecological data were collected in the backreef of either a fringing or barrier reef using a 25 meter contiguous transect tape.

Figure 1.1: Transect Layout





Once sites on the island were chosen, a global positioning system (GPS) was used to locate study sites. Three readings were recorded on a survey boat after the GPS was operating for twenty minutes and an average was taken to determine positions. After the GPS data were recorded, a random number was picked to select the placement of the first transect. This number represented the distance northward from the boat to the beginning of transect #1 in meters. The second transect was then placed 100m further away from the first transect, and the third transect 100m further away for the second. At two sites the reef was an unusual shape or size and the distances were changed between the three transects. Rarotonga Site #5 was changed to a distance of 50m and at Vatulele Site #2 was changed to 13m between transects. In addition the direction of the transect tape that was laid down was either parallel or perpendicular to the reef crest. Rarotonga Site #4, Ovalau Site #7, Ovalau Site #9, and Vatulele Site #2 are the four sites where data were collected using the parallel layout. Data collection for ecological comparison of sites and islands used a wide range of techniques and methods (Edinger et al. 1998; Porter and Meier 1992; Santavy and Peters 1997) including:

Table 1.5: Island Site Layout

Site	Random #	Three 25 m Transects – distance between each transect
Aitutaki #1	31 meters	Perpendicular to reef, 100 meters between each transect
Aitutaki #2	21 meters	Perpendicular to reef, 100 meters between each transect
Aitutaki #3	30 meters	Perpendicular to reef, 100 meters between each transect
Aitutaki #4	7 meters	Perpendicular to reef, 100 meters between each transect
Aitutaki #5	4 meters	Perpendicular to reef, 100 meters between each transect

Site	Random #	Three 25 m Transects – distance between

		each transect
Rarotonga #1	10 meters	Perpendicular to reef, 100 meters between each transect
Rarotonga #2	49 meters	Perpendicular to reef, 100 meters between each transect
Rarotonga #3	22 meters	Perpendicular to reef, 100 meters between each transect
Rarotonga #4	13 meters	Parallel to reef, 100 meters between each transect
Rarotonga #5	3 meters	Perpendicular to reef, 50 meters between each transect
Rarotonga #6	7 meters	Perpendicular to reef, 100 meters between each transect

Site	Random #	Three 25 m Transects – distance between each transect
Ovalau #6	7 meters	Perpendicular to reef, 100 meters between each transect
Ovalau #7	42 meters	Parallel to reef, 100 meters between each transect
Ovalau #8	16 meters	Perpendicular to reef, 100 meters between each transect
Ovalau #9	36 meters	Parallel to reef, 100 meters between each transect
Ovalau #10	42 meters	Perpendicular to reef, 100 meters between each transect

Site	Random #	Three 25 m Transects – distance between each transect
Vatulele #1	16 meters	Perpendicular to reef, 100 meters between each transect
Vatulele #2	13 meters	Parallel to reef, 13 meters between each transect
Vatulele #3	34 meters	Perpendicular to reef, 100 meters between each transect
Vatulele #4	2 meters	Perpendicular to reef, 100 meters between each transect
Vatulele #5	24 meters	Perpendicular to reef, 100 meters between each transect
Vatulele #6	29 meters	Perpendicular to reef, 100 meters between each transect

Qualitative Field Data Collection

1). Photo-Video Survey: Sony PC1 with Mako Light and Motion underwater system was used for video documentation. Photo-video surveys were taken in digital format to determine substrate, bioindicators such as fish, algae, mollusks, as well as document the present reef status. Ten minutes of video were taken at each site to characterize the environment, around the perimeter of the study sites transects. This methodology is often used in rapid reef assessment to document the state of the reef (Maragos and Cook 1995). No analysis is done with the video. It is solely for descriptive purposes. Sites were assessed on each island to assess inter and intra-island variability.

2). Fish surveys: This was done to further describe the study area. Rapid Visual Transect was done for 10 minutes at each site to document the genus of each species seen in the area (Cheal and Thompson 1997). This is a simple qualitative description of the study site.

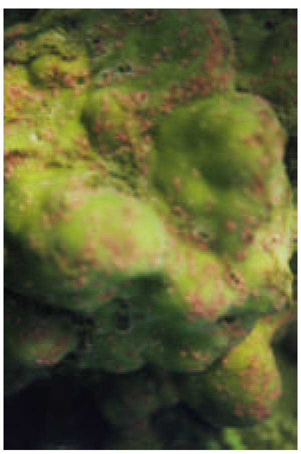
Picture 1.1: Damselfish, Ovalau, Fiji

Quantitative Field Data Collection

By carrying out ecological assessments around each island I have been able to make observations and acquire baseline data on coral reef health and contribute to a proxy of reef health.

1). Field Analysis of Transects: 25m x 1 m transects with three replicates were done to determine the reef health. Within each contiguous quadrat the following factors were determined:

- Percent live and dead cover of hard corals and soft corals
- Number of hard coral and soft species
- The number of corals affected by predators, parasites and pathogens[12] was counted by examining potential biotic factors. Examples of these factors are coral diseases, such as black band disease, parasitic organisms such as *Plagioporus* spp., or bleaching. In


Picture 1.2: *Plagioporus* spp. on Porites, Cook Islands

addition a coralline algae disease, coralline lethal orange disease (CLOD), was documented.

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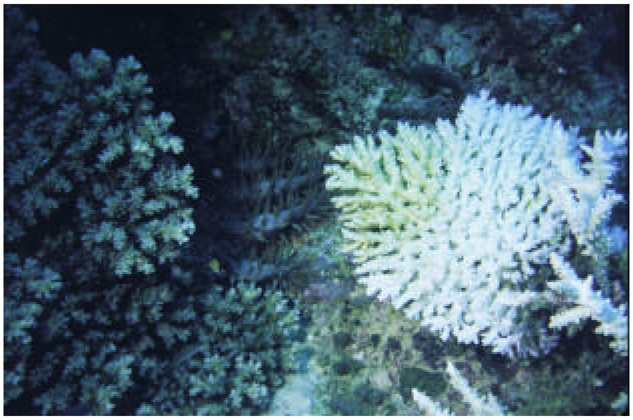
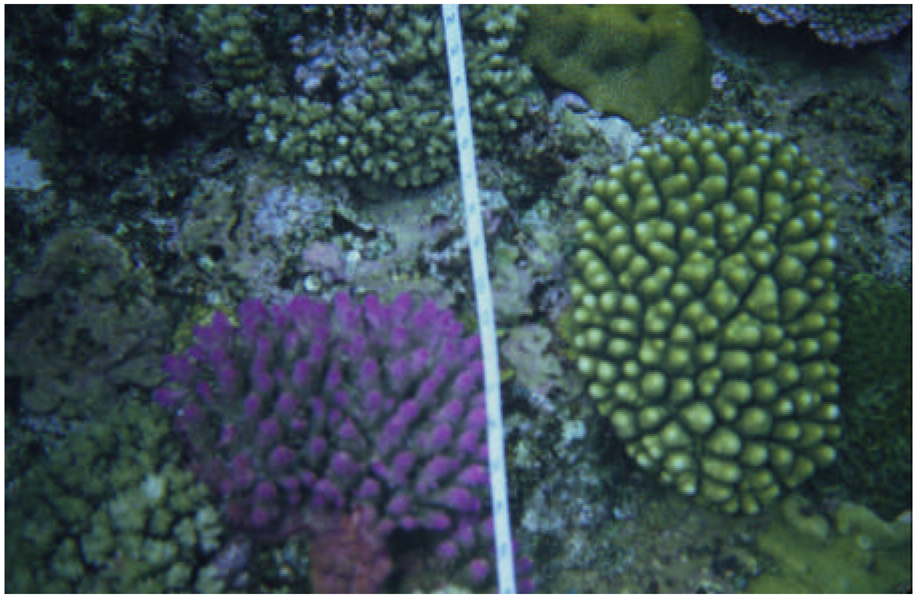
[12] Identification of predators, parasites and pathogens is based upon my knowledge and identification keys.


Picture 1.3: Bleached Coral, Fiji

- The genus of coral affected by the biotic factors when known.
- Clonal condition of the coral polyps was documented. This qualitatively documents the appearance of the coral tissues. Comments were documented describing the coloration of the tissue and the appearance of mucus.
- Presence and absence of coral disease and bioindicators such as filamentous algae and Cyanophyta.



Picture 1.4: Vatulele Transect

Data were collected on indicator species, coral affected by parasites and disease, and clonal condition using methods recommended by Santavy and Peters (Santavy and Peters 1997). The criteria above suggest that a significant difference in prevalence of one or more of the following factors indicates a threat to coral reef health: predators such as the Crown of Thorn Starfish, parasites such *Plagioporus* spp., tissue loss and discoloration, mucus production, and the presence of certain bioindicators such as filamentous algae and certain Cyanophyta (Naranjo et al. 1996). I used the DACOR (Dominant, Abundant, Common, Occasional, or Rare) method, a ranking system that describes the abundance of certain diseases (C. Hunter, personal communication 1998). Naturally occurring disease usually occur .5-1 percent and a dominant disease would constitute 20 percent abundance on the reef (Bruckner et al. 1997)(Hunter, personal communication 1998).

Table 1.6: COLLECTION OF DATA ON CLONAL CONDITION, INDICATOR SPECIES, PARASITES & PATHOGENS

	Data Needs	Description	Details
BASIC INFORMATION	Coral Species	Number of Affected corals	Which Species
	Basic data	Location, depth, date, etc.	
	Photo-document and record observations	Disease condition at different levels	Community Population Colony Tissue
	Extent of Disease	Spatial Estimates	Estimate percent population/colonies affected over time
CLONAL CONDITION	Location and pattern of tissue loss	Occurring over entire colony or localized	Circular or irregularly shaped patch(es)
		Base, top, or sides	of colony or branch
		Patches or margins	Surrounded by living tissue or living tissue on one side
		If branch, location	Base. Middle, and or tip
	Tissue margin appearance	Sharp line	Receding clean
		Uneven	Sloughing, Peeling
	Living Tissue appearance	Normal	Uniform pigmentation morphology and behavior
		Bleached	Partial or complete
		Abnormal	Swollen, sloughing, mucus, algal growth
	Relative Timing of Tissue Loss	Recent Loss	Bare coral skeleton at tissue margin
		Old Loss	Algae, sediment, and/or organisms cover skeleton next to tissue margin
POTENTIAL CASUAL FACTORS	Biotic Factors	Predators	Parrot butterfly, or damsel fish *Coralliophilia* or other snails, starfish, urchins, fireworms
		Parasites and Pathogens	Boring sponges, black-band disease, bacterial and fungal mats, parasitic worms such as *Plagioporus* species
	Abiotic Factors	Water Quality	Sediment/turbidity, salinity, temperature, nutrients, toxic chemicals
		Physical Damage	Boat Grounding, dredging, dynamiting, divers-hand/flippers damage, other habitat destruction

(Santavy and Peters 1997)

2). <u>Water Quality Data Collection:</u> Temperature and Secchi disk readings were done at each site. Three samples were taken at each site for determination of basic water parameters: nitrate, nitrite, salinity, and Ph. A LeMotte Salt Water Test Kit was used.

The interdisciplinary methods I use will help investigate and uncover some of historical trends and patterns of coral reef health and the communities' conservation and management practices that may influence coral reef health and disease. By collecting secondary sources on the coral reef and interview data from the local people and regional experts working on these islands I will be able to gain insight into reef health and changes to the fishery productivity on the reef. I will point out to reef scientists that the complexity of the reef requires this type of approach if the scientific community is to understand the death, degradation, or growth of the coral reef.

For the purpose of this study I compare sites and look at significant differences of coral diversity, percent coral coverage, as well as the abundance of certain biotic factors and the clonal condition of the coral. The findings of a study examining reef degradation in Indonesia suggest that certain types of land-based pollution reduced diversity of coral species 40-70 percent (Edinger et al. 1998). Other conclusions show that coral species diversity and live coral coverage are positively correlated. Low live coral coverage in the Pacific is not in itself a sign of bad health. Few reefs have more than 50 percent live coral coverage due to high wave energy, tropical storms, or dominance of coralline algae (Wilkinson 1998). In addition, leeward sides of islands generally have 15-20 percent more species diversity than windward sides because of wave energy and reef formations and structure (Edinger et al. 1998).

Statistical Analysis

Analysis of data will include a variety of statistical tools. Mortality Index will be calculated for each site of coral cover (Gomez 1994).

$$MI = \frac{\text{dead coral coverage}}{\text{live coral coverage + dead coral coverage}}$$

Nonparametric methods are used to correlate coral reef health and geographic variables and to compare study sites. Spearman Rho correlation coefficient will cross correlate the components of variability and identify key human geographic mechanisms of coral reef health, and the Wilcoxon test is used to distinguish significant differences between the island study sites. Histograms and graphs help identify trends and patterns such as mortality index and disease, parasite, and bioindicator prevalence.

Organization of Dissertation

This dissertation examines four island case studies in the South Pacific and specifically investigates social institutions' influence on coral reef health. Using a political ecology approach, this research identifies and describes the presence and history of certain social institutions and assesses their impact upon the reef, and then correlates reef health with these different social conditions and institutions. Through the next five chapters I will show that in order to understand coral reef health researchers must examine the history, development, and geography of each coral reef.

Chapter 2 will review the history and laws concerning marine tenure in the Cook Islands and Fiji, and Chapter 3 will examine these case studies and the various systems of marine tenure as well as marine resource development. In chapter 3, I will outline some of the effects of the changes upon the land and seascape, which will be discussed more thoroughly in Chapter 4. The data in Chapter 4 show that the commodification of the reef and reef resources is one of the primary factors causing the decline of coral reef health. Furthermore, these data show that the loss of traditional marine social institutions has affected coral reef health and transformed common property resources form communally owned property to state owned property with open access. The case study I describe in Chapter 5 will show how significant the control of access to marine resources can be to reef health. The resurgence of traditional marine social institutions as exemplified in the Rarotonga case study is improving coral reef health. In conclusion, Chapter 6 discusses how the image of the South Pacific as having "healthy" reefs shapes and forms conservation practices and policies as multiple spatial scales. Finally, in Chapter 6 I will also make recommendations for coral reef conservation in the South Pacific.

Chapter 2: The Colonial Transformation of Islands: Development, Property, and Environmental Change in the Cook Islands and Fiji from the 1800s to the Present

In this chapter I will examine the historical geography of the Cook Islands and Fiji from the 1800s to the present. The material presented will focus primarily on the colonial period, the introduction of capital into the Cook Islands and Fiji, and the penetration of western ideologies related to property ownership. First, I will briefly discuss the process of transformation in relation to market development, and then discuss more thoroughly the property regimes established by the local people prior to colonialism and then the changes made in the laws by the Europeans regarding land and sea rights. I will argue that population is only one factor leading to environmental degradation, and that researchers must also examine the local and regional political economy to assess the complexity of environmental change. I will discuss how and why the loss of traditional knowledge systems of marine management was caused by colonization and the change in marine property laws, as well as the commodification of marine resources which resulted. Therefore in this chapter the main point I make is that the property systems were transformed by the Europeans to create more productive lands and develop more markets. Thus, in order to understand and see if there is a correlation with socio-economic institutions and coral ecosystem change I must examine the historical context of development and property of each island.

These political and economic transformations have and continue to have important implications on environmental health and property rights. I will show in Chapter 4 and 5 that the commodification of reef and reef resources is one of the primary factors causing the change in coral reef health and the loss of traditional marine social institutions has affected coral reef health. Specifically, ecological change on the reefs in the recent past has been primarily influenced by the transformation of common property resources from communally owned property to state owned with open access status. The implementation of traditional marine social institutions as exemplified in a case study in Rarotonga, Cook Islands is improving coral reef health.

Reef and Coastal Environmental Change and Development in the South Pacific

In 1961 the 10th Pacific Science Congress was held to discuss the issues surrounding *Man's Place in the Island Ecosystem*. This meeting was the first meeting regarding the fragility of island ecosystems. Academics and managers gathered to discuss four main questions: 1. Why are islands worth studying; 2. What are the perception of local communities of the possibilities and limitations of nature; 3. Is it true that on islands there is close ecological and social adaptation to environmental problems; and, 4. Is there evidence that supports the claim that in the past the Pacific Island peoples did not mismanage of island resources until recent times (Bayliss-Smith 1988; Tuthill and Pacific Science Association 1963). This symposium represented some of the emerging ideas regarding issues related to resource management, limits to growth, and ecological adaptation in the 1960s and 1970s on Pacific Islands. This interdisciplinary conference questioned the ideas and stereotypes that emerged originally in the eighteenth century that Pacific Islands were bountiful Gardens of Eden with endless resources. The ideas and issues are different today. Coastal habitats are subject to human and natural disturbances that can be gradual as well as sudden. The ecosystems and coastal communities can change with sea level change, sea surface temperature changes, sediment sources, earthquakes, and hurricanes. Pacific Islanders from the past and the present have also transformed their land and seascapes by varying degrees and rates.

In order to understand why particular islands land and seascapes have changed and to determine whether or not there is a relationship between certain social institutions and economic factors on coral health, I must first explore the historical context of each island nation and discuss the changes in the recent past of some of the political and economic institutions.

Commodification of Nature

For the purpose of this study, I compare study sites based upon commodification of the coral reefs. The coral reef is an extremely valuable economic resource and can be developed and utilized both directly and indirectly. Before discussing the commodification of the reef, I will first explore some of the ideas around the concept of the commodification of nature. Then I will lay out the arguments pertaining to the commodification of the reef in Chapter 3 and discuss its relevant forms, how it has developed, and how it plays out in my four island case studies.

Karl Marx defines the commodification of an object as the transformation of the relationship and meaning of the object from one with a use value to a commodity with an exchange value (McLellan 1995). Building upon Marx's ideas, Karl Polanyi discusses in *The Great Transformation* that the commodification of nature is more complex than other objects, because people not only buy and sell land or nature, but also live from it and on it (Polanyi 1944). Therefore, the creation of markets and market development changes peoples' relationship with the land and sea, but most importantly this market development is intimately connected with social relations.

> Instead of economy being embedded in social relations, social relations are embedded in the economic system (Polanyi 1944: 57).

In my island case studies I will show that the commodification of marine resources changes the relationship with the peoples' sea with the sea through the transformation of marine property regimes.

The colonial state was a catalyst in transforming these relationships between market development and property regimes. This is due to the fact that, the colonial states' primary focus was to commence the penetration of capital, organize infrastructure to create markets and goods from land and labor (Bernstein 1982). For the purpose of this research I will focus upon how land and sea was appropriated for the sole purpose of producing commodities by the state and ruling class. State intervention in acquiring land and sea territory was essential to accumulate capital and develop commodity production and infrastructure.

This process of commodification and transformation of land systems has "extreme unevenness both between social formations and within them (regional differentiation)" (Bernstein 1982: 163). This is related to the different ways capital penetrates pre-capitalist societies and cannot be generalized because each place and political economic history is unique. Thus, the case study approach can contribute and provide insight into to the process of commodification and its ensuing social formations.

For this dissertation research, this approach is used in order to understand how the penetration of capital changed customary tenure systems at land and at sea in the Cook Islands and Fiji. I will examine 1) the inter and intra island differences between commodification of marine resources and marine property regimes; and 2) how these inter and intra island differ in levels commodification of marine resources and marine property regimes relate to the present state of coastal resource management and coral reef health.

According to Bernstein (1982), there are different patterns of exploitation of labor and land. In agreement with Bernstein's (1982) concept each island case study has a unique political economic history that has influenced the ways in which the state has claimed Crown Lands and enforced access and use of Crown Lands, as well as how the community views land and sea territory. For example, an island such as Vatulele in Fiji, with no apparent economic development opportunities for the British colony in the 1800s, did not have any land or sea territory claimed by the state as Crown Land. Thus now, all of the land and surrounding waters are community reefs and fishing grounds. By contrast, the harbor of Levuka on the island of Ovalau, Fiji and land and sea areas were claimed as Crown Land and strictly enforced by the state. Today, the Port Authority of Ovalau manages the Levuka harbor. Thus differences in customary marine tenure systems result from economic development and the transformation of traditional systems of customary tenure between the four island case studies. This will be discussed in more detail in Chapter 3.

The growth of capitalist markets change social and environmental conditions. These changes in the social sphere can result in dislocations, social resistance, and the degradation of the environment (Blaikie 1985; O'Connor 1988; Peet and Watts 1996; Polanyi 1944). This analysis provides a broad theoretical foundation to examine some of the problems surrounding the commodification of reefs.

Capitalism and Colonialism in The Cook Islands and Fiji

Like many developing countries, both The Cook Islands and Fiji were colonized in the 1800s for the sole purpose of developing the territory and producing cash crops, such as sugar cane and citrus (Bernstein 1982). The trading companies and the colonial state were all interested in the production and supply of cash crops. In particular the colonial state wanted to increase revenue, to create a continuous supply of raw materials to the home country, and to create economically productive and civilized citizens (Bernstein 1982). The role of the state is crucial to understanding the development of commodity relations on the islands. Primarily, this is through the accumulation by the ruling class of individual and/or state property (Bernstein 1982). In the next section I will discuss the penetration of capital and economic development of The Cook Islands and Fiji. Following this section I will discuss the simultaneous changes in the laws of land and sea ownership and access.

The Cook Islands

The Cook Islands were sighted in 1595 by the Spanish explorers Alvaro de Mendana and Pedro Quiros. Captain Cook explored the islands in greater depth on his second and third voyage (Keller 1998). Captain Cook named them the Hervey Islands and a century later the Russian cartographer, John von Krusenstern, renamed them the Cook Islands. The missionaries followed the explorers (Keller 1998). John Williams arrived in Aitutaki from England in 1821 to convert the natives to Christianity (Gilson and Crocombe 1980). Although the missionaries exterminated the local island religion, the local government remained in the control of the native chiefs. The missionaries not only brought Christianity, but also introduced agricultural crops such as cassava, papaya, melons, vanilla, mangoes, and oranges. The shipping routes imported and exported good from South America via Tahiti. The Chilean peso was the main source of currency in the last century (Gilson and Crocombe 1980).

In 1888 the British declared the islands a protectorate (Gilson and Crocombe 1980). Shortly after, in 1900, Rarotonga and some other islands were annexed to New Zealand. By 1901 all of the islands were annexed by New Zealand (Gilson and Crocombe 1980). The expectation was that the Cook Islands would be the main source of tropical agricultural products such as bananas, citrus, tomatoes, and other crops for New Zealand. Economic development of the islands was the main focus of the New Zealand administration. Because of the great advantages of the fertile soil and climate, the Cook Islands rapidly became an exceptional place for the growth of coconuts, coffee, bananas, and other tropical fruits. In the early 1900s there was a revival of the bêche-de-mer harvesting (Gilson and Crocombe 1980).

The problem native Cook Islanders began to have in the 1900s was how to generate a cash income. In the early 1900s money was generated through the sale of copra and oranges to ships sailing through the islands. Sales dropped and in the 1930s the Cook Islanders petitioned the New Zealand government for aid (Gilson and Crocombe 1980). This was a result of two problems. First, the exported citrus fruit were difficult to export without damage. The second problem was the infrequency of refrigerated ships to transport the goods. This created further damage to the produce and thus low prices.

In 1937, the Cook Islands Fruit Control Regulations act was passed to build a program to develop a citrus fruit industry (Syed and Mataio 1993). The Department of Agriculture sponsored the program called the Fruit Control Scheme and provided growers with fertilizers and improved varieties of citrus fruits (Gilson and Crocombe 1980). In addition, a steady supply of refrigerated ships began to pass through Rarotonga. This scheme also wanted individual growers to develop their own orange groves and had the Land Court partition ‘family land’ into individual plots (Gilson and Crocombe 1980). Many native Cook Islanders objected to this idea of individual title, but assistance from the government was limited to those growers who held sole ownership (Gilson and Crocombe 1980).

By 1945, the production of citrus had declined due to an increase in disease and pests so a new scheme was introduced, the Citrus Replanting Scheme (Gilson and Crocombe 1980). Large cash grants were given by the New Zealand government to local farmers to produce high quality fruit and levy local taxes. One way the government increased production was to change land tenure. There was growing state control over private lands. The Cook Islands Amendment Act of 1946 allowed multiple owners of land to vest their rights in one grower as long as they were growing citrus (Boer 1996). The land was then surveyed and planted with citrus by the Department of Agriculture, who had control over the crops, but ownership was still claimed by the co-owners. Growers realized that they greatly benefited from the scheme because they did not have to make any initial investment and the government just wanted recovery of the development costs. By 1949, orange grove plots under the scheme had increased 50 percent (Gilson and Crocombe 1980). In addition the government invested in cool store and central packing sheds as well as an additional ship to come through Rarotonga (Gilson and Crocombe 1980).

By 1961, the citrus industry was well established (Syed and Mataio 1993). A private company, W. Gregg and Co., established a pineapple processing plant (Syed and Mataio 1993). When the Cook Islands became independent in 1965 the government emphasized the need to develop the outer islands (Syed and Mataio 1993). The New Zealand government guaranteed a market for such crops as citrus, pineapples, tomatoes, bananas, and copra. From 1961 to 1971 production grew steadily (Syed and Mataio 1993). Aitutaki was producing regular shipments of bananas from its 500 acres under intensive cultivation. By the mid '70s and throughout the '80s the production of the four main crops, oranges, pineapples, bananas, and copra, dropped and the export of papayas, vegetables, and root crops increased. Agriculture was crucial to the Cook Island economy and in 1972 exports contributed to 66 percent of total export earnings. By 1991 this number fell to 17 percent (Syed and Mataio 1993). Furthermore, in 1960 the Cook Islands Amendment Act (No. 32, 1960) was passed and this allowed the individual ownership of a house (Boer 1996). A person would be permitted to build a house on a quarter of an acre lot. The opportunity to generate cash from building houses increased as tourism grew. Between 1986 and 1991 building grew by 16 percent in Rarotonga (Syed and Mataio 1993).

The first population estimates for the southern group of islands was made by the missionary John Williams (Gilson and Crocombe 1980). Between 1821 and 1831 he visited all of the islands and reported the population of each island. He recorded 6,000 to 7,000 people on Rarotonga in 1827 and at the time of European contact approximately

12,500 to 15,500 for all of the southern islands and between 2,500 to 4,000 for the northern group of islands (Gilson and Crocombe 1980). After 1826 the population began to decline and fell to 8,213 by 1902 (Syed and Mataio 1993). The introduction of disease and migration were the main factors causing the population decline. Furthermore, records show that in 1831 and 1833 two cyclones hit houses and crops, which led to many deaths due to starvation. The population began to grow again from 1902 to 1971. Another declining trend in the population began in 1971 and continued until 1986 as thousands of Cook Islanders emigrated to New Zealand. Most of the population lives on Rarotonga and has increased to the present. The slow economic growth has led to the mass exodus of Cook Islanders to New Zealand. According to the Asian Development Country Profile, the negative GDP growth has stopped and in 1999 there was 2.5 percent growth. The industries leading this growth are the black pearls mariculture and the tourist industries (Asian Development Bank 1999).

Since self-government in 1965, the Cook Islands has experienced rapid economic progress when compared with other South Pacific Island Nations. In the early stages of self-governance the primarily goal was to reduce dependence upon the New Zealand government, which heavily subsidized the Cook Island economy. Foreign policy and defense were left to New Zealand at first and then slowly the Cook Island government opened its own Ministry of Foreign Affairs. The only defense issue is the surveillance of marine resources. New Zealand and Australia help with technical assistance (Gilson and Crocombe 1980). To this day Cook Islanders are citizens of New Zealand. Queen Elizabeth may have executive authority over the country, but the government is carried out by a Prime Minister and up to eight cabinet ministers. The cabinet is responsible for the Parliament, which consists of 25 members who are elected every five years and The House of *Ariki*, which has 15 members who are hereditary chiefs and can advise the government but have no real legislative power (Boer 1996).

Fiji

Although many explorers were actively exploring the Pacific waters prior to 1643, at this time Abel Janszoon Tasman became the first European to visit Fiji (Kerr and Donnelly 1969). He never made any landing because the weather and waves were rough and reefs dangerously close to shore so he wrote unfavorable reports of the island environments. Europeans thus avoided the region for the next 130 years. Not until the second voyage of Captain Cook on the *Resolution* and accompanied by the *Adventure* did European explorers come across the Fijian Islands (Kerr and Donnelly 1969). On July 2, 1774 Cook saw a small island, which he then named Turtle Island. He landed there to trade some goods and charted the reef to the south known today as Vuatu Vatoa. Turtle Island or Vatoa, was his only discovery in the island group. Cook gave the islands the name Fiji after having heard the Tongans call them Viti. Fifteen years later, British Lt. William Bligh made discoveries of numerous islands in Fiji during his voyage on the *H.M.S. Bounty* gathering breadfruit plants from Tahiti to grow in the West Indies (Kerr and Donnelly 1969). During this voyage Bligh made accurate charts of the islands and reefs he passed through on his route. He made no landings either. In 1792 Bligh returned to Fiji on the *H.M.S Providence* while making a second trip to Tahiti. He saw more islands and confirmed his earlier sightings. The islands were known for a long time as 'Bligh Islands'. Many more explorers sailed through the reefs and passages of the Fijian

Islands. But not until the nineteenth century did the Europeans have an impact on the environment and way of life of the Fijian people (Kerr and Donnelly 1969).

Europeans first came to Fiji looking for sandlewood and bêche-de-mer. In the early 1800s, a ton of sandlewood could be traded for such articles as scissors, saws, knives, tobacco, muskets, and powder (Kerr and Donnelly 1969). The Fijians became skilled traders and a new source of wealth developed on the islands. Other resources began to be exploited, such as whales, and by the 1830s a small whaling settlement was established in Levuka. With the traders came the missionaries and further exploration (Bayliss-Smith 1988).

In 1840 an American expedition to Fiji led by Commodore Wilkes voyaged to Fiji and spent three months exploring the environments of the islands (Kerr and Donnelly 1969). Slowly, more Westerners, primarily English people, began to settle in Fiji and plantations of vanilla and coconut emerged. When the Europeans bought the land for these plantations they thought they bought the rights of the land, but the Fijians were usually only selling the rights to use the land. This created some conflict. As the region developed and more plantations were established, the need for labor increased as did the desire by the settlers for governance. In 1874 Fiji became a British colony. After Cession the government focused upon the need for obtaining land, labor and capital (Lal et al. 1992: 13). The British government under the guidance of Sir Arthur Hamilton Gordon convinced the Australian Colonial Sugar Refining Company (CSR) to begin operating in Fiji in 1882. It remained in Fiji until 1973. This company became the "backbone of the economy in Fiji" (Lal et al. 1992: 13). In order for sugar production to become a successful industry Fiji needed capital and cheap labor. Melanesians and

Gilbertese laborers were imported into Fiji for the sugar industry and by 1878 the first agreement for Indian workers was made. By 1916 more than 60,000 laborers from India were living in Fiji. Part of Gordon's strategy for governing the Fijian people was to create a system which he described as "indirect rule" designed to "seize the spirit in which native institutions had been framed, and develop the utmost extent the capacities of the people for the management of their own affairs, without exciting their suspicions or destroying their self-respect" (Lal et al. 1992: 14). This philosophy was felt in all aspects of governance, from labor to taxes and land. The Native Lands Commission was established to assess the validity of settlers' land claims and also to determine the structure of indigenous land ownership. Before Cession, European settlers purchased most of the best coastal land, the majority of the freehold land. Freehold land can be bought and sold to any person in the community. This land is also primarily for large sugar and copra plantations. Sugar cane was the most important export, and it accounts for 60-75 percent of Fiji's exports while the CSR was present in Fiji. The sugar cane and copra plantations are concentrated on the coastal flats and nearby inland hills.

In the past forty years the primary industries in Fiji have shifted. Sugar dominated its exports while Fiji was a British colony, with growth rates averaging 5 percent a year from the 1870s to 1940s. Sugar accounted for up to 70 percent of Fiji's total exports. Economic activity has diversified in the past few decades with the growth of tourism, commercial agriculture, and mining. The Fijian community has become more educated. Between 1995 and 1997 Fiji had 297 million dollars in international tourist receipts (UNDP 2000). And in 1997 agriculture was 18 percent of its Gross Domestic Product; 26 percent was industry, and 56 percent service (UNDP 2000).

Since European contact, 200 years ago, the Fijian population has changed. Since independence thirty years ago, the far eastern and northern island peoples have slowly migrated to Viti Levu and primarily Suva. Along with this movement there has also been a shift in how Fijians obtain their livelihood. They no longer live from subsistence crops, but earn an income through cash-crops or wages. Fiji's population is growing at a present rate of 1.2 percent (UNDP 2000). Its population in 1976 was 588,000, in 1986 715,375, and today it is 817,000 (The World Bank 1991; The World Bank 1998). Fiji is a middle-income country with a competitive sugar industry, tourist industry, and industrial base with prospects for future development targeted by the World Bank as forestry, fisheries, and other agricultural crops.

The Laws of the Land..and Sea: The Introduction and History of Western Property Laws in the Cook Islands and Fiji

The Cook Islands

The Cook Islands have 58,452 acres of land, and 58 percent of this land is arable (Syed and Mataio 1993). Access to and ownership of this land changed when Europeans colonized the islands. In pre-European times, land rights were owned by social groups. The head of each group, the *ariki*[13], held the title of the land. All of the land was accountable for by this system because a certain tribe and lineage claimed ownership for all of the land and sea territory. The *ariki* spoke and acted on behalf the tribe, but realized the need and importance to retain the support of the people. Although, it may seem that the chief had more rights and power than the tribe, the chiefs were thought of as synonymous with the tribe.

The *ariki's* rights were symbolic because the land was divided amongst the *mataiapo*[14] and then the minor lineage and households. The issues and questions around chiefly rights to lands only really came into question after commercial agricultural began and land assumed a cash value. During pre-European contact, chiefs had lands for food supply and residence, but the ownership of land was not considered very significant in the subsistence economy. Tribal land rights in the Cook Islands really were individual rights, which were held in common and exercised collectively. Members of the tribe could move between lands held by different lineages on designated paths and during the daytime. There were also lands for tribal use for particular functions such as sacred sites and the production of food for tribal feasts. The lands were divided into *taperes*, which is the demarcation of lineage land and it ran from mountain peak to the edge of the lagoon.

> …the boundary of each *tapere* ran from two points on the outer reef, across the lagoon and the adjacent lowlands, up two flanking ridges, to end at a point in the central mountain core (Syed and Mataio 1993: 40).

Access and rights to the reef and the marine resources were coordinated by the *matakeinanga*[15] inhabiting the *tapere*. There was no formal system of demarcating the territory although coral rocks have been mentioned as markers. Fish weirs were owned by the extended family whose ancestors had built them. Use without permission was considered theft. Access to the reef passages were granted by the senior title owner of

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[13] The *ariki* are the high chiefs Crocombe, R. G. (1964). *Land Tenure in the Cook Islands*, Oxford University Press, Melbourne, Australia..

[14] The *mataiapo* are the chiefs of major lineages Crocombe, R. G. (1964). *Land Tenure in the Cook Islands*, Oxford University Press, Melbourne, Australia..

[15] The *matakeinanga* is the name for the local group of the major lineage. The *mataiapo* is the chief of this major lineage group Crocombe, R. G. (1964). *Land Tenure in the Cook Islands*, Oxford University Press, Melbourne, Australia..

the lineage of the *tapere* for a small fee, a portion of the catch. Fruits, such as the wild plantain, were common property of the lineage.

Rights to the land were shared by more than one person. The idea of communal tenure has been used, but is not quite an accurate description of the situation prior to European contact on the Cook Islands for a number of reasons. First, this term implies equal ownership of the land, which was not the case. Second, land was divided within the *tapere* into plots for the households, but these boundaries were not as thoroughly defined as they were for the lineage.

The adaptation of the traditional land tenure system to the economic markets deterred intensive cultivation (Gilson and Crocombe 1980). Cook Islanders always had enough food to live a healthy life. In 1827 trading stores were opening up and the concept of bartering and selling emerged on the Cook Islands. At this time the missions began encouraging the chiefs to have the lineages plant cash crops. The production and exchange of cash crops strengthened chief status.

After annexation by New Zealand in 1900, in an attempt to increase agricultural productivity, leased land was provided to settlers. A Land Court was established in 1901. During this time the Land Court began registering individual titles to land freehold titles. Title-holders could not sell land, but were encouraged to lease land to settlers for incentives to cash-cropping. Access to the land based upon descent, sex, and status was abolished. Under the new system everyone inherited land equally. This new system of land inheritance has made land parcels smaller, and many times there are multiple owners. The Land Courts required that the majority of owners agree to the use and leasing of the lands.

The formal ties to New Zealand beginning in 1901 had a significant influence on the Cook Islands' legal system. The laws written at this time are still in the Constitution. For example, on issues related to land rights and ownership the following laws are still in place. The Cook Islands Act of 1915[18] gives recognition to native customs and makes the following provision in relation to land:

> Every title to and interest in customary land shall be determined according to ancient custom and usage of the Natives of the Cook Islands.

But, all land lying below high water mark was declared by section 419 to be Crown Land, thus annulling the indigenous pattern of rights to reef and lagoon waters (Boer 1996: 106). Furthermore, the 1986/87 Conservation Act declares all foreshores and soil under the water owned by the Crown (Boer 1996). This Act further protects the foreshore by prohibiting the removals of silt, sand, gravel, coral, cobble, and boulders from foreshore and coastal waters without permission from the Conservation Council. These three laws are crucial to the issue access and ownership of the waters and reef health.

Traditional agricultural systems and social systems allowed the islands to support a high population without environmental degradation. Today, the Cook Islanders rarely use the land for land subsistence, but rely on it heavily for a few export food crops. According to Syed and Mataio:

> The relative volume of food produced and consumed in the period before European contact, the colonial era and in the present, had not been compared, though there has been a steady decline. The former social system has all but disappeared, and with it the 'ideal' traditional control of land use (Syed and Mataio 1993: 59).

In the past century mechanization has made land clearing and cultivation fast and easy, but because of the steep slopes and heavy rainfall the fertility of the soil has declined.

Furthermore, erosion has become a big problem, especially on pineapple plantations. Erosion has also been documented along the coastline, river banks, and streams.

Fiji

Under the new British government all land not occupied by a chief or tribe or needed for the future use by the indigenous people and not occupied by Europeans became Crown Land. In 1875 a land commission was established to make sure that all land purchased by Europeans had been bought fairly. The British policy under Sir Arthur Gordon intended to let the Fijians rule themselves and this played out in the issue of land rights as well. The communal system of land ownership was approved in the Native Lands Ordinance of 1880. The Council of chiefs and the Native Regulation Board made laws relating to native Fijian matters, which were enforced by the communities' own courts. The system that Gordon established remains to this day, with little change (Lal et al. 1992).

There was much internal debate about these policies. The Colonial Office in London said that the "course of events during the last 30 years has rendered it impossible for the Government of Fiji to adopt any position other than that the waste lands of Fiji must continue to be regarded as the property of the natives as much as the occupied land" (Lal et al. 1992: 32). From the time of Cession in 1873 to the early 1900s the Colonial government wanted the unoccupied Fijian land surrendered to the Crown, but it was an extremely sensitive issue. Afraid that violence might erupt, the British left it alone. The Native Lands Acquisition Ordinance allowed the government to acquire land for public needed such as roads, buildings, canals and other infrastructure that the government felt was need at a mutually agreed upon price. The government tried to promote individualism and personal enterprise amongst the Fijians (Lal et al. 1992: 30). By 1959 the British House of Commons had resolved that the British government should be helping their colonies become completely independent. By 1970 independence was achieved.

The system of land rating was slowly introduced in the mid-1900s. In 1968, Tailevu and Kadavu Islands began collecting the money. The system was established to increase native production of Fijian land. Since the land is divided into tribes and then into individual parcels a tax is placed on whether or not the land is improved. If it is, a lower tax will be imposed upon the individual (Fong and South Pacific Forum Fisheries Agency 1994).

Fiji is one of the few countries of the world that has established a marine tenure system. The *qoliqoli* (fishing grounds) encompasses all rivers, creeks, lakes, and sea areas which a particular *vanua*, *yavusa* and *mataqali*[16] claimed as their traditional fishing grounds. The *qoliqoli* according to Ravuvu is open to a wider community group of related kinsmen to obtain protein (Ravuvu 1983). Sometimes the *qoliqoli* is put under *tabu*. This is a temporary restriction or prohibition on fishing in the area for a time in order to increase the supply of fish for a particular ritual or event. The *tabu*[17] is lifted on

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[16] *Yavutu* "a social unit of agnatically related members larger than the *mataqali* and the members of which claim descendents from a common founding male ancestor. The *vanua* is land, people, and custom and the *mataqali* is an agnatically related social unit – usually a lineage of the larger clan Ravuvu, A. (1983). *The Fijian Way of Life - Vaka i Taukei*, Institute of Pacific Studies of the University of the South Pacific, Suva, Fiji..

[17] A *tabu* is a prohibition because of its sacred nature Crocombe, R. G. (1964). *Land Tenure in the Cook Islands*, Oxford University Press, Melbourne, Australia..

the water on the date of the special function, such as a marriage, birth, or death, and people are allowed to fish once again.

According to Hornell, before Cessation in 1874 the *mataqali* did not like people accessing their fishing grounds (Hornell 1940). Interpretation of access and resource use varied from island to island. These differences will be illustrated in my two Fijian island case studies, Ovalau and Vatulele, in Chapter 3. The social structure is associated with title to land and sea areas as well as title to customary office. But, interpretations of the definitions of kinsmen was also widely open to interpretation. Beginning in the 1890s the Native Lands Commission simplified the structure of Fijian society[18]. This system formally documented the village organizations and prevented the past flexibility of the traditional system. This was of great concern especially with fishing rights becoming "codified".

Hornell, the Fisheries Advisor to the Government of Fiji, wrote:

> Prior to voluntary cession of Fiji to the British Crown, fishing in the rivers and in the sea was ruled by custom. The rights of the Chiefs were paramount, and in the practice the Chiefs were the distributing agency in the area which each controlled. Each tribal unit, the *matangali* (*matagali*), had its fishing areas accurately defined; fishing within this area by people of another *matanggali* was resented, and the intruders treated as poachers (Hornell 1940).

The *vanua* or the *yavusa* were the social units associated who possessed rights to the fishing areas. At the time of Cessation, Sir Hercules Robinson said that the Chiefs could "trust her (the Queen) to govern them righteously and in accordance with native usages

[18] The *vanua* is land, people, and custom and the *mataqali* is an agnatically related social unit – usually a lineage of the larger clan Ravuvu, A. (1983). *The Fijian Way of Life - Vaka i Taukei*, Institute of Pacific Studies of the University of the South Pacific, Suva, Fiji.. *Vanua* equals the tribe, *Yavusa* the clan, *Matagali*, the sub-clan or lineage, *Tokatokoa* is the sub-lineage or extended family and *Vavale* is the

and customs" (Hornell 1940). The Deed of Cession signed October 10, 1874 contains the following articles:

> 1. That the possession of and full sovereignty and dominion over the whole of the group of islands…known as the Fijis…and over the inhabitants thereof, together with the possession of and sovereignty over the waters adjacent thereto and of and over all ports harbors havens roadsteads rivers estuaries and other waters and all reefs and foreshores within or adjacent thereto are hereby ceded…to the intent that from this time forth the said islands and the waters reefs and other places as aforesaid lying within or adjacent thereto may be annexed to and be a possession and dependency of the British Crown….
>
> 4. That the absolute proprietorship of all lands not shown to be now alienated so as to have become bona fide the property of Europeans or other foreigners or not now in the actual occupation of some chief or tribe or not actually required for the probable future support and maintenance of some chief or tribe shall be and is hereby declared to be vested in Her majesty her heirs and successors….
>
> 7. That on behalf of her Majesty His Excellency Sir Hercules George Robert Robinson promise (1) that the rights and interests of the said Tui Viti and other high chiefs ceding parties hereto shall be recognized so far as is and shall be consistent with British Sovereignty and Colonial form of Government….[19]

These articles are open to interpretation and are still contentious regarding marine environments. In 1880, the Rivers and Streams Ordinance was passed to define public access to rivers and steams. Later it also applied to soils, minerals, and marine areas. This Ordinance states the "all waters in Fiji which the natives have been accustomed to traverse in *takais* or canoes (including rivers) …shall, with the soil under the same, belong to the Crown and be perpetually open to the public for the enjoyment of all right

household Ravuvu, A. (1983). *The Fijian Way of Life - Vaka i Taukei*, Institute of Pacific Studies of the University of the South Pacific, Suva, Fiji..

[19] From Fong, G. M., and South Pacific Forum Fisheries Agency. (1994). *Case Study of a Traditional Marine Management System: Sasa Village, Macuata Province, Fiji*, Food and Agriculture Organization of the United Nations, Rome.

incident to rivers." In 1881, the new Governor Sir George Williams des Voeux stated during a speech to the Native Council that, "Chiefs of Fiji….I now return with the Queen's letter, and as I have to tell you, with regard to your representation on the subject of the reefs, that the matter will be carefully investigated, and that it is Her Majesty's desire that neither you nor your people shall be deprived of any rights in those reefs which you have enjoyed under your own laws and customs; and I may tell you, on my part, that measures will be taken for securing to each *matanggali* the reefs that properly belong to it, exactly in the same way as the rest of their land will be secured to them…" Based upon these two laws it is concluded that the British thought that waters and seabeds were property of the Crown and that the Queen's subjects had access to fishing and navigation within these waters and seabeds (Lal et al. 1992). But, Fijians did not have similar views and understandings as the British regarding property ownership and even the divisions between land and waters. The Fijians saw land and waters as intimately connected and the waters as an integral part of land. Although the British Government discussed the "traditional fishing" rights for the Natives, there were no formal steps taken to implement this viewpoint until the Birds, Game, and Fish Protection Ordinance of 1923 (Fong and South Pacific Forum Fisheries Agency 1994). In Section 16 it states:

> Notwithstanding anything contained in the Rivers and Streams Ordinance 1880 it shall be unlawful for any person to fish on any reef or on any *kai* (cockle) or other shellfish bed in any water forming part of an ancient customary fishing ground of any *matanqali* unless he shall be a member of such *matanqali* or shall first have obtained a licensed so to do under the hand of the Colonial Secretary. Provided that the granting of such license shall be in the discretion of the Colonial Secretary and shall not be necessary in the case of persons fishing with hook and line or with fish traps between any reefs or in any tidal river.

The main purpose of Section 16 was to override the Rivers and Streams Ordinance and basically imply that the Crown was the owner of the river and seas beds and the Fijians had ownership over inshore fishing rights. Section 17 further outlined how to handle disputes between *mataqalis* and their fishing boundaries. This Section stated that the Governor of Council shall make the decisions about such disputes. In the 1940s, when Hornell was in charge of the Fisheries Division, he wanted the limits of the reefs and shellfish beds owned by the various *mataqalis* defined and recorded officially with the Government. By January 1, 1942 a fisheries Ordinance was enacted and is still in the Fijian Fisheries laws to this day. The passing of this Ordinance created the Native Fisheries Commission, which is responsible for fishing rights and boundaries (Fong and South Pacific Forum Fisheries Agency 1994).

Now Fijians have customary fishing rights and can exclude others from commercial fishing and claim compensation when development affects the marine resources they have rights to harvest. The 1990 Fijian Constitution was careful to preserve the rights of ownership by the State that the British view had established. Many Fijians were unhappy with this resolution, especially since boundaries documented by the native Fisheries Commission were not all made in the 1920s, but some not documented until the 1950s and 1960s and often times not all of the fishing grounds were accurate (Fong and South Pacific Forum Fisheries Agency 1994). The Constitution states that land and seabeds and " any royalties or proceeds received by the State in respect of any minerals extracted from any land or from the seabed over which there exists any registered customary fishing rights, shall from the date of the commencement of this Constitution become payable to the owner of the surface of that and or the beneficiary or the registered customary fishing rights as the case may be…" (Fong and South Pacific Forum Fisheries Agency 1994). Section 5(3) of the Fisheries Act states that it is illegal to take fish and shellfish, sponges, holothurians, sea urchins, crustaceans, and turtles and their eggs without a license. There are two types of licenses: 1). Inside demarcated areas (IDA) licenses refer to inshore areas, which fall within fishing rights areas and 2). Outside demarcated areas (ODA) refer to areas beyond the reef (Fong and South Pacific Forum Fisheries Agency 1994). Section 13 of the Fisheries Act and regulation 4 of the Fisheries Regulations requires license applicants to obtain a prior permit to take fish or any reef or any shellfish bed in any area in respect native customary fishing rights from the Commissioner of the Division. The permits may contain specific local exclusions of the fishing methods, species, or area of accessibility. This law does not require the owners of the fishing grounds to consent – it is up to the Commissioner to decide (Fong and South Pacific Forum Fisheries Agency 1994).

Royalty payments to the owners of fishing rights do not have any explicit statutory confirmation, but are very common. The amount of money and approach varies from Chief to Chief and agreements vary from place to place.

The Commodification of Nature and the Loss of Customary Tenure Systems and Management Regimes

The Cook Islands and Fiji are examples of two South Pacific Island Nations that have had different histories of development and colonialism. These histories, in turn, have transformed the islands' traditional property regimes. The change of the natural resources in Fiji and the Cook Islands from objects to a use value to a commodity with an exchange value transformed peoples' relationship with the land and sea. Traditional property systems were transformed by Europeans to develop markets and productive land and sea resources. In 1888 when Britain declared The Cook Islands a protectorate, Rarontonga was becoming a major importer and exporter of goods to South America, and later to New Zealand. Furthermore, the main island, Rarotonga, had fertile soil and a perfect climate for agricultural cash-crops such as coconuts, bananas, and copra as well as abundant quantities of bêche-de-mer found in all of the islands. Agriculture was seen by the New Zealand government as an opportunity for economic development and importation. Once New Zealand annexed The Cook Islands in 1900, a land court was immediately established and all land below the high water mark was determined as Crown Land. This ruling erased the indigenous marine property regime. Prior to this law, traditional families owned and managed their land and sea property from the mountain to the reef. Outer islands that the government did not deem economically valuable did not enforce the change in land and sea ownership and access to resources. For example, the law states that the ocean is Crown Land up to the high water mark, but the communities enforce and respect the traditional systems of ownership and management, which are still in place.

In Fiji prior to Cession, European settlers purchased most of the coastal land. After Cession, the British government claimed all land not occupied or used by the indigenous people or European settlers as Crown Land. Furthermore, the Native Lands Acquisition Ordinance allowed the government to acquire land and sea areas for public needs, such as canals, buildings, and roads. The marine waters were seen as Crown Land. Not until 1923 were traditional fishing rights and access to customary waters implemented. Customary marine tenure and native title is recognized by the government, but not everywhere. The waters that became centers of economic activity, such as harbors, now do not have community customary marine tenure systems in place. The less developed, remote communities and island waters and reefs do.

In both countries, the more isolated islands that had little, if any, economic development have in place customary marine tenure institutions. In Fiji the communities today have legal rights to these reefs. Presently, in the Cook Islands the communities do not have legal rights, but the outer island communities still respect and enforce the traditional ways. Thus in Fiji the communities with little economic development and no land or sea claims by the Crown were easily able to claim their territories. In the Cook Islands the laws of the land and seas were not strictly enforced if economic development was not an incentive for the government. This is apparent in the remote Northern Cook Islands as well as the remote islands of Fiji. In Fiji, 83 percent of the land and sea areas are owned by Fijians, 8 percent is freehold, and the rest government owned. By contrast, in the Cook Islands the government does not legally acknowledge marine areas owned by the communities because it is Crown Land (The World Bank 1991; Syed 1993).

Table 2.1: Island Study Site Characterization

Island	Marine Property Laws	Level of Tourism Development	Level of Harvesting Marine Resources	Level of Agro/Industrialization	Present Population
Aitutaki, Cook Islands	Common Property Resource	Mid-size	Subsistence, mariculture industry & commercial harvesting	Commercial Agriculture Heavy Industry	2,389
Rarotonga, Cook Islands	Common Property Resource	Mass tourism	Subsistence, mariculture industry & commercial harvesting	Commercial Agriculture	11,225
Ovalau, Fiji	Common Property Resource & Customary Marine Tenure	Small scale	Subsistence & commercial harvesting	Heavy Industry & Commercial Agriculture	8,647
Vatulele, Fiji	Customary Marine Tenure	Small scale	Subsidence & Small-scale commericial fishing	No agro/industry	914

(Bureau of Statistics 1996; Cook Islands Statistics Office 1999; Turva 1988)

An Island Tragedy?

Privatization of the reef, such as the model of customary marine tenure in Fiji, is suggested as a way to save this precious ecosystem.

> "Privatise It" - in Fiji the reefs in [this] country, although not exactly privately owned, are in the custody of the chiefs of Fiji's clans….If local people have ownership, or rights over a reef, they have a motive to protect it from unreasonable exploitation, and so will police and monitor the reef themselves. Privatization can also open up more lucrative ways of exploiting reefs (Economist 2000: 88).

Most reefs and waters are common property. They have no owners and thus can create environmental chaos, known as "The Tragedy of the Commons". Garrett Hardin wrote the classic article in *Science*, "The Tragedy of the Commons," which argued that common property, and free and unregulated access to scarce resources would resort in exploitation of resources (Hardin 1968).

> The rational herdman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another ….but this is the conclusion reached by each and every rational herdsman sharing commons. Therein lies the tragedy. Each man is locked into a system that compels him to increase his herd without limits – in a world that is limited…Freedom in a commons brings ruin for all (Hardin 1968: 1244).

Hardin's suggested that increased population pressure was the main culprit of the demise and degradation of the commons. In many case studies, however, common property is seen as the cause of the demise of certain resources. Private ownership may be the only way to protect resources. This is not always the case; and furthermore, there are more nuances to every situation. As scholars have discussed, in order to really understand the tragedy of the commons one must look at the historical, cultural, social, and economic context and recognize the model's many assumptions (McCay and Acheson 1987). The one assumption I would like to point out is that common property does not equal open access to resources, especially for marine resources. Certain areas may be designated as common property, but there may not be rules to control and monitor exploitation. This is an extremely significant point to highlight especially for the distinctions between my island study sites. As you will see in the next chapter, due to the various histories of development on the islands even in the same country, the individual islands currently have different systems of property rights and social norms based upon the embedded historical context which in turns affects reef health. In Chapters 3 and 4 I will show that commodification of the reef is one of the primary factors causing the decline of coral reef health. In addition, I will argue that the loss of traditional marine social institutions has influenced coral reef health. Specifically, the decline in live coral coverage and species diversity on the reefs in the recent past has been primarily influenced by the transformation of common property resources from communally owned property to state owned with open access status.

Chapter 3: Commodification of the Reef

The main purpose of this chapter is to describe and analyze the human geographic variables on the four island case studies. The first category of analysis examines the level of market development/intensity in three sectors, marine tourism, harvesting of marine resources, and agro/industry. The second explores the different property systems: traditional customary marine tenure and state owned and regulated, and resource management institutions in place: traditional management system, common access, private ownership, and protected area. The third investigates externalities, sewage, anchor damage, coastal development, destructive fishing, inputs and outputs from mariculture, industrial pollutants, sedimentation and manure, fertilizers, and petro-chemicals, associated with development of each market sector on the four island case studies: Aitutaki, Cook Islands, Rarotonga, Cook Islands, Ovalau, Fiji, and Vatulele, Fiji.

This chapter will first define and explain the phenomena of the commodification of the reef and explain the systems of classification used to analyze each island. Second, each island will be described with the available data and will be classified based upon a ranking system. The availability of descriptive data, secondary sources, interviews, and observations, varies from island to island. However, all of the categories chosen to categorize and rank are based upon my observations and interviews with local people.

The purpose of categorizing and ranking the sites is to create a framework to compare sites and islands and show in Chapter 4 the correlations with reef health and the human geographic variables outlined in this chapter. Other studies have looked at macro factors as a proxy for coral health (as discussed in Chapter 5), but fail to use current data to examine every site. They look at point-source factors, while this studying looks at point-source and non-point source influencing variables (Bryant, 1998).

The final point made in this chapter is to show that there is a correlation between market intensity, property regimes, and externalities. I will argue in the conclusion of this chapter that the property system and/or level and intensity of market development will be a proxy for the type and quantity of externalities that influence the reef.

I categorize the commodification of the reef in terms of direct and indirect exchange value. Examples of direct value can be tourism, subsistence, and fisheries. Indirect value would incorporate agro/industry and the outputs by industrial activity. Tourism, harvesting of marine resources, and agro/industrialization are the three market sectors I will be examining. These three markets sectors will be qualitatively and quantitatively described for each island case study in this chapter. In the chart below I have listed the levels of market intensity, the different types of property and resource management institutions as well as the externalities associated with each market. Within each market sector I first will look at the intensity of market development and then the following two variables, marine property regimes and externalities, which are consequences generated by the intensity of market development. Next, I will analyze the social institutions surrounding property and resource management for all of the market sectors. Finally, to assess the transformation and changes in the environment, I look at the externalities associated with each sector. This set of variables (market intensity, property and resource management institutions, and externalities) that I have selected to examine the relationship between reef degradation and commodification of the coral reef and changes in property and resource management regimes will combine empirical data with qualitative data discussing the historical - environment - development relationships. Before I discuss my specific case studies, I will first generally discuss commodification and values of coral reefs.

Table 3.1: Forms of Commodification of the Coral Reef

Variables	Marine Tourism (Direct)	Harvesting Marine Resources (Direct)	Agro/Industrialization (Indirect)
Level of Market Development/Intensity	- Small Scale Tourism - Mid-size Tourist Industry - Mass Tourism	- Subsistence - Small-scale - Commercial - Aqua/Mariculture Industry	- Small scale - Commercial - Heavy Industry
Property Institutions	<u>Property</u> 1. Traditional Customary Marine Tenure	2. State Owned & Regulated	
Externalities	1. Sewage and waste disposal 2. Anchor damage 3. Coastal Development	1.Destructive, Exploitative Fishing 2. Inputs and Outputs from Mariculture	1. Industrial Pollution 2. Sedimentation 3. Manure, Fertilizers and Petro-chemicals

The Value of Coral Reefs

Coral reefs contain 25 percent of all identified marine life world-wide. Approximately 4,000 species of fish and 800 species of reef-building coral have been described to date (Paulay 1997: 303). Reefs are one of the most biologically diverse ecosystems on the planet. A small reef in Indonesia will house more than 400 species of coral, 700 species of fish, and many thousands of other plants and animals (Wilkinson 1998: iii). But, coral reefs are no longer just thought of as a biological term or habitat. Today they are associated with fisheries, ecosystems utilized by humans for subsistence, cultural activities, or commercial development for industries and tourism. They are important because they contain high biological diversity and abundant economic and ecosystem services for millions of people (Costanza 1997). In the past five years researchers have begun to develop models to place dollar values on ecosystems. I am presenting some of the results of these studies to illustrate this point, even though I may not agree with the actually monetary numbers. One estimate claims that coral reefs provide $375 billion worth of services and resources a year (Costanza 1997). These services include such industries as tourism, new medicines, and other products such as jewelry, as well as biodiversity, coastal protection, and food.

The table below lists the main direct and indirect uses of coral reefs.

Table 3.2: Values of Coral Reef

Type of Value	**View of Current or Future Importance of Coral Reef**
Direct Use – (extractive)	Food and other Resources Pharmaceuticals and other Industrial Chemicals Construction Material
Direct Use Value (non-extractive)	Educational and Scientific Interest Tourism and Recreation
Indirect Values	Biological Support (breeding grounds etc.) Coastal Protection (prevent erosion)
Non-Use Values	Fall-back life support (during agricultural crisis) Genetic Resources Global Heritage and Sacred Sites Unknown future functions

(Cesar 1996: 13)

Extractive direct uses include harvesting the reef for food and other marine resources as well as for pharmaceutical products and industrial chemicals. Coral reefs in developing countries provide one-quarter of the total world fish catch, and, for example, produce food for one billion people in Asia alone (Hinrichsen 1997; Jameson 1995). Ninety percent of Pacific Islanders get their protein from the sea by collecting trochus, bêche-de-mer, and other fruits of the sea as well as catching fish. According to the World Bank, because of poorly managed coral reefs, Indonesia loses more than ten million dollars a year in declining productivity, fishing, and coastal protection (Cesar 1996). The World Bank estimates that through careful management these reefs could support a $320 million dollar industry employing 10,000 fishers (Cesar 1996). But, it does not stop there. According to Cesar, the cost of destroying or mismanaging 1 kilometer of reef ranges from about $137,000 to $1.2 million over a twenty-five year period when considering just tourism, fisheries, and protection value of reefs (Cesar 1996). This does not include the value coral reefs provide for biotechnology, the $4 billion annual aquarium industry, the jewelry which was valued at $500 million in 1981 or even coral mining for construction which is popular in Sri Lanka and India for building material (Green and Hendry 1999; Weber 1993)

The United States is the largest importer of coral because of the demand by the aquarium and biotechnology industries (Cesar 1996). American researchers have been using coral for clinical trails for bone graphs and from 1991 to 1992 imports of coral increased 500 percent (Green and Shirley 1999). Since 1995, coral exports from Fiji, Mozambique, Taiwan, and Tonga have steadily increased. Sixty-four other nations also export live and dead coral (Cesar 1996). In 1996, coral exports listed in the Convention on International Trade of Endangered Species (CITES) Trade Database consisted of more than 2.5 million pieces of live coral, 670,000 kg of coral, and 31,000 colonies of black coral from 114 genera and 181 identified species (Bureau of Oceans and International

Environmental and Scientific Affairs U.S. Department of State October 19, 1998). Exports totaled 420,000 pieces in 1993. The total value of this ornamental trade is unknown (Cesar 1996).

Extractable direct use of coral such as collecting, mining and dredging all heavily affect the reef ecosystem. Sites where coral mining took place 10 or more years ago show slow if any recovery or the reef and a collapse of the fishery (Cesar 1996). There are other impacts of mining, such as sand erosion, land retreat, and sedimentation that can greatly affect in turn the Tourist industry because the coral protects and builds the gorgeous white sandy beaches (Cesar 1996).

Tourism, education and research are examples of non-extractive direct use of the coral reef. Tourism is a large source of income for countries with coral reefs. It is the fourth largest growing industry in the world, and tourism in areas with coral reefs have the opportunity and potential to develop and sustain the tourist industry. This is especially relevant in developing countries.

> Worldwide, coastal tourism is the largest sector of the $250 – billion tourism industry (Weber 1993).

It brings in annually $1.6 billion in Florida alone, and is an $8.9 billion industry in the entire Caribbean (Birkeland 1997). Hawaii claims tourism revenue brings in $8.6 million per square mile of coral reef, and a mere $800 million a year for Australia (Bureau of Oceans and International Environmental and Scientific Affairs U.S. Department of State October 19, 1998; Weber 1993: 124). This is big money and often comprises a large percentage of the countries' GNP.

Indirect values are primarily constituted of ecosystem services. This includes coastal protection and breeding grounds. In addition, there are numerous non-use values of coral, which I cannot even place a numerical value upon. These uses include future functions and potential of the reef, genetic resources, cultural heritage and potential resources in a crisis situation.

Coral reefs are intimately related to ethics, religion, social, and economic values in societies. The use value of coral reefs can have direct value such as tourism, subsistence, and fisheries, indirect value would incorporate ecosystem functions, and future value (Costanza 1997: 253). Non-use value is the value to conserve and protect coral reefs from any sort of utilization. This can be justified through arguments such as 1) bequest value, which is the need to protect biodiversity for our children and their children; 2) existence value, the concept that I want to protect species for their survival; and, 3) option value, is insurance against the future and the unknown (Jeffries 1997: 139). The differences in valuation of coral reefs by different peoples effects how one use and conserve them. Conservation and protection of the reef will be discussed further in Chapter 6 and 7.

Assessing Case Studies

The four island case studies are categorized according to their level of reef commodification, the property institution they have in place, and the externalities associated with each market sector of commodification. In the next section of this chapter, I will discuss the present and recent past of each sector of island development, as well as present a description of present property institutions in place, and the externalities associated with each market sector. I will present charts ranking each island and each study site within the island on these categories.

Each island is categorized by being either a high island or a low island. In addition, the island sites are separated into having a fringing and barrier reef. Commodification of the reef and the island sectors of marine tourism, harvesting and agro/industry are broken down into three levels. Furthermore, each category has a different level of intensity, which is determined by the following standards and when doing my analysis will be associated with a number on a scale of 1-3 for tourism, 1-4 for harvesting marine resources and 1-4 for agro/industry:

Table 3.3: Levels of Market Development

Market Sector	Level of Market Development/Intensity
Marine Tourism	1- Small Scale Tourism is fewer than 50 tourists a day 2 - Mid-size Tourist Industry more than 50 and fewer than 1000 tourists a day 3 - Mass Tourism more than 1000 tourists a day
Harvesting Marine Resources	1- Subsistence fishing and collecting 2- Small-scale commercial fishing for local markets 3- Commercial fishing for export 4- Aqua/Mariculture Industry
Agro/Industrialization	1- Subsistence Agriculture 2- Small scale commercial sector selling at local markets 3- Commercial agriculture for export 4- Heavy Industry

The next category that each island and site will be categorized under is the property and resources management institutions presently in place. They will first be classified as either having government control over the area or traditional control. Then within each category there are four subcategories, which describe the different ways that property can be categorized on these islands. Some islands and sites have more than one of the following systems in place. Each type of property institution listed below has a system has a different relationship and set of rules between the resources and the users. Traditional management systems are governed by the local people, and social norms and pressures control the management of the area. Common access means that there are no restrictions or regulations on who can access the waters. The waters are open to all. In other instances the waters have become privatized. For example, in Fiji communities can sell rights to companies in the tourist industry or fishing industry to access their territories and governments sell rights to fish in their Exclusive Economic Zones (EEZ). Furthermore, access in both the commons and in private areas can be competitive. In the commons users compete to be the first in the area to utilize or access the resources in the area. In the private areas users compete to purchase rights to the waters and marine resources. This can be seen in the tourist and fishing sectors where there is competition to access a special site known for diving or fishing. The fourth category documents whether or not the area is a protected area. This could be a government, community, or environmental non-governmental organization (ENGO) such as the World Wildlife Fund, an initiative or organization that is involved with the management of the marine area.

Table 3.4: Property Institutions

Property Institution	Governance of Marine Resources
1. Traditional Customary Marine Tenure	1. Traditional Management System
2. State Owned & Regulated	2. Common Access
	3. Privatization
	4. Protected Area

Externalities are associated with each sector and based upon data collected and observations. I will assess each study site and rank the intensity of the externality.

Table 3.5: Externalities

Market Sector	Externalities
Marine Tourism	1. Sewage and waste disposal 2. Anchor damage 3. Coastal Development
Harvesting Marine Resources	1. Destructive/Exploitative Fishing 2. Inputs and Outputs from Mariculutre
Agro/Industrialization	1. Industrial Pollution 2. Sedimentation 3. Manure, Fertilizers and Petro-chemicals

Each externality has a level of intensity on a scale that is described in the chart below.

Table 3.6: Site Analysis for Externalities and the Scale of Intensity

Externality	The Meaning of 0-3 Scale - with 3 being the highest
Sewage and waste disposal	0. no hotels 1. within 3 kilometer area fewer than 35 rooms [20] 2. within 3 kilometer between 35 – 200 rooms 3. within 3 kilometer more than 200 rooms
Anchor damage	0. no tourist water-based tours 1. fewer than 20 people taking watertours or renting boats daily [21] 2. between 20- 50 people taking watertours or renting boats daily 3. more than 50 people taking watertours or renting boats daily
Coastal Development	0. no hotels within 1 kilometer 1. within 1 kilometer area less than 5 hotels 2. within 1 kilometer between 5 – 10 hotels 3. within 1 kilometer more than 10 hotels

[20] Rooms were used to determine intensity of the externality since the size of hotels can vary so much.

[21] Which is worse, bigger boats with more people, or more, smaller boats with fewer people? Both scenarios, have impacts – bigger boats have bigger anchors, but the boat holds more people and therefore there could be fewer boats on the water. The other scenario is smaller boats with smaller anchors, but potentially more boats on the water. I decided to base it on the number of people rather than type of boat.

Destructive/Exploitative Fishing	0. no fishing 1- Subsistence fishing and collecting 2- Small-scale commercial fishing for local markets 3- Commercial fishing for export
Inputs and Outputs from Mariculture	0. no mariculture 1. within 3 kilometer area, less than 3 mariculture farms [22] 2. within 3 kilometer area between 3-5 mariculture farms 3. within 3 kilometer area more than 10 mariculture farms
Industrial Pollution	0. no industry 1. industrial effluent in the past within 3 kilometers 2. industrial effluent within 10 kilometer 3. industrial effluent within 3 kilometer
Sedimentation	Stream within 3 kilometers has runoff from: 0. no streams within 3 kilometers 1. subsistence agriculture 2. small scale agriculture 3. commercial agriculture
Manure, Fertilizers and Petro-chemicals	Stream within 3 kilometers has runoff from: 0. no stream within 3 kilometers 1. subsistence agriculture 2. small scale agriculture 3. commercial agriculture

Within each island study site, I have categorized localized market sectors, as well as different intra-island property regimes, as well as point-source externalities. This analysis will lead to insight on the management and practices of the island. Correlation with all of these different practices, market development, property institutions, and externalities with reef health will be assessed in Chapter 4.

Commodification of the Reef: Aitutaki, Cook Islands

Direct Value of the Reefs: Tourism and Harvesting of Reef Marine Resources

> Tourism is [the] backbone of this island's economy (Aitutaki Interview #1).

The Cook Islands have a mid-sized tourist industry, which has increased in the 1990s when compared with the number of visitors in the 1980s. Peaking in 1994, The

[22] Distances and the scale changes chosen to compare the externalities and the level of intensity are based upon my experience.

Cook Islands had 57,321 tourists, and the government is actively trying to encourage major airlines to route tourists through Rarotonga (see chart below). The gross annual turnover by hotels and motels in 1981 was NZ $3,961,000 and in 1998 NZ $47,768,0000 (Cook Islands Statistics Office 1999). The changes in the number of tourists reflects the termination and development of major airline service to Rarotonga from United States and Canada (Asian Development Bank 1996). Of the tourists landing in Rarotonga, approximately 18,000 visit Aitutaki each year according to the Ministry of Marine Resources (Aitutaki Interview #2). As of July 1999, Aitutaki had one hotel, five self-catering lodges, and seven hostels/ budget rooms (Cook Islands Statistics Office 1999). Most of these establishments have emerged in the past ten years, along with tour operators taking tourists to snorkel and dive around the reefs of the vast lagoon.

Table 3.7: Total number of Arrivals to the Cook Islands 1988-1999

1988	33,886
1989	32,907
1990	34,218
1991	39,984
1992	50,009
1993	52,868
1994	57,321
1995	48,500
1996	48,819
1997	49,964
1998	48,629

(Cook Islands Statistics Office 1999)

The harvesting of marine resources has developed significantly in the past few decades. The commodification of marine resources is happening at all market levels. Locals fish for subsistence, there is a small-scale fishery and there is a commercial and mariculture industry that has developed in the past two decades. According to the Cook Island Statistics Bulletin, in 1988 out of approximately 2,300 people living on Aitutaki 781 fish with a rod, 310 with a speargun, and 419 with a net (see chart below). Furthermore, 169 people have outboard motors and can easily access remote reef areas (see chart below). Most of this local fishing activity is inside the

Table 3.8: Aitutaki Fishing Equipment

Speargun	Canoe	Boat	Fishing Net	Fishing Rod	Outboard Motor
310	179	141	419	781	169

(Turva 1988)

reef primarily for subsistence (see table below). There are forty commercial fishers on the island (see table below).

Table 3.9: Private Occupied Dwellings in Aitutaki Engaged in Fishing Activities

	Fishing Activity			Dwelling Engaged in Fishing Activity		
Total # of Dwellings	Subsistence	Commercial	No activity	In Reef	Outside Reef	Both Inside & Outside
496	369	40	87	144	4	261

(Turva 1988)

Many different species of marine organism are harvested on Aitutaki. *Tridacna maxima* is a major collecting and commercial industry on the island, as well as some exploitation of *Caulerpa sp*. and *Turbo setosus* (Sims 1985). Fishermen trap the crab *Scylla serrata* and banded stomatopod *Lysiosquilla maculata* in the muddy parts of the lagoon. *Trochus niloticus* was first introduced in 1957 from Fiji and was well established (Miller 1980), although, the first commercial harvest was not until 1981 (Sims 1985). *Trochus* are a source of mother-of-pearl for the manufacturing of buttons and wood inlays and seen by the Aitutaki Island Council as an export fishery. Furthermore, they provide a significant source of income in many parts of the Pacific and are not considered food by the local community. Under the supervision and regulation of the Ministry of Marine Resources and Island Council, the *trochus* fishery has had seven official harvests since 1981. Other experiments in mariculture are happening in the lagoon such as the growing of seaweed (Syed and Mataio 1993). Another species has been introduced into the lagoon in Aitutaki. The Ministry of Marine Resources is presently trying to establish a clam hatchery to re-stock the lagoon. The baby clams are imported from Australia (Aitutaki, Interview #2).

Indirect Commodification of the Reef: Agro-industry

Banana, coffee, vanilla, root-crops, and vegetables were the main export crops. Aitutaki produced regular shipments of bananas that totaled 7000 cases produced from a mere 500 acres of intensive cultivation, using insecticides, herbicides, and fungicides (Mowbray et al. 1988). Fifty-seven dwellings were commercial farmers (see chart below) producing mostly bananas. Rarotonga and Aitutaki are the two islands that grow bananas in the Cook Islands. There are 58,452 acres of land in the Cook Islands and 16,509 acres are in Rarotonga and 4,519 acres in Aitutaki. Of the 4,519 acres in Aitutaki 2,292 are suitable for the growing of cash crops. In 1970 the Cook Islands produced

511.0 tons of bananas and in 1971 production peaked at 4,042.4 tons[23] (Syed and Mataio 1993). From the mid-70s to late 80s the present banana production slowed dramatically, and tourist revenue has increased.


Picture 3.1: Coconuts in Aitutaki

Table 3.10: Private Occupied Dwellings by Island and Agricultural Activity in Aitutaki

Total # of Dwellings	Subsistence	Commercial	No Agricultural Activity
496	332	57	107

(Turva 1988)

Based on the ranking system described on page 7 I have classified each site according to the parameters.

Table 3.11: Aitutaki Market Development Classification

	Island & Reef Type	Tourism	Harvesting	Agro/Industry
Aitutaki Island Classification	Almost Atoll	2	4	4
Aitutaki Site 1	Fringing	1	3	1
Aitutaki Site 2	Barrier	1	4	4
Aitutaki Site 3	Fringing	2	3	4
Aitutaki Site 4	Barrier	1	3	4
Aitutaki Site 5	Barrier	1	3	4

[23] Since there are no data on agriculture production in Aitutaki, I will present some country data. I am going to assume that Aituaki followed the same production trends as the entire country.

Marine Property and Resource Management Institutions

As of 1999 there were no traditional resource management systems currently in place.[24] Although all foreshores and soils under the water are owned by the crown, access to the waters for fishing and harvesting is open. Fishing quotas are regulated by the local government. In the past, the Ra'ui [25] were used to manage fish stocks, but they are not used on Aitutaki any longer. The Ministry of Marine Resources does not patrol inside the lagoon, but focuses instead on the high seas and protecting their Exclusive Economic Zones (EEZ). Such countries as Korea, Taiwan, United States and Japan have bought rights to fish in the Cook Island's EEZ as well as other Pacific Island states (Aitutaki, Interview #2); (Syed and Mataio 1993).

Cook Islanders are not supposed to use gill nets or fish for certain species such as *Trochus* but there is little enforcement of these laws on Aitutaki. Trochus quotas are in place as based upon stock assessment surveys.

Table 3.12: Aitutaki Property Institutions

Study Site	Property Institution
Aitutaki Site 1	Government -Common access
Aitutaki Site 2	Government -Common access
Aitutaki Site 3	Government -Common access
Aitutaki Site 4	Government -Common access
Aitutaki Site 5	Government -Common access

[24] The Ra'ui system has been implemented in Aitutaki in three different sections of the reef. This started in January 2000.
[25] The Ra'ui is a traditional no-take zone at land and at sea.

Externalities from the different market sectors

> I grew up here and left 25 years and now I am back…Banana plantations were in the middle of the island and they used manure and petrochemicals and fertilizers. No rivers just swamps and agricultural runoff which leaks and leaches into the lagoon from the swamps (Aitutaki, Interview #3).

Externalities from Tourism: Sewage is a major concern, especially septic tank leaching that runs along the shoreline. Anchor damage from tourism boat operators is a problem because no mooring buoys are present. The central lagoon had extensive dynamiting during the early 1950s when it served as a flying-boat landing strip (Wells and Jenkins 1988). There has also been occasional blasting and dredging at Arutanga, Papua for canoe passages (Wells and Jenkins 1988).

Externalities from Harvesting: There has been continual exploitative fishing and overfishing in the lagoon.

Externalities from Agriculture/Industry: Pesticides and fertilizers have leached into the reef. The misuse of biocides and fertilizers in the past and the present is a big concern, but little is known, as there are no regular monitoring systems established (Thistlethwait and Votaw 1992). In 1980, South Pacific Regional Environment Programme (SPREP) reported that the chemical dip used in the banana packaging is potential an extremely serious threat, as it was discharged into the lagoon (South Pacific Commission et al. 1981). In a report written in 1971 by Summerhayes the lagoon was thought to be silting up (Wells and Jenkins 1988). The analysis of each site's externalities is listed in the chart below based on the ranking system described on page 10. This will be done for each island.

Table 3.13: Aitutaki Externalities

Study Site	Tourism Externalities	Harvesting Externalities	Agro-Industry Externalities	Total
Aitutaki Site 1	Sewage - 1 Anchor - 1 Dev. - 1	Destructive -3 Mariculture inputs/outputs-3	Sedimentation - 1 Fertilizer - 1 Industrial Pollution - 0	11
Aitutaki Site 2	Sewage - 1 Anchor - 2 Dev. - 1	Destructive -3 Mariculture inputs/outputs 3	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 0	16
Aitutaki Site 3	Sewage - 2 Anchor - 1 Dev. - 1	Destructive -3 Mariculture inputs/outputs -3	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 1	17
Aitutaki Site 4	Sewage - 0 Anchor - 2 Dev. - 1	Destructive -3 Mariculture inputs/outputs -3	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 1	16
Aitutaki Site 5	Sewage - 0 Anchor - 2 Dev. - 1	Destructive –3 Mariculture inputs/outputs -3	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 1	16

Commodification of the Reef: Rarotonga, The Cook Islands

Direct Value of the Reefs: Tourism and Harvesting of Reef Marine Resources

Tourism in Rarotonga started more than twenty five years ago when the Rarotongan Hotel was built (Rarotonga, Interview #9). Shortly after, a few other resorts opened and then the first youth hostel (Rarotonga, Interview #9). By the late 1980s, tourism really started to grow and by the 1990s was booming (Rarotonga, Interview #9). The number of visitors in 1988 was 33,886 and by 1998 grew to 48,629 (Cook Islands Statistics Office 1999). Ngatangiia Harbour and Muri Lagoon are extensively used by tourists as the main center of accommodation as well as for water sports. As of July 1999 Rarotonga had seven hotels, nineteen self-catering lodges, and fifteen hostels/ budget rooms (Cook Islands Statistics Office 1999).

Artisanal, subsistance, as well as commercial fishing are important on the island. Fish traps are used around the island as well as a variety of other fishing techniques (see chart below). More than half of the population fishes for subsistence and there is a commercial

Table 3.14: Rarotonga Fishing Equipment

Speargun	Canoe	Boat	Fishing Net	Fishing Rod	Outboard Motor
760	145	190	760	1,659	196

(Turva 1988)

fishing industry and a medium scale live fish trade for fish collectors, as well as mariculture experiments around the island (Rarotonga, Interview #9). The live fish trade began in 1988 and is based in Rarotonga (Wood 2001). There is one company that employs six full-time employees and three part-time employees (Wood 2001). Export annually started in 1989 as 10,000 fish and rose to 20,000 by 1994 (Wood 2001). Thirty-five species are collected for the acquaria trade (Wood 2001).

Table 3.15: Private Occupied Dwellings in Rarotonga Engaged in Fishing Activities

	Fishing Activity			Dwelling Engaged in Fishing Activity		
Total # of Dwellings	Subsistence	Commercial	No activity	In Reef	Outside Reef	Both Inside & Outside
2,569	1,459	65	1,045	722	87	715

(Turva 1988)

Ngatangi Harbor housed two experiments with growth trials of the green mussel *Perna viridis* in 1985 as well as commercial bivalve production (Sims 1985; Wells and Jenkins 1988).

Indirect Commodification of the Reef: Agro-industry

Many Cook Islanders still practice subsistence agriculture and a small percentage of the population are involved in commercial agricultural ventures (see table 3.16 below).

Table 3.16: Private Occupied Dwellings by Island and Agricultural Activity in Rarotonga

Total # of Dwellings	Subsistence	Commercial	No Agricultural Activity
2,569	1,407	144	1,018

(Turva 1988)

> Before the 1970s we grew citrus such as oranges, lemons, bananas, some tomatoes. There was a juicing and canning factory, but we slowed down because New Zealand started importing from Brazil, which was cheaper (Rarotonga, Interview #10).

Agricultural exports have fallen significantly in the past few decades on Rarotonga with the four main crops of orange-citrus, bananas, pineapples, and copra (Syed and Mataio 1993). Rarotonga and the Cook Islands cannot compete to export any crop or product in the large to medium agro-processing industry (Syed and Mataio 1993). The Ministry of Agriculture has decided to focus on more exclusive, "high-end crops such as eggplant, paw paws, chili, and mangoes" (Rarotonga, Interview #10). The export of these non-traditional crops has gradually increased. This is highlighted in the table 3.17, which documents acreage for crops in 1975 and 1988. Citrus and banana have dramatically decreased the amount of land being used for cultivation and paw paw and taro has increased as well ad the other high end crops. These non-traditional crops are more profitable and have the potential to create a domestic market and sustainable agriculture.

Table 3.17: Rarotongan Land Under Selected Crops, 1975 and 1988 (in acres)

Crop	1975	1988	% Change
Taro	142.11	256.00	80.14
Citrus (Orange)	459.17	352.00	-23.34
Banana	269.54	108.30	-59.82
Coconut	400.96	445.40	11.08
Kumara	85.92	91.50	6.49
Tarua	49.56	45.38	-8.60
Tomato	24.57	31.60	28.61
Water-melon	30.95	28.00	-6.95
Paw-Paw	22.00	173.60	689.09
Total area of holdings	2,391.00	2,099.00	-12.21
Number of holdings	1,055.00	965.00	-8.53

(Syed and Mataio 1993)

In summary, Rarotonga is one of the more developed islands in the South Pacific. The tourist industry has slowly replaced the agro/industry, and the fishing sector inside and outside the lagoon continues to increase productivity. The chart below shows the classification of the island development for each study site based upon the criteria on page 7.

Table 3.18: Rarotonga Market Development Classification

	Island & Reef Type	Marine Tourism	Marine Harvesting	Agro/Industry
Rarotonga Island Classification	High Island	3	4	4
Rarotonga Site 1	Fringing	2	1	4
Rarotonga Site 2	Fringing	2	3	4
Rarotonga Site 3	Fringing	3	1	3
Rarotonga Site 4	Fringing	3	3	3
Rarotonga Site 5	Barrier	3	4	3
Rarotonga Site 6	Fringing	2	1	3

Marine Property and Resource Management Institutions

Rarotonga has similar laws and policies governing its marine resources as Aitutaki. There is one primary difference between the two islands; in the past three years a traditional system of management has emerged. The re-implementation of a traditional no-fishing zone, called a Ra'ui, by communities and supported by the Cook Island Government has been in place around the island. These demarcated zones protect the lagoon environment from fishing and collecting. These sites are routinely moved around the islands and are also opened and closed for set periods of time (for more information see chapter 5, The Re-implementation of the Ra'ui).

Table 3.19: Rarotonga Property Institutions

Study Sites	Property
Rarotonga Site 1	Government -Traditional Management System -Protected Area
Rarotonga Site 2	Government -Common Access
Rarotonga Site 3	Government -Traditional Management System -Protected Area
Rarotonga Site 4	Government -Common Access
Rarotonga Site 5	Government -Common Access
Rarotonga Site 6	Government -Traditional Management System -Protected Area

Externalities from the different market sectors

> Thirty-two years ago when I arrived the lagoon was very much alive. The coral [was] alive, fish [were] inshore, shellfish, and now it is all gone. This has been a gradual decline and the lagoon is degraded. This affects the sediments because not as much organic material is being produced. Primarily this shift is reducing production and increasing coastal erosion (Rarotonga, Interview #11).

Many factors have contributed to the decline in the Rarotongan lagoon and fringing reef. This includes heavy industry effluent from a juice cannery, intensive agriculture, and tourist development.

Externalities from Tourism: The increase in the number of visitors creates garbage and sewage as well as more tourist and anchor damage to the reef. Waste disposal is one of the primary externalities produced by tourism on Rarotonga. Hutchinson calculated that tourists generate 50 percent more waste per person than an islander (Hutchinson 1996). As of 1996, Rarotonga had an estimated 2,000 septic systems and two unlined landfills (Hutchinson 1996). One land-fill is adjacent to the airport on the northern coast, and the other is near Matavera on the east coast. Regulations on waste disposal on Rarotonga have become stricter. For example, all septic systems must be closed systems and must be placed at least thirty meters away from the high water mark on the coastline and five meters from a stream. This has not helped enough. The island sands are extremely permeable:

> due to high high permeability (estimated at 1x10-3 m/s) and transmissivity of the Aroa Sands, septic waste travels rapidly to the lagoon where it is discharged. Breakouts of raw sewage were observed at numerous locations around the island and indicate that this point-source of pollution is ubiquitous. The water carried in the reticulated network has tested

> positive for the presence of *E. coli* in concentrations just <u>above</u> the World health Organization standards (Hutchinson 1996).

The stream by Papua Passage has "a lot of sediment from the Sheraton building a $30 million dollar project" (Rarotonga, Interview #5). "The stream by the airport has numerous leaking systems feeding into it. The sewage enviro-flow system overflows …now leaking and going into the stream" (Rarotonga, Interview #5).

Coastal development from tourism creates sediment and coastal erosion. Coastal erosion is a big concern around the densely populated northern and western coasts of Rarotonga. An erosion and inundation scheme has been suggested by the local people to protect the coastline. Concrete coastal protection units have been established in front of the Rarotongan Hotel. It has been recorded that 1200 cubic meters of sand was trapped in three months. These open-ended permeable traps could be established around the island (Sem et al. 1992). There has been extensive dredging in the harbor north of the Avana Stream mouth in order to allow docking of large ships.

Externalities from Harvesting: *Ora*,[26] which contains rotenone in the root, was used by the Cooks to stupefy fish. According to one community leader, "in the 1950s, 1960s, and 1970s *ora* caused a lot of damage and the 1980s nothing was in the lagoon." People do not fish with *ora* anymore (Rarotonga, Interview #12). Recently, Ciguatera has really slowed down the number of fish people are able to collect in the lagoon (see Chapter 5). The health risk that Ciguatera imposed upon the local people allowed the community to re-stock fish by putting the Ra'ui system in place.

Externalities from Agriculture/Industry:

> In the old days, there was a pineapple and orange juice pipeline. The sea was orange from the grind of the rind (Rarotonga, Interview #9).
>
> Today, pigs are not tied on trees. Now [they are] on concrete and [the] manure goes right down the drain to the sea. Plus there are more pigs (Rarotonga, Interview #10).

In the 1970s the Ministry of Agriculture promoted the use of fertilizers and pesticides, and now they have more variety. Furthermore there has been "lots of erosion especially with pineapple." (Rarotonga, Interview #10). According to the Department of Conservation and the Environment "agricultural activities are really minimal now" (Rarotonga, Interview #5). In the 1970s the juice cannery's effluent flowed into the Avatiu River. There are now only two main streams that are polluted from agro/industry. This is Avana Stream from the piggeries and the stream by the Ministry of Agriculture, which tends to experiment with different petro-chemicals (Rarotonga, Interview #10). Finally the Quarry on the north-west side of the island also emits some effluents. A detailed analysis of the study site's externalities is documented in the chart below.

Table 3.20: Rarotonga Externalities

Study Site	Tourism Externalities	Harvesting Externalities	Agro-Industry Externalities	Total
Rarotonga Site 1	Sewage - 0 Anchor - 1 Dev. - 0	Destructive - 0 Mariculture inputs/outputs- 0	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 3	10
Rarotonga Site 2	Sewage - 0 Anchor - 1 Dev. - 0	Destructive - 2 Mariculture inputs/outputs- 0	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 3	12
Rarotonga Site 3	Sewage - 2 Anchor - 2 Dev. - 2	Destructive -0 Mariculture inputs/outputs -0	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 0	12
Rarotonga Site 4	Sewage - 2 Anchor - 2 Dev. - 2	Destructive - 2 Mariculture inputs/outputs - 0	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 0	14
Rarotonga Site 5	Sewage - 3 Anchor - 3 Dev. - 3	Destructive – 2 Mariculture inputs/outputs - 1	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 0	18
Rarotonga Site 6	Sewage - 1	Destructive – 0	Sedimentation - 3	8

[26] *Derris* spp. is found in the Cook Islands (Rarotonga, Interview #12).

	Anchor - 1 Dev. - 0	Mariculture inputs/outputs - 0	Fertilizer - 3 Industrial Pollution - 0	

Commodification of the Reef: Ovalau, Fiji

Direct Value of the Reefs: Tourism and Harvesting of Reef Marine Resources

Bars and hotels were built more than 140 years ago to house the merchants, traders, whalers, sailors, and sandalwood dealers. The capital of Fiji was moved to Suva in 1881 and the population and activity immediately slowed down. Today there are four hotels for guests to stay in Ovalau. Three of them are in Levuka town, and one is in Rukuruku Bay. Four restaurants, a tour operator, as well as one dive operator to support the mid-size tourist industry.

Subsistence fishing is a way of life for the local people living around Ovalau, as is the commercial exploitation of marine resoures.

> People work the reef flats at low tide, [to collect organisms like] trochus shell. Ten years ago [there were] tons of sea slugs [and] bêche de mer. [An organism] locals call "gris," they cannot find them in the same amount of abundance. (Ovalau, Interview #2).

Picture 3.2: A woman fisher catching goatfish, outside of Levuka

Locals are allowed to fish for subsistence. In the evening they try to catch skipjack tuna, mahi mahi, yellowfin tuna, big eye tuna, black marlin, sail fish, sword fish, and albacore (Ovalau, Interview #3). Women fish for small reef fish, primarily goat fish, as well as do most of the collecting (Ovalau, Interview #3). But, there are "more fishermen and more fishing techniques" (Ovalau, Interview #12). People line fish, surprise fish with nets, use spearguns, and other equipment as well as boats. When fishing for commercial purposes the government requires people to obtain a license. Locals have and still do sell trochus, triton, and bêche de mer. Approximately "ten-tweny slugs gets you $20F – good money" (Ovalau, Interview #10). Nineteen people have licenses to fish commercially around the reefs of the island (Ovalau, Interview #2). But, "people sneak in and no warden at night, no boat, no way to enforce the law." (Ovalau, Interview #2).

According to two locals there use to be a pearl button industry in Levuka (Ovalau, Interview #5). The main factory on Ovalau was shut down in the early 1900s, but "once a month at low tide for two-three days villages collect shells for buttons factory. This is big money for the villages" (Ovalau, Interview #8).

Coral and aquarium fish is another marine industry on the island of Ovalau. This industry developed as early as 1965 in coastal villages to exploit reef-building organisms to construct sea wall and make ornaments. The first commercial exploitation of hard corals for export was in 1985 (Viala 1988). This large scale commercial fishery exported from all of the Fijian Islands in 1985 40,000 fish, and by 1997, it is estimated to have doubled (Wood 2001). In addition, the exporting of live coral has also been growing (Wood 2001). A report for the South Pacific Commission, stated that collecting activity for coral was confined to Ovalau, the east coast of Viti Levu and the Bau waters. Ocean

2000 Limited stated in 1997 that it collects live coral and fish around Ovalau, as well as other sites in Fiji: "Collection of live products is not performed by Ocean 2000 but by the people who own the fishing grounds" (South 1997: 30).

Indirect Commodification of the Reef: Agro-industry

Levuka is the center of deep-sea fishing since the completion of an industrial tuna factory in 1964. In the 1960s, foreign vessels owned by the Japanese and South Koreans fished the waters within 1,000 mile radius of Fiji. The factory stored albacore tuna, yellow-fin tuna, big-eye tuna, and other pelagic fish. In 1969 the Pacific Fishing Company (PAFCO) canned approximately 1,650 to 1,800 cans a day of tuna, and the factory also produces fish meal for stock feed (Kerr and Donnelly 1969). PAFCO is still operating and is the main company in Fiji exporting fresh and chilled fish. The industrial tuna cannery is composed of pole and line fishery, longshore fishery, and a purseine fishery. The pole and line fishery consists of nine pole and line vessels, seven of which are locally owned and operated. There are twenty foreign and forty-eight domestic long-line vessels and occasionally foreign purseiners unload at PAFCO (Ministry of Agriculture Fisheries and Forests 1995). All of the fishing takes place primarily offshore and in the EEZ of Fiji. According to data provided by the Ministry of Agriculture Fisheries and Forests, in 1995 PAFCO received 14,000 metric tons of fish and imported tuna from Solomon, Kiribati, and New Zealand and expected a total of 1520 tons of frozen fish valued at $3.48 million (Ministry of Agriculture Fisheries and Forests 1995). Canned tuna exports in 1995 by PAFCO are estimated at $34 million from 920,000 cartons and contributed 51 percent of the total export revenues from all fish and marine products in Fiji (Ministry of Agriculture Fisheries and Forests 1995). Five hundred and thrity tons of fishmeal was also produced at a value of $275,000 in 1995 (Ministry of Agriculture Fisheries and Forests 1995).

Picture 3.3: PAFCO dumping garbage on the reef. They are supposed to dump three miles from the land, but were less than a mile from the island.

The fertile volcanic soil and three main rivers in Ovalau have made a number of cash crops very successful on the island. Intensive agriculture around Ovalau began with cotton in the 1800s and has continued until the present. In addition, sugar-cane, kava, pineapple, cotton and taro are commercially grown crops. People use fertilizers, weed killer and pesticides (Ovalau, Interview #6).

Table 3.21: Ovalau Market Development Classification

Study Site	Island & Reef Type	Tourism	Harvesting	Agro/ Industry
Ovalau Island Classification	High Island	1	3	4
Ovalau Site 6	Barrier	1	3	4
Ovalau Site 7	Barrier	1	3	3
Ovalau Site 8	Barrier	1	3	4
Ovalau Site 9	Barrier	1	3	4
Ovalau Site 10	Barrier	1	3	3

Marine Property and Resource Management Institutions

Villages own, manage, and sell rights to their reefs. The communities each have designated reefs and fishing areas, but Levuka Harbor is operated by the Port Authority. Over half of the island has marine tenure and the town of Levuka does not. According to the OHD Act, the Port Authority is responsible for pollution in the harbor (Ovalau, Interview #5). They have authority from the Toki entrance to Naululu Entrance (Ovalau, Interview #5).

It is illegal to use *duva* and so is the catching of sea turtles. *Duva* [27], which contains rotenone in the root, is used by the Fijians to stupefy fish. The villagers abide by these laws and do not access reefs during certain community events as well as when it is bad weather (Ovalau, Interview #8).

Table 3.22: Ovalau Property Institutions

Study Site	Property
Ovalau Site 6	Government -Common Access
Ovalau Site 7	Traditional -Privitization and access is sold
Ovalau Site 8	Government -Common Access
Ovalau Site 9	Government -Common Access
Ovalau Site 10	Traditional -Privitization and access is sold

Externalities from the different market sectors

Externalities from Tourism: Most tourists who visit Ovalau are interested in the cultural heritage. The dive operator goes to the Northern Ovalau reefs and to another

[27] *Duva* is a *Derris* spp. Three species of *Derris* are found in Fiji. *Derris elliptica* was introduced in 1935. *Derris malaccensis* was also introduced and *Derris trifoliate* Parham, J. W. (1972). *Plants of the Fiji Islands*, The Government Printer, Suva, Fiji..

island called Waykaya. People sailing around the Pacific or around Fiji often stop for a few days at the harbor to get new supplies and visit the sites. This mid-size market sector has minimal impacts.

Externalities of Agro/Industry: Ovalau has commercial agriculture and heavy industry on the island. Sedimentation from agriculture runoff on the leeward side of the island has smothered the fringing reefs (Ovalau, Interview #5 and #6). The main town, Levuka, has a large harbor and is home to PAFCO, a tuna cannery, which has an infamous pipe line. The effluent that comes for the pipeline is primarily freshwater, but some locals believe ammonia is dumped as well as fishmeal and oil (Ovalau, Interview #5). In a report written by the Institute of Applied Science at the University of the South Pacific, scientists documented a difference in water clarity in waters close to the PAFCO cannery. The lowest clarity was 3m and clarity increases as samples were taken further away from the cannery and clarity increased to 13m. The Biological Oxygen Demand was taken at sites close and far away from the discharge outlet, and "BOD of 11 mg/L indicated gross pollution while other sites had BOD of less than 2 mg/L" (Tamata 1995: 7). Hydrocarbon concentrations were higher closer to the wharf and *fecal coliform* standards where higher by the discharge area than recommended by the World Health Organization.

Externalities from Harvesting of Marine Resources: Subsistence fishing and commercial collecting of marine resources could be lowering the abundance of present marine resources. Fisherpeople realize that more people are not only fishing around the island, but also they are employing more techniques that are more effective. Furthermore, they realize that the pollution from PAFCO, silt and petro-chemicals from intensive agriculture, and garbage dumped in the water could also be harming their reefs. As one fishermen states "when I was a child I would go fishing in the morning and return at noon and now I go fishing in the morning and return at 3pm" (Ovalau, Interview #12).

Table 3.23: Ovalau Externalities

Study Site	Tourism Externalities	Harvesting Externalities	Agro-Industry Externalities	Total
Ovalau Site 6	Sewage - 2 Anchor - 1 Dev. - 1	Destructive – 3 Mariculture inputs/outputs 0	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 3	16
Ovalau Site 7	Sewage - 1 Anchor - 1 Dev. - 1	Destructive - 2 Mariculture inputs/outputs -0	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 0	11
Ovalau Site 8	Sewage - 2 Anchor - 1 Dev. - 1	Destructive - 3 Mariculture inputs/outputs -0	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 2	15
Ovalau Site 9	Sewage - 2 Anchor - 1 Dev. - 1	Destructive – 3 Mariculture inputs/outputs - 0	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 3	16
Ovalau Site 10	Sewage - 0 Anchor - 1 Dev. - 1	Destructive – 2 Mariculture inputs/outputs -0	Sedimentation - 3 Fertilizer - 3 Industrial Pollution - 2	12

Commodification of the Reef: Vatulele[28]

Direct Value of the Reefs: Tourism and Harvesting of Reef Marine Resources

Vatulele has a small-scale tourist industry with an "eco-sensitive" five star luxury resort on the island with eighteen bungalows. It opened in 1990 and employs approximately fifty local people. Other tour operators from the mainland occasionally dive around Vatulele.

[28] All information in this section has been obtained from local people on the island. There is little written information on this tiny Pacific Island.

Fishermen from village collect and fish for subsistence and small-scale commercial ventures. The villagers use various methods for fishing because there are many different types of fish. They use spearguns, nets, their hands, lines, fish drives with many people, and they also collect at low tide. Before the 1970s people used *duva* only to catch big fish (Vatulele, Interview #10). During the 1970s they used *duva* everyday to catch "all the fish and 1970 there were many people" (Vatulele, Interview #10). Although it is illegal to use, *duva* is still used to fish, as " as it has been for generations" (Vatulele, Interview #9). In the 1980s, the Japanese supplied the Ministry of Fisheries, which in turn gave numerous Fijian island communities' engines, nets, and boats (Vatulele, Interview #9). The Japanese stopped supplying the equipment when the use of drift nets was made illegal (Vatulele, Interview #9). The fishers sell to the resort and at markets on the mainland. The local men say they get $100 for Triton – " the food inside and the shell" (Vatulele, Interview #9). They also sell coral trout, skipjack, lobster, and many other fish to the resort. They sell to the resort approximately 30kg three-four times a week $3.50 per kg (Vatulele Interview #6).

Indirect Commodification of the Reef: Agro-industry

There is no Agro-Industry on Vatulele. The Sigatoka River northeast of Vatulele at certain times of the year discharges effluent that contains silt, garbage, and petrochemicals, which can flow to Vatulele, especially when the winds reverse and come from the northwest (see photo) (Vatulele, Interview #2).

Table 3.24: Vatulele Market Development Classification

Study Site	Island & Reef Type	Tourism	Harvesting	Agro/Industry
Vatulele Island Classification	Low Limestone Island	1	1	1
Vatulele Site 1	Fringing	1	2	1

Vatulele Site 2	Fringing	1	2	1
Vatulele Site 3	Barrier	1	2	1
Vatulele Site 4	Fringing	1	2	1
Vatulele Site 5	Barrier	1	2	1
Vatulele Site 6	Barrier	1	2	1

Marine Property and Resource Management Institutions

There are four villages on the island that have divided up their rights to the reefs. They have sold sections of access to Vatulele Island Resort. The villages of Vatulele have traditional fishing rights and ownership of the reefs surrounding Vatulele. Rights are sold to a few other dive operators to dive around the reefs of Vatulele. Lomanikaya and Ekuba villagers walk across the island and fish on the leeward side and around the southern tip and Ekuba and Taunova villagers share the access to the northern reef and barrier reef.

Table 3.25: Vatulele Property Institutions

Study Site	Property
Vatulele Site 1	Traditional -Privitization and access is sold
Vatulele Site 2	Traditional -Privitization and access is sold
Vatulele Site 3	Traditional -Privitization and access is sold
Vatulele Site 4	Traditional -Privitization and access is sold
Vatulele Site 5	Traditional -Privitization and access is sold

Externalities from the different market sectors

Externalities from Tourism: There is anchor damage from dive boats. Vatulele Island Resort is extremely environmentally conscious. There are only eighteen bungalows and they have a septic tank and wastewater system that is inland, and, according to the hotel engineer, is highly unlikely to leach out (Vatulele, Interview #8).

Garbage is sorted into what is usable and unusable and then it is either composted, recycled, or burned (Vatulele, Interview #8).

Externalities from Harvesting of Marine Resources: The main problem is due to the over- fishing and harvesting of marine resources and the use of destructive fishing practices. According to one informant, people still sometimes use the poisonous vine *duva* (Vatulele, Interview #2). People have mostly stopped using *duva* since the government made it illegal to use, and have switched to using primarily fish nets to fish (Vatulele, Interview #3 and #5). Furthermore, "people sometimes come from the mainland and once in a while fish in Vatulele and use destructive fishing practices" (Vatulele, Interview #2). Two elders of the village told their son that "ten-twenty years ago many more fish lived inside the lagoon. Spearfish inside the lagoon, cannot do anymore, now they spearfish using a speargun" (Vatulele, Interview #3). This is a much more effective and efficient form of fishing.

Externalities of Agro/Industry: There are no externalities from Agro/Industry on Vatulele Island since there is no agro/industry.

Table 3.26: Vatulele Externalities

	Tourism Externalities	Harvesting Externalities	Agro-Industry Externalities	Total
Vatulele Site 1	Sewage - 1 Anchor - 1 Dev. - 1	Over-fishing/ Destructive -2 Mariculture inputs/outputs - 0	Sedimentation -0 Fertilizer - 0 Industrial Pollution - 0	5
Vatulele Site 2	Sewage - 0 Anchor - 1 Dev. - 0	Over-fishing / Destructive -2 Mariculture inputs/outputs - 0	Sedimentation - 0 Fertilizer - 0 Industrial Pollution - 0	3
Vatulele Site 3	Sewage - 0 Anchor - 1 Dev. - 0	Over-fishing/ Destructive -2 Mariculture inputs/outputs - 0	Sedimentation - 0 Fertilizer - 0 Industrial Pollution - 0	3
Vatulele Site 4	Sewage - 0 Anchor - 0 Dev. - 0	Over-fishing / Destructive –2 Mariculture inputs/outputs - 0	Sedimentation - 0 Fertilizer - 0 Industrial Pollution - 0	2
Vatulele Site 5	Sewage - 0 Anchor - 1	Over-fishing/ Destructive –2	Sedimentation - 0 Fertilizer - 0	3

	Dev. - 0	Mariculture inputs/outputs - 0	Industrial Pollution - 0	
Vatulele Site 6	Sewage - 1 Anchor - 1 Dev. - 1	Over-fishing/ Destructive – 2 Mariculture inputs/outputs - 0	Sedimentation - 0 Fertilizer - 0 Industrial Pollution - 0	5

Comparative Analysis: Similarities and Differences Among the Four Islands

The four islands I have chosen as study sites each have unique political and economic histories that have shaped the marine property regimes that are presently in place. The more developed the island and reef resources, and the earlier it became developed by colonizers, the more likely colonizers claimed rights to the waters and traditional fishing grounds and customary marine tenure systems were not acknowledged (Grove 1995; Nietschmann 1997). The type of property institutions governing the reef in turn affects how people and industry choose to use and access the marine resources and waters of the island. Thus, this relates to the intensity of exploitation and degradation of the marine environment as result of the externalities associated with the commodification of the reef (Hardin 1968).

As described in table 3.28, all four islands have different intensity levels for the forms of commodification of the reef and types of marine property systems in place. Aitutaki has a mid-sized tourism industry, mariculture and commercial harvesting of marine resources, as well as declining agro-industry. In addition, it has a property system of common access that is owned by the

Table 3.27: Island Characteristics: Market Development and Property Regime

Island	Level of Tourism Development	Level of Harvesting Marine Resources	Level of Agro/Industrialization	Property and Resource Management Institutions
Aitutaki, Cook Islands	Mid-size	Subsistence , mariculture industry & commercial harvesting	Commercial Agriculture Heavy Industry	1. Common access 2. State owned and regulated 3. Competition - first come first serve
Rarotonga, Cook Islands	Mass tourism	Subsistence , mariculture industry & commercial harvesting	Commercial Agriculture	1. Common access 2. State owned and regulated 3. Competition - first come first serve 4. Traditional Management (Sites #1, #3, and #6) 5. Protected Area (Sites #1, #3, and #6)
Ovalau, Fiji	Small-scale	Subsistence & commercial harvesting	Heavy Industry & Commercial Agriculture	1. Traditional Tenure (Sites #6 & 9) 2. Access to the reef is bought and sold (Sites #6 & 9) 3. Port Authority owns and regulates marine waters (Sites # 7 & 10) 4. Common access (Sites # 7 & 10)
Vatulele, Fiji	Small scale	Subsidence & Small-scale commericial fishing	No agro/industry	1. Traditional CMT 2. Privatization

government. Tour operators compete to access the waters and fishers compete to harvest the fish. In comparison, Rarotonga has a bigger tourism industry and an extremely small commercial fishery. Commercial agriculture has declined over the years, but is still a large part of the income on the island. Like Aitutaki, the marine areas are recognized as Crown Land. In the common access areas surrounding Rarotonga there is competition between tour operators, as well as fishers to access waters and resources. Although, Rarotonga has the same laws as Aitutaki[29], it has recently created traditional restricted fishing areas called Ra'ui, which will be discussed in detail in Chapter 5. Ovalau has small-scale tourism, heavy agro-industry, as well as commercial fisheries. The island has two property systems in place. The Port Authority governs the reef from Nalulu to Toki entrance. This is a common property regime. The rest of the island communities have customary tenure of the reefs. They sell access rights to fishers and dive operators. The two different systems may be due to the fact that at the time Fiji was recognizing and documenting traditional fishing grounds, Levuka town did not make any traditional claims to the reef since the town was settled by immigrants and booming with trade and industry in the 1800s. Vatulele has a small-scale commercial fishery, no commercial agriculture, and small-scale tourism. The communities have customary tenure of the reefs and sell access to dive operators, and a hotel.

The creation of these marine resource markets and market development on the islands changed the communities' relationships with the sea. Furthermore, the growth of these markets changed environmental conditions. Aitutaki has the largest number of externalities, 15.2, due to the fact that is has had heavy agro-industry, presently has mariculture and a big commercial fishery and mid-size tourism industry. In comparison, Rarotonga has marine resource market development and thus fewer externalities, 12.3. Ovalau also a high level of externalities, 14, that are a result of heavy agro-industry and a commercial fishery. Amongst all four islands, Vatulele has the lowest level of marine market development and the fewest externalities, 3.5.

Challenging Neo-Malthusian models of population and resource degradation, the data in the table 3.27 and 3.28 on island characteristics show that population density does not correlate with the intensity of the externalities and exploitation of the reefs on these

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[29] Aitutaki has recently implemented the Ra'ui system.

Table 3.28: Island Characteristics: Area, Population, and Externalities

Island	Island Land Area	Population per Square Kilometer	Average of Externalities Totals per Island
Aitutaki, Cook Islands	16.8 square kilometers	142	15.2
Rarotonga, Cook Islands	67 square kilometers	168	12.3
Ovalau, Fiji	103 square kilometers	84	14
Vatulele, Fiji	31.6 square kilometers	29	3.5

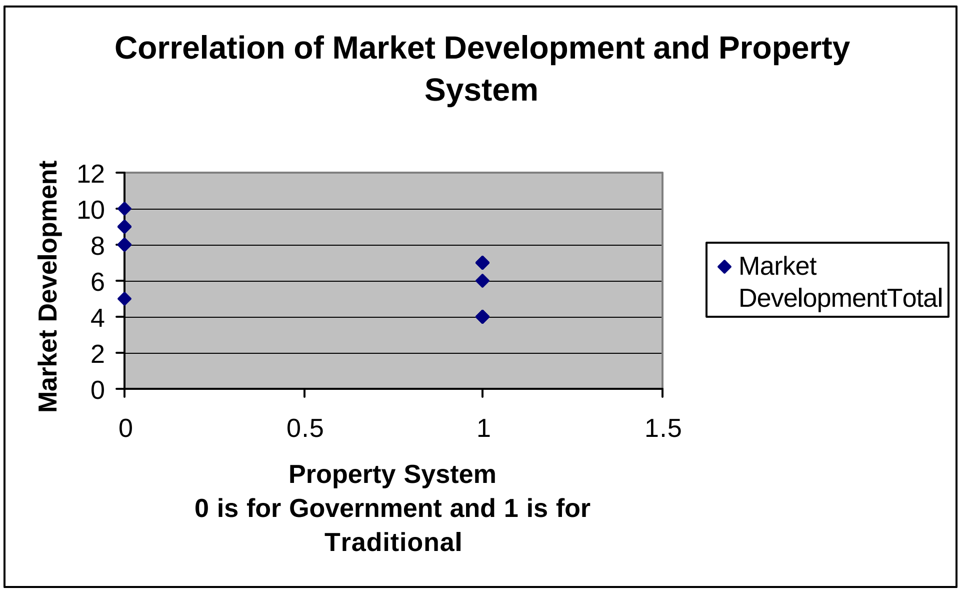
islands (Ehrlich 1968). Rarotonga has the greatest number of people per square kilometer and ranks third with the average of externalities and their impacts. Furthermore, to measure the strength of the association between two variables I have done nonparametric correlation analysis to show the covariance between two variables. I use Spearman's Rho for each pair of variables to show the significant probability that these variables are correlated. In the chart below the two variables analyzed are described and the results are all significant.

Table 3.29: Correlation of Market Intensity, Property Institutions, and Externalities

Variable X	Variable Y	Nonparametric Correlation using Spearman's Rho
Total of Market Development Levels per Site	Labeling Property Regime as either Traditional or Government per Site	-.81 - as X decreases Y increases (traditional was 1 and government was 0)
Total of Market Development Levels per Site	Total of Externality Intensity per Site	.91 – as X increases Y increases
Total of Externality	Labeling Property Regime	-.82 - as X decreases Y

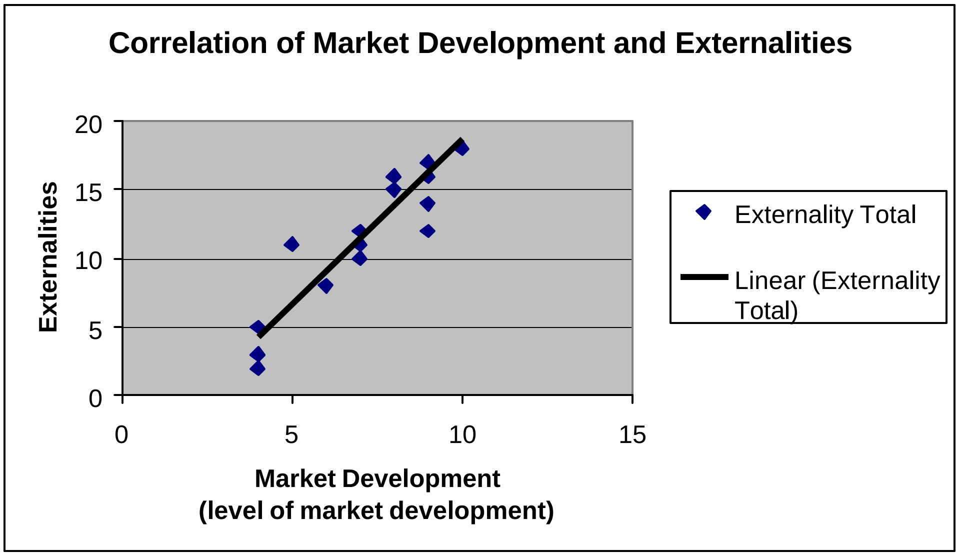
Intensity per Site	as either Traditional or Government per Site	increases (traditional was 1 and government was 0)

The representation of these relationships are also illustrated in the 3 graphs below. In the first graph I show that the sites with more intense market development have marine property systems owned by the government.



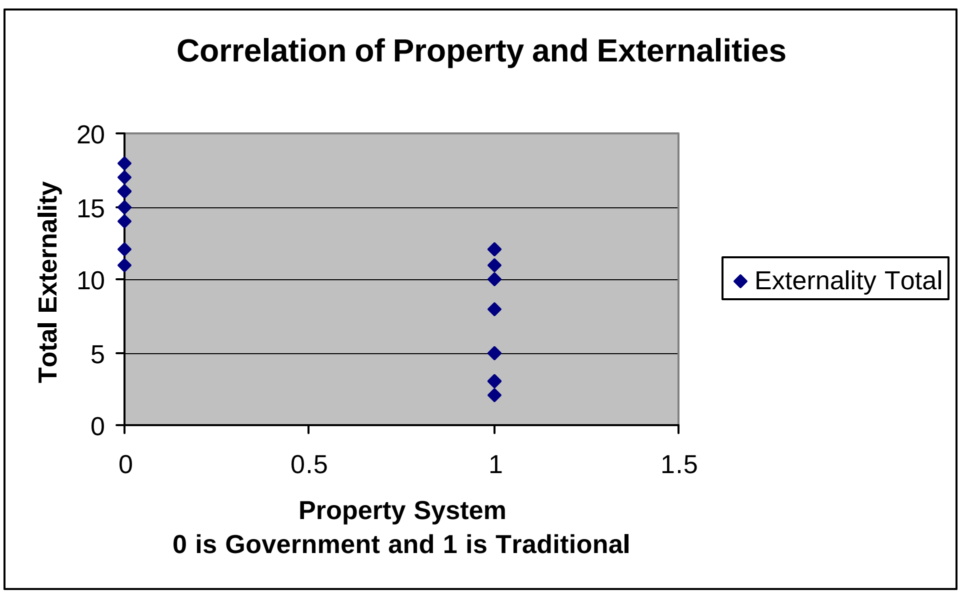
Graph 3.1

The second graph shows the linear relationship and positive correlation with the level of market development and the number of externalities at each site.



Graph 3.2

Finally, in the third graph I again show the relationship between government controlled marine property systems and the total number of externalities.



Graph 3.3

In the next chapter I will discuss the ecological habitats of the four islands and see whether or not there is a correlation between reef health and the three market sectors, property systems, and the externalities. I will show that commodification of the reef and reef resources is one of the primary factors causing the decline of coral reef health. Agro-industry may cause the most harm to the reef system. In addition, I will argue that the loss of traditional marine social institutions has affected coral reef health.

Chapter 4: Reefs of Plenty to Reefs of Death

Coral Health in The Cook Islands and Fiji

In this chapter I will describe the study sites and known data on the reef health and the natural events impacting the reef. I will then present the quantitative ecological data on the reef health and analyze these data to determine the relationship between reef health and marine resource market development and marine property institutions. I make six key findings: 1) In the cases of Ovalau and Rarotonga where there are combined types of marine tenure regimes on the island, non-point and point source pollutants upcurrent still affect traditional areas downcurrent; 2) Agro-industry externalities have the biggest impact upon the Mortality Index (MI) and hard coral species diversity; 3) Biotic factors affecting corals, such as disease and predators, occur naturally in a coral reef system; 4) Large-scale studies on reef changes and causes of degradation are difficult to carry-out. High variability in data and the uniqueness of each reef make large-scale studies inaccurate; 5) Local peoples', (head fishermen, divers, as well as resource managers) perceptions of reef health are accurate. 6) Reefs with traditional systems of marine management, such as in the case of Rarotonga, helps control harvesting of marine resources.

Qualitative Description of Coral Reefs

Aitutaki, Cook Islands

Aitutaki has sixty-six square kilometers of lagoon and ten square kilometers of reef flat (see map 4.1). The large shallow lagoon has a maximum depth of 10.5m and most of the lagoon is less than 4.5m. The barrier reef forms a triangle, which has sides that are thirteen-fifteen km long and the total periphery is forty-five km. The reefs are approximately 600-1000m wide with a maximum width of 1700m (Wells and Jenkins 1988). This almost atoll was first described by Agassiz (1903) and was later visited by the 1969 Cook Bicentenary Expedition (Agassiz 1903: Stoddart, 1975 #286). The reefs have been studied by Stoddart (1975) and the lagoon later by Gibbs (1975) and Paulay (1985) (Gibbs 1975; Paulay 1985; Stoddart 1975).

Paulay's dissertation research in Aitutaki documented a total of sixty-eight coral species, sixty of which are found in the inner reef, forty-six coral species in the lagoon out of a total of sixty-eight species, and all are found on the outer reef (Paulay 1988).

The reef has had numerous impacts the past three decades. The corals have had bleaching events and crown of thorns starfish (COTS) outbreaks as well as incidences of coralline lethal orange disease (CLOD) (Littler and Littler 1995).


Picture 4. 1: Crown of Thorns Starfish (COTS)

Change to the reef due to other natural events such as fluctuations in sea surface temperature (SST) and cyclone events have been prevalent on Aitutaki (Wells and Jenkins 1988). Aitutaki's large lagoon easily rises in SST and a result of this are coral bleaching events. Bleaching events were documented in 1992 and 1998. *Acanthaster* *planci* outbreaks were documented in 1971 and 1987. Five hurricane status cyclones have hit Aitutaki in the past thirty years (Cook Islands Department of Meteorology, Interview #17).

Table 4.1: Known Natural Events Impacting the Reef in the Past 30 Years

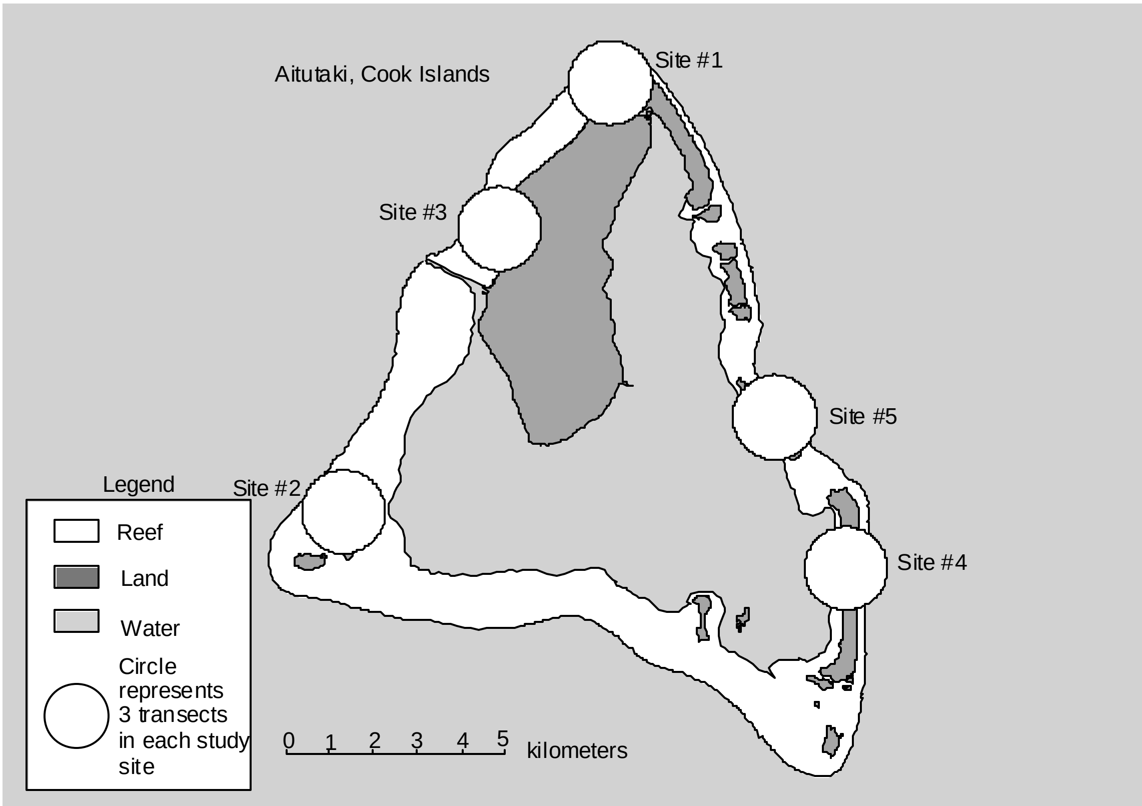
Number of Hurricanes in past 30 years	Number of Bleaching Events	Number of COTS outbreaks	Number of Coral Disease Outbreaks
5	2	2	1 - CLOD

Five sites were surveyed around Aitutaki following the methodology outlined in Chapter 1.

Table 4.2: Reef Type and Geography

Site	Reef Type	Windward/Leeward
Site #1	Fringing	Windward
Site #2	Barrier	Leeward
Site #3	Fringing	Windward
Site #4	Barrier	Leeward
Site #5	Barrier	Leeward

Map 4.1: Aitutaki Study Sites, Cook Islands



Site #1: Descriptive Data of Papamutu Reef by Airport W159.46.604 S18.49.602

Site #1 is a barrier reef on the windward side of the island. The substrate was combination of patch reef, sand, and coral rubble. There were a few *Porites* micro atolls. The large coral heads were alive and healthy and a few *Porites* were covered with pink spots thought to be *Plagioporus* spp., a parasitic trematode. There was no soft coral, but some encrusting sponges. Coral cover expect to be low because of wave energy and anthropogenic impacts. There was sediment in the water column. The Cyanophyta, *Schizothrix calcicola*, was present on the transect, as well as some filamentous green algae

Dominant taxa on Site #1 were *Porites*, *Montipora*, *Pocillopora*, (all scleractinian corals), *Millepora* (non-scleractinian coral), many *Echinometra mathaei* (urchins), *Linckia laevigata* (starfish), *Stichopus chloronus*, *Holothuria* spp. (sea cucumbers). In addition, I observed many damselfish, and large schools of *Scarus sardidus* and a *Acanthurus triostegos*. Fish rapid visual transect (RVT) observations are in Table 4.3

Site #2: Descriptive Data of Reef by Motu Maina W159.50.215 S18.54.463

Site #2 is a barrier reef on the leeward side of the island. The substrate was combination of patch reef, sand, and coral rubble. The coral was alive, but extremely pale in color, except the encrusting *Montipora* spp.. There was no soft coral, but some encrusting sponges. Coral diversity and cover were higher in Site #2 than Site #1. I observed branching coralline red alga as well as *Halimeda* algae. *Schizothrix calcicola* were seen on the third transect, as well as some filamentous green algae.

Dominant taxa on Site #2 were *Fungia*, *Porites*, *Montipora*, *Pocillapora damicornis*, *Pocillapora verruscosa* and *Pocillapora eydouxi*, (all scleractinian corals), *Millepora* (non-scleractinian coral), and many *Echinometra mathaei* (urchins), *Linckia laevigate* (starfish), *Stichopus chloronus*, *Holuthia* spp. (sea cucumbers). I observed one large red *Acanthaster planci*. In addition, I observed damselfish and many *Ephinephelus cephelopholus* (groupers). Fish RVT observations are in Table 4.3.

Site #3: Descriptive Data of Reef by Amuri W159.47.620 S18.51.086

Site #3 is a barrier reef on the windward side of the island. This site was near Amuri, which is approximately 1.5 km from Arutanga town. The substrate was a combination of patch reef, sand, and coral rubble. Sand was finer closer to shore and had a very anoxic smell. Locals said garbage pits and septic tanks were close to shore

(Aitutaki, Interview #1). The coral was alive, but extremely pale in color and covered with mucus and algae, such as *Turbinaria*, *Dictyota*, *Halimeda*, was covered with an epiphetic algae. *Schizothrix calcicola* was seen on the third transect, as well as some filamentous green algae.

Dominant taxa on Site #3 were *Porites rus*, *Montipora*, *Acropora*, *Pocillopora damicornis*, *Pocillopora verrucosa*, and *Galaxea* (all scleractinian corals), *Millepora* (non-scleractinian coral), and many *Discosoma* spp., *Stichopus chloronotus*, *Holuthuria* spp. (sea cucumbers). I observed one large red *Acanthaster planci*. In addition, I observed a large school of *Chromis*. Fish RVT observations are in Table 4.3.

Site #4: Descriptive Data of Reef by Motu Tekopua W159.43.872 S18.55.093

Site #4 is a barrier reef on the leeward side of the island. The substrate was combination of patch reef, sand, and coral rubble. All transects had little live coral coverage. Coral heads were pale in color with mucus and a few *Porites lobata* and *Porites lutea* were covered with pink spots thought to be *Plagioporus* species. There was no soft coral, but some encrusting sponges. *Schizothrix calcicola* was on the sandy substrate.

Dominant taxa on Site #4 were *Porites*, *Porites rus*, *Montipora*, *Pocillopora damicornis*, *Pocillapora veruscosa*, (all scleractinian corals), *Millepora* (non-scleractinian coral), and a few *Stichopus chloronotus, Holothuria* spp. (sea cucumbers). In addition, I observed three *Parapeneus* juveniles. Fish RVT observations are in Table 4.3.

Site #5: Descriptive Data of Reef by Motu Papua W159.44.798 S18.53.341

Site #5 on the barrier reef on the leeward side of the island. The substrate was combination of patch reef, sand, and substrate was primarily composed of coral rubble. Similar to Site #4 all transects had little live coral coverage. Coral heads were pale in color with mucus; a few *Porites lobata* and *Porites lutea* were covered with pink spots thought to be *Plagioporus* species. There was no soft coral, but some encrusting sponges. *Schizothrix calcicola* carpeted the sandy substrate and a gray filamentous algae covered dead coral, *Halimeda*, and *Caulerpa racemosa*.

Dominant taxa on Site #1 were *Porites*, *Porites rus*, *Montipora*, *Pocillopora damicornis*, *Pocillopora verucosa*, (all scleractinian corals), and *Millepora* (non-scleractinian coral), a few *Stichopus chloronotus*, *Holothuria* spp. (sea cucumbers). The fish RVT is in the chart below.

Table 4.3: Rapid Visual Transect of Aitutaki Fish by Genus

Site #1 RVT	Site #2 RVT	Site #3 RVT	Site #4 RVT	Site #5 RVT
Chaetodon	Labroides	Labroides	Centropyge	Centropyge
Thalassama	Naso-	Naso	Pomacentrus	Canythoichthys
Acanthurus	Thalassama	Chaetodon	Plectroglyphidodon	Pomacentrus
Epinephelus	Acanthurus	Parapeneus	Acanthurus	Labroides
Mulloides	Epinephelus	Heniochus	Epinephelus	Parapeneus
Centrepyge	Mulloides	Abudefduf	Stethojulis	Abudefduf
Abudefduf	Centropyge	Ctenochaetus	Scarus	Acanthurus
Scarus	Scarus	Acanthurus	Dascyllus	Scarus
Dascyllus	Dascyllus	Epinephelus	Lutjanus	Dascyllus
Chrysiptera	Chrysiptera	Stethojulis	Gamphosus	Lutjanus
Pomacentrus	Pomacentrus	Scarus	Cheilenus	Cheilenus
Parapercis	Arothron	Dascyllus	Thalassoma	Scolopsis
Canthigaster	Canthigaster	Chrysiptera	Chaetodon	Monotaxis
Ctenachaetus	Ctenachaetus	Lutjanus	Canthigaster	Canthigaster
	Menotaxis	Gamphosus		
	Lutjanus	Chromis		
	Kyphosus	Gnathodentax		
	Arothron	Cheilenus		
	Zebrasoma	Cheilodipterus		
	Paracirrhites			
	Fistularia			
	Chromis			
	Rhinecanthus			
	Coris			
	Gamphosus			
	Sargocentron			
	Gymnothorax			
	Istiblennius			
	Gnathodentax			

Rarotonga, Cook Islands

Rarotonga is a classic high island, an elevation of 650m, with a fringing reef (Wells and Jenkins 1988). The reef increases in width from the southeast corner counterclockwise (see map 4.2). Thus the narrowest reefs (50-100m) are windward and the widest are in the south with a moat more than 800 meters wide (Paulay 1988). The fringing reefs around Rarotonga were first described by Crossland (1928) and Dana (1898), and more recently by Stoddart (1972), Dahl (1980b), Gauss (1982) and Paulay

(1985) (Crossland 1928; Dahl 1980b.; Dana 1898; Gauss 1982; Lewis 1980; Paulay 1985; Stoddart 1972).

More than 120 species of coral have been documented to date in the Cook Islands, many of which are in the Northern Islands (Paulay 1985; Stoddart 1972). According to Paulay (1988) there are sixty-two species of coral found in the Rarotongan reefs. In the past five years the Ministry of Marine Resources has begun surveying the Rarotongan forereef (Miller 1994; Ponia 1999).

Rarotonga's reefs have been affected by many natural events. Five hurricane status cyclones hit the island in the past thirty years (Cook Islands Department of Meteorology, Interview #17). Bleaching events were also reported in 1992 and 1998 (Ponia 1999). In addition, starting in the 1970s, COTs outbreaks have been prevalent with outbreaks at similar times of Aitutaki's outbreaks in 1971 and 1987 (Wells and Jenkins 1988). Reports of CLOD have also been documented (Littler and Littler 1995).

Table 4.4: Known Natural Events Impacting the Reef in the Past 30 Years

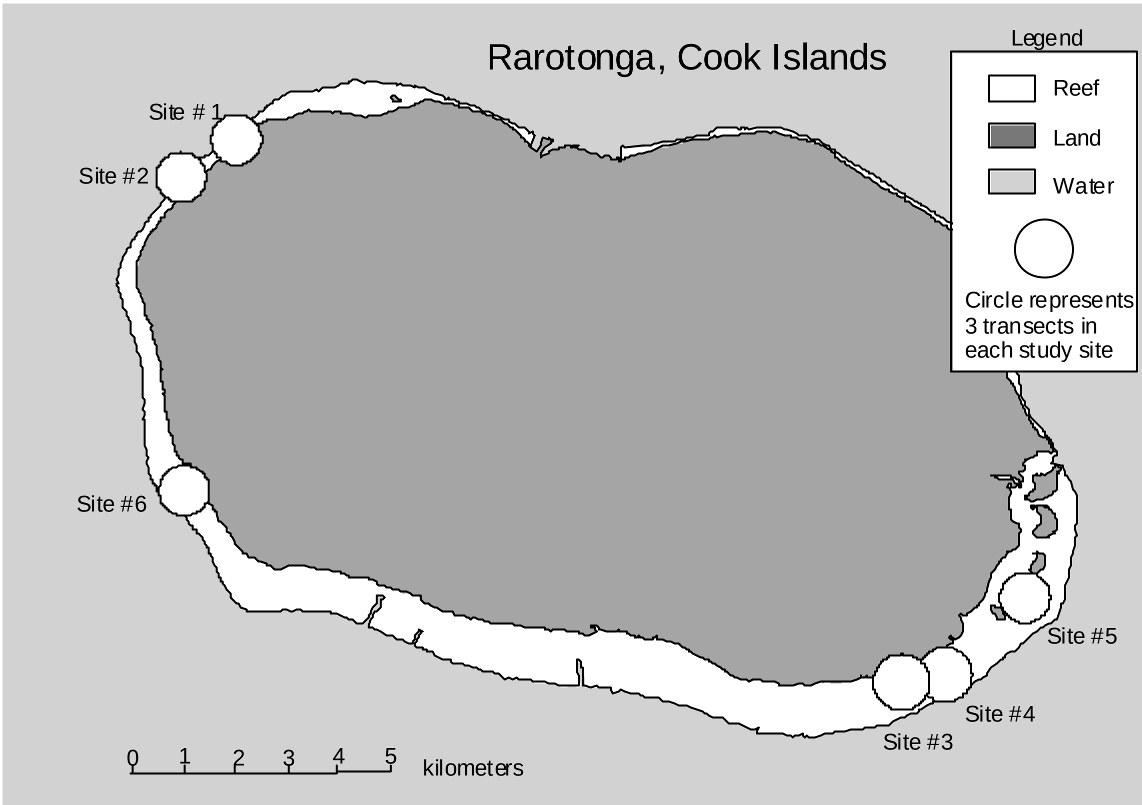
Number of Hurricanes in past 30 years	Number of Bleaching Events	Number of COTS outbreaks	Number of Coral Disease Outbreaks
5	2	2	CLOD

Six sites were surveyed around Rarotonga following the methodology outlined in Chapter 1.

Table 4.5: Reef Type and Geography

Site	Reef Type	Windward/Leeward
Site #1	Fringing	Windward
Site #2	Fringing	Windward
Site #3	Fringing	Leeward
Site #4	Fringing	Leeward
Site #5	Barrier	Leeward
Site #6	Fringing	Windward

Map 4.2: Rarotonga Study Sites, Cook Islands



Site #1: Descriptive Data of Nikao, Ra'ui: W159.49.376 S21.12.474

Nikao is a fringing reef on the windward side of the island. The substrate was a combination of reef, sandy, and coral rubble. There was little to no soft coral, but many juvenile stony coral. Coral diversity and cover expect to be low because of wave energy and anthropogenic impacts. Filamentous algae are diverse, green, gray and red, but generally not abundant. Sea urchins are common. Visible coral mucus was primarily on *Porites* species, with a few having some discoloration and infected with *Plagioporus* species. There are an unusually high number of fish bites on *Porites* spp. compared to other sites around Rarotonga

Dominant taxa on the twenty-five ha section of reef were *Porites*, *Montipora*, *Favites*, (all scleractinian corals), Trochidae (trochus shells), *Tridacna* (giant clams), *Serpulorbis* (worms), many *Echinometra mathaei* (urchins), *Linckia laevigata* (starfish), *Tripneustes gratilla*, *Stichopus chloronotus*, *Holothuria* spp. (sea cucumbers). I observed one large red *Acanthaster planci* and a large anemone, *Heteractis crispa*. In addition, I previously saw a large school of *Scarus sardidus* juveniles with some adults and approximately five *Chaetodon* on transect one and two, which had particularly high coral cover. There many *Naso* juveniles, many *Canthigaster* in pairs, and I saw a damsel protecting its eggs from a sunset wrasse, which was very aggressive. The high percentage of live coral coverage creates an environment that is suitable for *Chaetodon*. Although I saw numerous *Chaetodon* during the transects, I did not count any on the fish survey, but did see a variety during the RVT, see Table 4.6.

Site #2: Descriptive Data of Nikao, no Ra'ui: W159.49.388 S21.12.470

Site #2 is located immediately west of Nikao Ra'ui. The reef habitat was similar, but with more calcareous algae. Similar species were also present at Site #2 as Site #1, though with fewer coral recruits and coral buds, and not as many large *Scarus*, but more fish documented overall in the transect at Site #2 compared to the Ra'ui, Site #1, see Table 4.6.

Site #3: Rarotonga, Tikioki - Ra'ui W159.44.511 S21.16.227

Declared in 1998 as Tikioki Ra'ui, the Ra'ui was lifted on February 1, 2000 and moved west to Akapuao. Site #3 is a fringing reef on the leeward side of the island. The substrate was combination of reef, sand, and coral rubble. Big corals heads were dispersed randomly. The shoreline was composed of a conglomerate platform. Coral diversity and cover were expected to be high because local people said this is the most popular snorkeling spot on the island (Rarotonga, Interview #3). Filamentous algae are diverse, green, gray and red, and abundant and so is *Schizothrix calcicola*. A tangled, hair-like cyanobacterium, *Lygnbya majuscula*, covered most of the coral heads. Visible coral mucus was primarily on *Porites* species, with a few having some discoloration and infected with *Plagioporus* species. There were fish bites on *Porites* spp. and possibly some tumors.

Dominant taxa on the reef were *Porites*, *Acropora*, and *Montipora*, (all scleractinian corals), a few *Stichopus chloronotus*, *Holothuria* spp. (sea cucumbers). In addition, I observed a large number of *Ostracion* spp. and carnivorous fish such as *Caranx* and *Naso*. Fish RVT observations are in Table 4.6.

Site #4: Rarotonga, Tikioki W159.44.510 S21.16.216

This site was just North of Site #3. The reef habitat and reef health is similar to Site #3, but I observed soft coral and the coral heads are denser.

Dominant taxa on the reef were *Porites*, *Acropora*, and *Montipora* (all scleractinian corals), *Lobophyllia* spp., *Sinularia* spp (soft coral) and a few *Stichopus chloronotus*, *Holothuria* spp. (sea cucumbers). In addition, I observed a large school of *Acanthurus* feeding on algae and many *Parupeneus* and fish RVT observations are in Table 4.6.

Site #5: Rarotonga, Muri Beach W159.43.576 S21.159.539

Site #5 is a barrier reef on the leeward side of the island. The substrate is a shallow reef flat east of a motu with a conglomerate platform. There were many *Porites* micro atolls. This site was a popular place for collecting sea cucumbers and octopus.

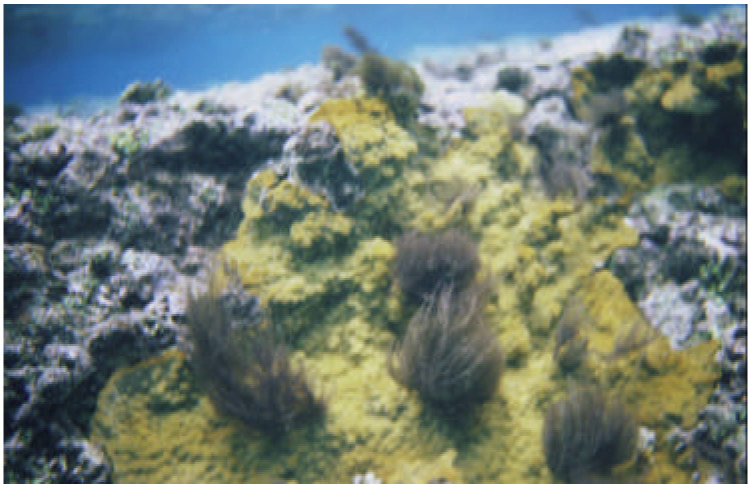
Filamentous green algae, tangled, hair-like algae, *Lygnbya majuscula*, or the *Schizothrix calcicola*, covered most of the coral heads. Visible coral mucus was primarily on *Porites* species, with a few having some discoloration.

Dominant taxa on the reef were *Porites*, *Acropora*, and *Montipora (*all scleractinian corals), *Millepora* (non-scleractinian coral), and some *Stichopus chloronotus*, *Holothuria* spp. (sea cucumbers). In addition, I observed a three *Zebrasoma scopas* juveniles and a school of stripped *Acanthurus*. Fish RVT observations are in Table 4.6.

Site #6: Rarotonga, Kavera Ra'ui W159.49.655 S21.14.442

This site was declared in March 1, 1999 Kavera Ra'ui. The Ra'ui was lifted on December 31, 1999, and moved west to Akapuao. Site #6 is a fringing reef on the windward side of the island. The substrate is a combination of reef and sand, with a high amount of sediment in the water column. Filamentous algae were diverse, green, gray and yellow, and abundant as well as *Schizothrix calcicola*. Visible coral mucus was primarily on *Porites* species, with a few having some discoloration and infected with *Plagioporus* species particularly at the edges of the Porites micro atolls and overgrown with algae. There were fish bites on *Porites* spp. and possibly some tumors.

Dominant taxa on the reef were *Porites* and *Montipora* (both scleractinian corals) and a few *Stichopus chloronotus*, *Holothuria* spp. (sea cucumbers). Many different types of algae such as *Halimeda*, *Chlorodesmis*, *Neomeris*, *Actinotrichia*, *Padina*, *Dictyota*, *Dictyosphaeria* were identified. In addition, I observed a large number of juvenile *Acanthurus triostegus* and *Coris* spp. juveniles, fish RVT observations are in Table 4.6.


Picture 4.2: *Lygnbya majuscula*

Rarotonga, Cook Islands

Table 4.6: Rapid Visual Transect of Rarotonga Fish by Genus

RVT#1	RVT#2	RVT#3	RVT#4	RVT#5	RVT#6
Epinephelus	Chaetodon	Rhinecanthus	Abudefduf	Scolopsis	Grammistes
Mulloides	Stethojulis	Ostracion	Chromis	Abudefduf	Parapercis
Paneneus	Thallasoma	Siganus	Pomacentrus	Parapercis	Chaetodon
Chaetodon	Scarus	Gymnothorax	Plectroglyphidodon	Chaetodon	Rhinecanthus
Centropyge	Naso	Acanthurus	Sargocentrion	Scarus	Stethojulis
Chromis	Acanthurus	Coranx	Chaetodon	Mulloidichthys	Thalassama
Chrysiptera	Aulostemis	Stethojulis	Dascyllus	Rhinecanthus	Coris
Bothus	Chromis	Chaetodon	Monotaxis	Canthigaster	Acanthurus
Cheilinus	Parapeneus		Ephinephelus	Naso	Heniochus
Rhinecanthus	Naso		Scarus	Acanthurus	Dascyllus
Stethojulis	Fistularia		Mulloidichthys	Ctenochaetus	Chrysiptera
Thallasoma	Mulloidichthys		Labroides	Siganus	Pomacentrus
Scarus	Siganus		Cephalopholis	Ostracion	Cheilinos
Parapercis	Canthigaster		Zanclus	Zebrasoma	Labroides
Naso			Centropyge	Stethojulis	
Acanthurus			Rhinecanthus	Zanclus	
Ctenochaetus			Stethojulis	Montaxis	
Zanclus			Naso	Fistularia	
Siganus			Acanthurus	Myripristus	
			Ctenochaetus	Thalassama	
			Siganus	Labroides	
			Ostracion	Neanphan	
			Zebrasoma	Parupeneus	
			Gamphosus	Coris	
			Lutjanus	Heniochus	
			Gnathodentex		
			Parupeneus		
			Heniochus		

Ovalau, Fiji

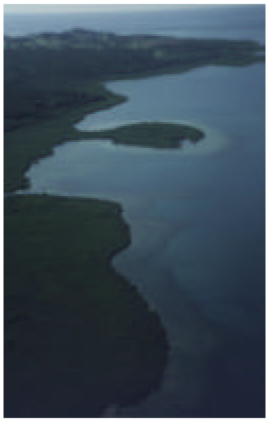
The reefs of Fiji are known for the high diversity in both soft and hard coral species diversity. Fiji has approximately fifty genera of hard coral, while the Cook Islands has thirty genera (Veron 1986).

Ovalau is part of the Lomaiviti Groups, the Koro Sea Islands, fifteen islands compose this group just east of the main island Viti Levu. Most of the islands are of volcanic origin. The complex reefs of Ovalau encircle this high island. Reefs to the west are fringing and patch reefs and the east coast is a barrier reef.

Agassiz was one of the first western scientists to describe the reefs of Ovalau:

> Both Ovulua and Moturiki are surrounded by fringing reef (Agassiz 1899: 110).
>
> To the westward and northward of Ovulua reach the extensive flats full of patches which connect the west shore of Ovulua with the mainland, and reach on the northwest to Tova and south towards Mbau flats which are formed by the disintegration of the low bluffs, consisting of bedded volcanic mud, which must once have extended eastward close to Ovulua and Motutiki. The patches are covered with growing coral (Agassiz 1899: 113).

Other observations have been made by Davis (Davis 1920). Since then few reports have been written on the reefs of Ovalau. Tamata and Lovell examined the reefs twice for environmental impact reports of the PAFCO effluent pipeline (Tamata 1995).


Picture 4.3: Ovalau Coastline

Data on the natural events affecting the reefs were obtained from the local population. Two hurricanes hit Ovalau in the past thirty years (Director of Meteorology 2001). Hurricane Kina greatly damaged Ovalau's reef in 1993. COTS outbreaks have been documented starting in the 1970s and there have been no reports of any coral disease. Bleaching started in 1999. Local people's knowledge and their perceptions of reef health were collected to gain more insight into reef health.

> Productivity [is] down [from] Naqeledamudamu Point to Cakaunmoli reef (Interview #5, Ovalau).
>
> When I was a child I would go fishing in the morning and return at noon and today I go fishing in the morning and return at 3:00 pm (Interview #12, Ovalau).

Locals have seen changes in their reef productivity in terms of harvesting marine resources and also seen a correlation with the installation of PAFCO.


Picture 4.4: Ovalau Dead Reef

Table 4.7: Known Natural Events Impacting the Reef in the Past 30 Years

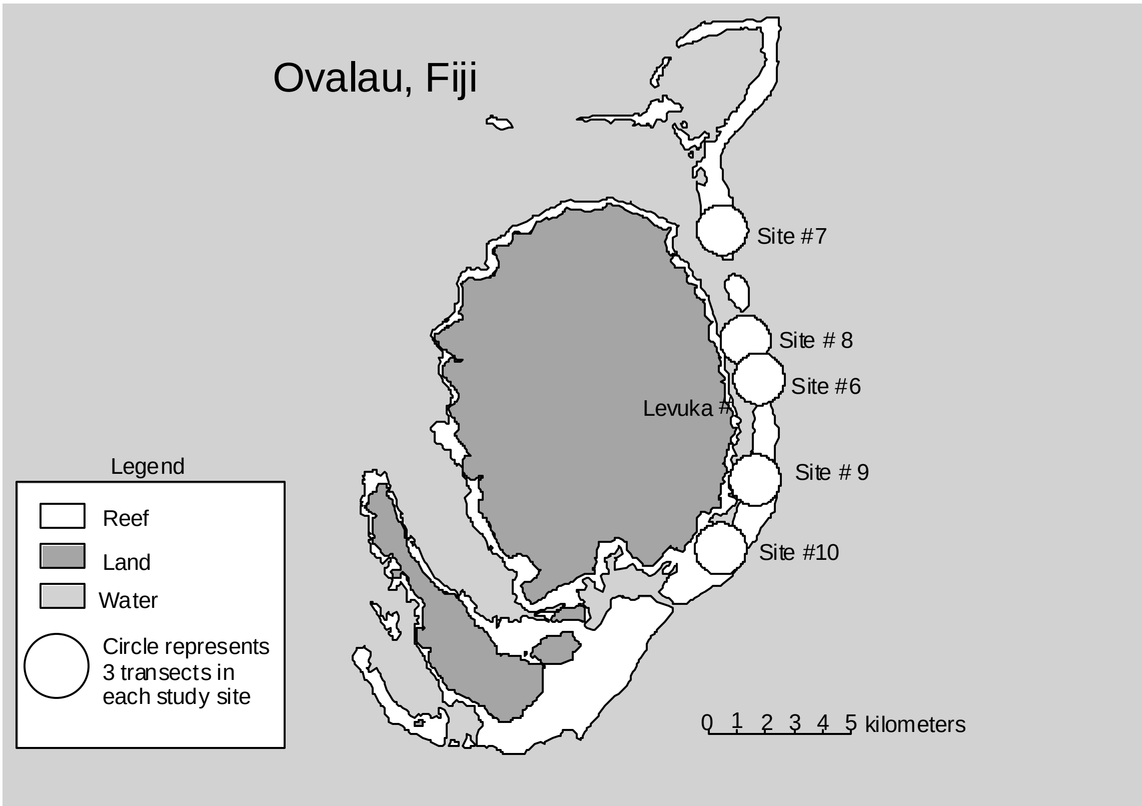
Number of Hurricanes in past 30 years	Number of Bleaching Events	Number of COTS outbreaks	Number of Coral Disease Outbreaks
2	1	2	0

Six sites were surveyed around Ovalau following the methodology outlined in Chapter 1.

Table 4.8: Reef Type and Geography

Site	Reef Type	Windward/Leeward
Site #6	Barrier	Windward
Site #7	Barrier	Windward
Site #8	Barrier	Windward
Site #9	Barrier	Windward
Site #10	Barrier	Windward

Map 4.3: Ovalau Study Sites, Fiji



Site #6: Cakaulekaleka, E178.50.631 S17.40.565

Site #6 is a barrier reef on the leeward side of the island. This site is just north of the PAFCO pipeline. While doing the counts I witnessed a boatload of fishmeal and other garbage being dumped into the water by the pipeline. Local people told me that this was a PAFCO boat and they often do this (Ovalau, Interview #2). They are supposed to dump one mile from the shore, but this was less than a mile. The substrate is combination of reef, sand, and coral rubble. Algae (*Padina, Sargassum, Halimeda*) was diverse and abundant and I saw patches of the *Schizothrix calcicola*. Blue tumors were observed on the branches of the *Acropora*.

Dominant taxa on the reef were *Porites lobata*, *Fungia*, and *Acropora* (all scleractinian corals), and *Millepora* (non-scleractinian coral) and *Sinularia* spp. soft corals, as well as some *Linckia laevigata* and four anemone *Heteractis crispa.* In addition, I observed a sea snake and three schools of parrotfish juveniles.

Site #7: Cakaubalavu, E178.49.812 S17.37.614

Site #7 is a reef on the leeward side of the island. The substrate was a combination of reef, sandy, and coral rubble. Although there was less coral rubble at this site than at site #6, there was a higher number of *Schizothrix calcicola*. In addition, a red and gray filamentous algae was growing over *Turbinaria* algae. Visible yellow slime was covering the soft coral, *Sarcophyton* species. On *Porites* species, a few had some discoloration and were infected with *Plagioporus* spp.

Picture 4.5: Ovalau Site #7 Coral


Picture 4.6: Ovalau Site #7 Coral

Dominant taxa on the reef were *Acropora tenius, Acropora spp., Seriatopora hystrix, Pocillopora,* and, *Montipora,* all scleractinian corals, and soft coral such as *Sarcophyton* spp., many *Echinometra mathaei* (urchins), and *Linckia laevigata* (starfish). There were not many damselfish or butterfly fish. I also saw numerous parrotfish juveniles and schools of surgeon fish and a large anemone, *Heteractis crispa*.

Site #8: Cakaulekaleka, E178.50.491 S17.39.799

Site #8 is a reef on the leeward side of the island. The substrate was a combination of reef, sandy, and coral rubble.

Dominant taxa on the reef were *Porites rus* and *Porites lobata,* both scleractinian corals, and soft coral such as *Sarcophyton* spp.. There were many damselfish and butterfly fish. I also saw numerous parrotfish juveniles and schools of surgeon fish and three schools of *Chromis* and an anemone, *Heteractis crispa*.

Site #9: Balavu, E178.50.736 S17.41.956

Site #9 is a reef on the leeward side of the island. The substrate was a combination of reef, sandy, and coral rubble. Locals were fishing using the surprise net fishing technique. I was told by a local that the PAFCO factory lets out an enormous amount of freshwater at night and the land breezes push the fresh water currents into this area (Ovalau, Interview #13).

Dominant taxa on the reef were *Acropora* spp., other scleractinian corals and soft coral such as *Sarcophyton* spp.. There were many damselfish and triggerfish within the live and dead branches of the Acropora, which was covered with green filamentous algae. I saw red snapper and marlet.

Site #10: Cakaubalavu, E178.49.990 S17.43.842

Site #10 is a barrier reef on the leeward side of the island. The substrate was combination of reef, sandy, and coral rubble. Locals were collecting octopus, clams, and oysters. There were many soft corals. Filamentous green algae covered the *Acropora* and was abundant. Damselfish were common. Visible coral mucus was primarily on *Porites* species, with a few having some discoloration and infected with *Plagioporus* species.

Dominant taxa on the section of reef were *Acropora* spp., scleractinian corals and the soft corals *Sarcophyton* spp. and *Sinularia* spp.. I observed three *Acanthaster planci* and a large anemone. In addition, I observed many schools of *Chromis*, goat fish and some butterfly fish.

<u>Vatulele, Fiji</u>

Vatulele is a low island with both a fringing and barrier reef. The western coast has vertical cliffs of limestone and slopes and caves on the eastern coast. The fringing reef is on the east and has three nearby islets. In 1899, Agassiz described the reef:

> Nearly the whole lagoon is covered with patches of corals and of reef rock especially in the southern and western parts…the north

> side of the lagoon is protected by an outer reef flat fully half a mile wide in some places. On it coral are flourishing (Agassiz 1899: 67-68)

No research has been published on Vatulele's reef and there is no "gray" literature on Vatulele's reef. Data on the natural events affecting the reef is from the local people of the island. COTS were first noticed approximately eighteen years ago. There were big outbreaks in 1997 and presently Vatulele Island resort collects 150 COTS a day (Interview #3). Bleaching has occurred on the island twice as well as one hurricane (Director of Meteorology 2001). There have been many gales force storms (Director of Meteorology 2001).


Picture 4.7: COTS Collected at Vatulele Island Resort

1998. The local divers said they have noticed diseases on the coralline algae, which has a similar description to CLOD.

Table 4.9: Known Natural Events Impacting the Reef in the Past 30 Years

Number of Hurricanes in past 30 years	Number of Bleaching Events	Number of COTS outbreaks	Number of Coral Disease Outbreaks
1	2	2	1 - CLOD

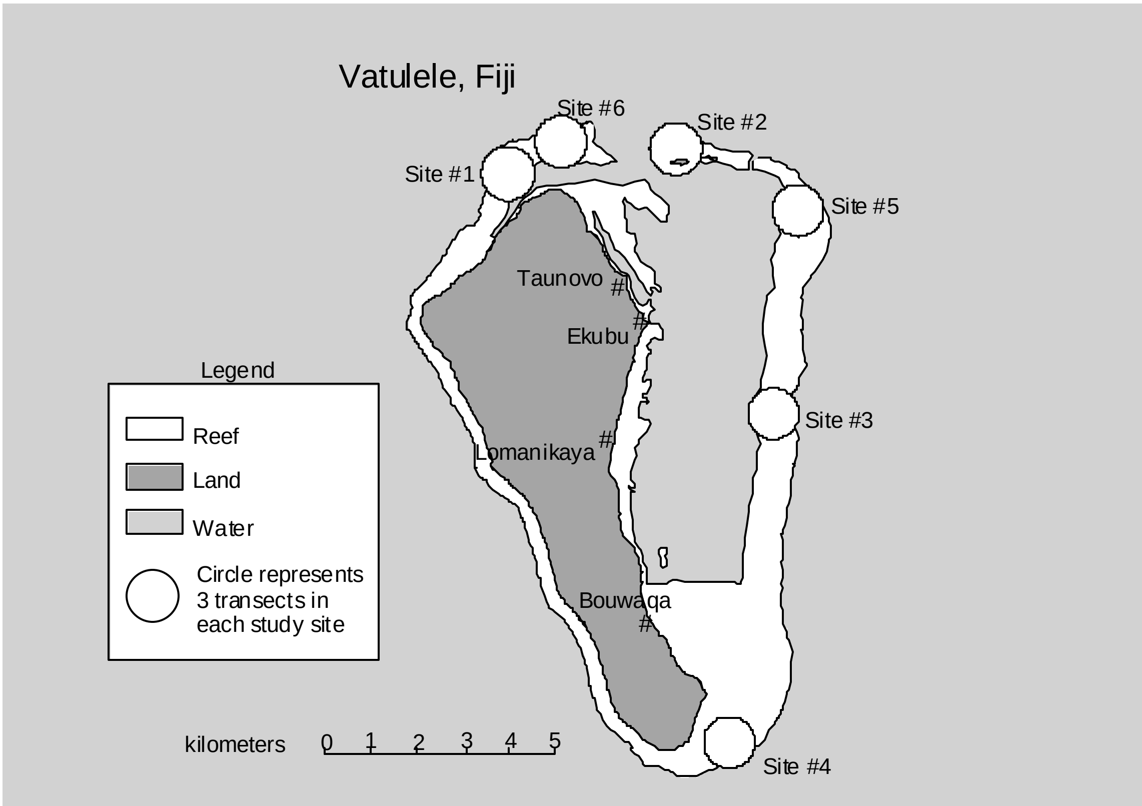
Six sites were surveyed around Vatulele following the methodology outlined in Chapter 1.

Table 4.10: Reef Type and Geography

Site	Reef Type	Windward/Leeward
Site #1	Fringing	Leeward
Site #2	Fringing	Leeward
Site #3	Barrier	Windward
Site #4	Fringing	Windward
Site #5	Barrier	Windward
Site #6	Barrier	Leeward


Picture 4.8: Vatulele Barrier Reef

Map 4.4: Vatulele Study Sites, Fiji



Site #1 Resort Reef, E177.36.709 S18.29.933

Site #1 is a fringing reef on the leeward side of the island, west of Vatulele Island Resort. The substrate was a combination of reef, sandy, and coral rubble. The day I collected data there was a strong current from the northeast, which happens occasionally. This reef had high algae diversity, such as *Turnbinaria*, coralline algae, *Chlorodesmis*, *Halimeda*, *Actinotrichia*. I observed CLOD on coralline algae and some of *Schizothrix calcicola*. As the transects moved further northeast I observed more filamentous algae and less live coral, as well as more coral rubble. In addition, I observed a large number of *Scarus*, juvenile parrotfish. Fish RVT observations are in Table 4.11.

Site #2 Bird Island Reef, E177.39.141 S18.29.008

Site #2 is a fringing reef on the leeward side of the island, just north of Bird Island. The substrate was a combination of reef, sandy, and coral rubble. The day I collected data there was a strong current from the northeast, which happens occasionally. This current often brings large quantities of trash with it from the main island. Sponges and soft coral were abundant on this reef. Epiphytic algae was growing over the *Stylaster* coral and over *Halimeda* algae. I observed CLOD on coralline algae. In addition, I observed a large number of *Scarus* schools and four *Labroides* cleaning stations. Fish RVT observations are in Table 4.11.

Site #3 Cakau Levu Barrier Reef, south of Lomamikaya, E177.40.673 S18.32.501

Site #3 is a barrier reef on the windward side of the island, just south of Lomanikaya village. The substrate was a reef flat. There was a high diversity of sponges, hard coral, and soft coral. Transect #1 had a lower coral percent cover, but had high diversity and many new coral recruits. According to a local informant, this particular area of the reef was hit hard by a hurricane last year (Vatulele, Interview #3). On transect #2 and #3 there were a few corals with partial bleaching. Encrusting corals dominated the reef as well as algae, *Chlorodesmis*, *Dictyosphaeria*, *Halimeda*, and *Caulerpa*. In addition, I observed a higher number of corallivores on this reef than site #1 and site #2. I also saw a small school of *Acanthurus* and small schools of *Scarus* juveniles. Fish RVT observations are in Table 4.11.


Picture 4.8: Reef Fish Site #3, Vatulele

Site #4 Reef at Valolo Rocks, E177.39.861 S18.35.972

Site #4 is a fringing reef on the windward side of the island, just south east of Valolo Rocks. The substrate was a combination of reef, sandy, and coral rubble. Filamentous red algae, *Schizothrix calcicola* and encrusting hard coral, *Porites lutea* and *Porites lobata* dominate the reef. Little live coral coverage was observed. Transect #1 had a lower coral percent cover and more coral rubble. Transects #2 and #3 had more patchy reef and new coral recruits. I saw many schools of *Tylosaurus*. Fish RVT observations are in Table 4.11.

Site #5 Cakau Levu Barrier Reef, across from Ekubu village, E177.40.995 S18.29.729

Site #5 is a barrier reef on the windward side of the island, just south east of Valolo Rocks. The reef is known to have big waves. The substrate was a combination of reef, sandy, and coral rubble. Filamentous red algae, *Schizothrix calcicola* and encrusting hard coral, *Porites lutea* and *Porites lobata* dominate the reef. There was little live coral coverage. Transect #1 had a lower coral percent cover and more coral rubble. Transects #2 and #3 had more patchy reef and new coral recruits. I saw many schools of fish eating algae. Fish RVT observations are in Table 4.11.

Site #6 Nooki Nooki Island Reef, E177.37.048 S18.28.812

Site #6 is a barrier reef on the leeward side of the island, just south of Nooki Nooki Island. The substrate was a combination of reef and sand. There were many plate corals and branching coral on this reef. *Halimeda*, *Chlorodesmis*, *Dictyosphaeria*, and *Caulerpa*, encrusting hard coral, and a few ascidians and sponges covered the reef. I observed high levels of CLOD on coralline algae. In addition, I saw many different species of *Scarus* and schools of juveniles. There was a high live coral coverage that could support many different species and pairs of *Chaetodon*, butterfly fish. Fish RVT observations are in Table 4.11.

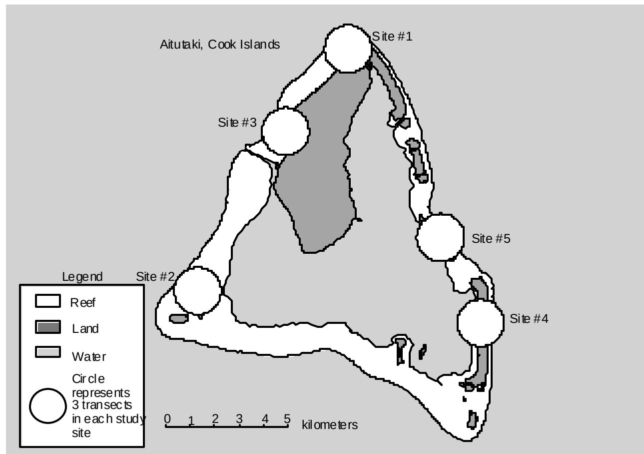
Table 4.11: Rapid Visual Transect of Vatulele Fish by Genus

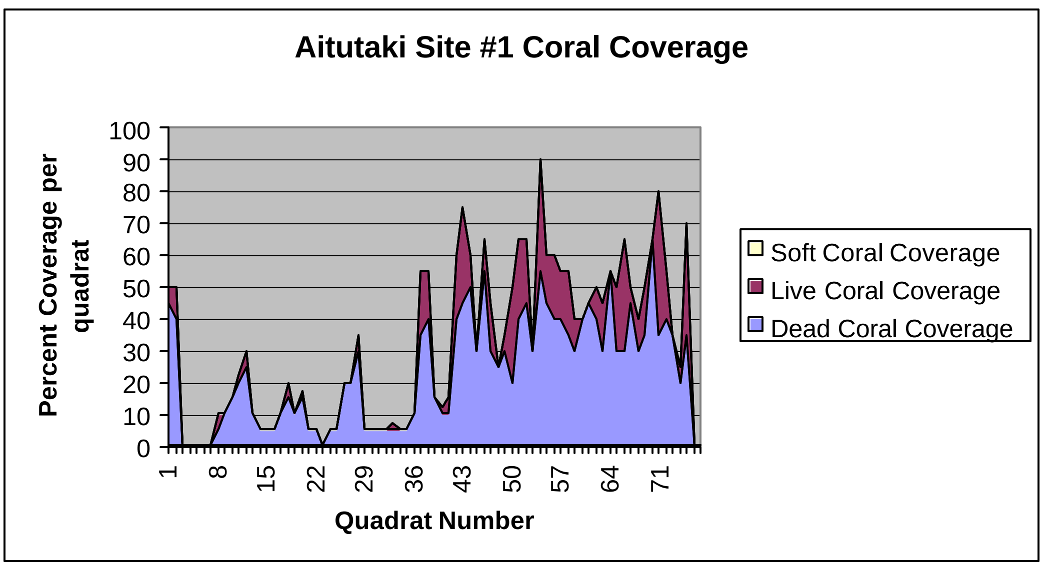
RVT#1	RVT#2	RVT#3	RVT#4	RVT#5	RVT#6
Cephalophalus	Chaetodon	Gamphosus	Cephalophalus	Chaetodon	Priacanthus
Parupeneus	Pomacentrus	Parupeneus	Chaetodon	Chrysiptera	Myripristus
Chaetodon	Thallasama	Rhinecanthus	Pomacentrus	Labroides	Neoniphon
Pomacentrus	Labroides	Zebrasoma	Labroides	Coris	Scarus
Chromis	Stethojulis	Scarus	Scarus	Halichoeres	Labroides
Stethojulis	Coris	Synodus	Acanthurus	Sethojulis	Acanthurus
Labroides	Acanthurus	Stethojulis	Parapercis	Acanthurus	Ctenochaetus
Gomphasus	Coranx	Paracirrhites	Epinephelus	Pomacentrus	Zebrasoma
Zebrasoma	Plectroglyphidedon	Pomacentrus	Stethojulis	Ostracion	Gamphasus
Acanthurus	Chromis	Siganus	Fistularia	Peruagar	Sethojulis
Scarus	Amphipron	Halichoeres	Macropharyngodon	Cephalophalus	Pomacentrus
Synodus	Parapeneus	Thallasama	Cheilenus	Zebrasoma	Plectroglyphidodon
Chrysiptera	Centropyge	Coris	Halichoeres	Zanclus	Chromis
Thallasama	Sargocentron	Cirripectes	Novaculichthys	Cirripectes	Epinephelus
Cirripectes	Cephalopholis	Chaetodon	Rhinecanthus	Scarus	Cephalopholus
Sufflamen	Ostracion	Cephalophalus	Coris	Centropyge	Centropyge
Coris	Dascyllus	Pomacanthus		Navaculichtys	Paracirrhites
Oxychielerus	Scarus			Parupeneus	Coris
	Paracirrhites			Paracirrhites	Chaetodon
	Novaculichthys				Dascyllus
	Cirripectes				Abodefduf
	Signanus				Parupeneus
	Balistoides				Lutjanus
	Sufflamen				Zanclus
					Pygoplites
					Monotaxis
					Chrysiptera
					Cheilinas
					Hemigymnus
					Novaculichthys
					Cirripectes
					Balistapus
					Syfflamen
					Oxymonocanthus
					Forcipiger

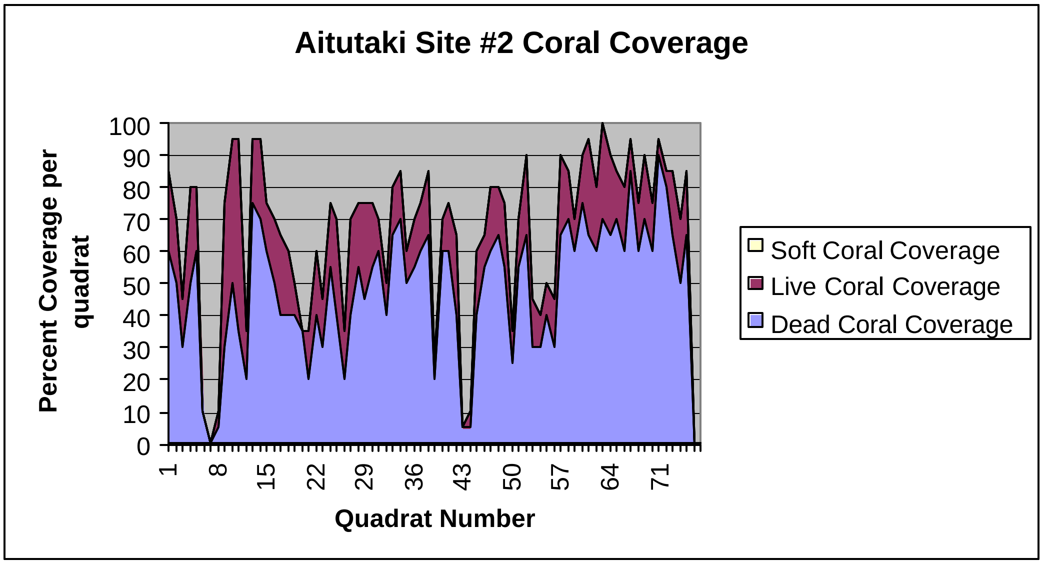
Quantitative Ecological Data

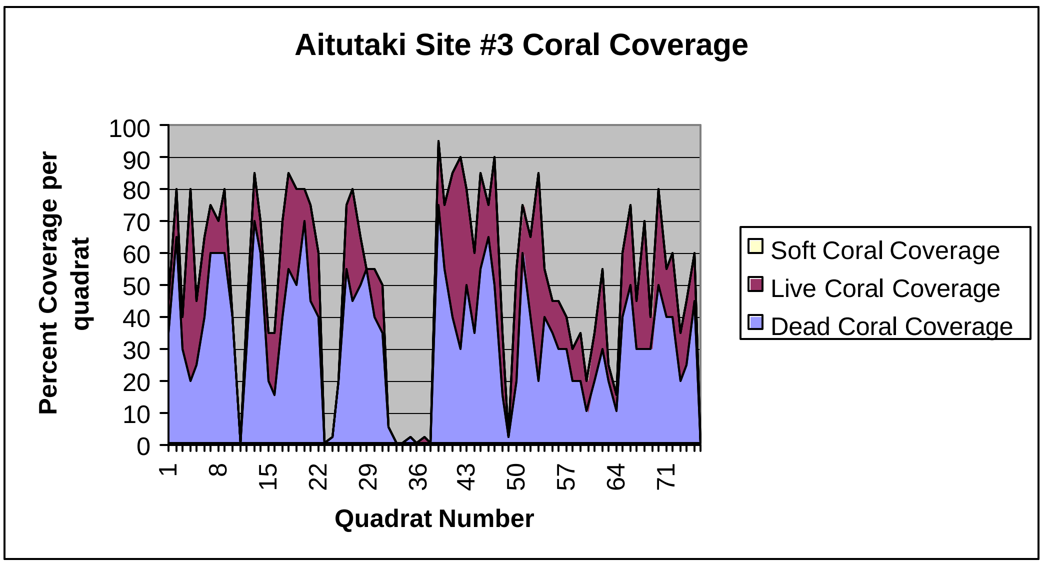
Data were obtained using the methods outlined in Chapter 1. As previously described, each site was composed of three, 25 meter transect lines with counts done every meter for a total of 75 quadrats for each site. Data for each island study site is presented in graphs. The graphs on percent coral coverage quantify the percent coverage of hard and soft coral for each quadrat. Both hard and soft coral species diversity per quadrat is displayed. In addition, the presence the bioindicators filamentous algae and Cyanophyta are shown as well as the number of coral impacts. The number of coral impacts is composed of quantification of the clonal condition and the number of affected coral and coralline algae by a biotic factor.

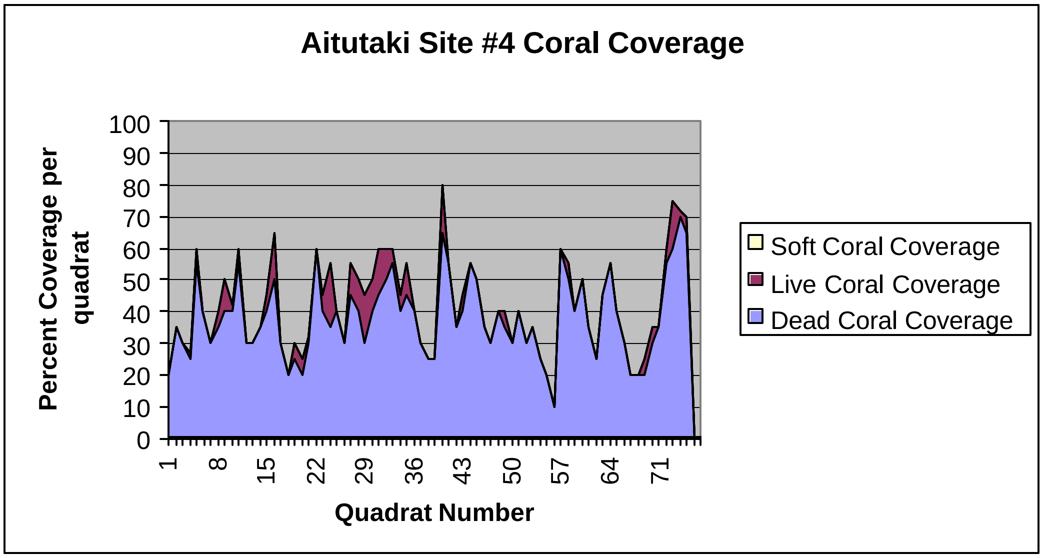
Graphs 4.1 – 4.5: Percent Coral Coverage, Aitutaki, Cook Islands

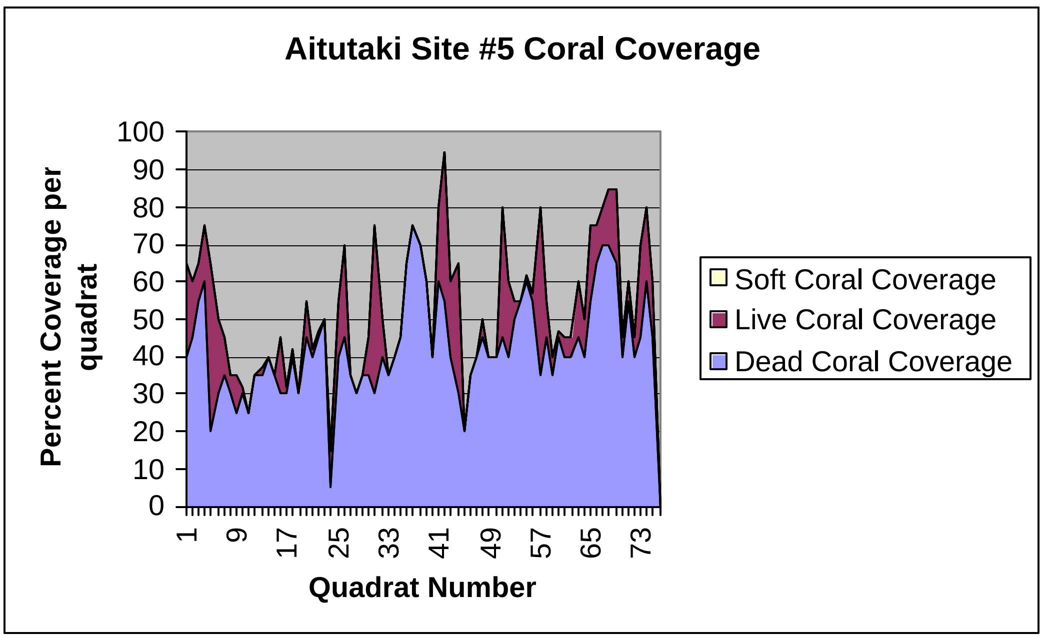




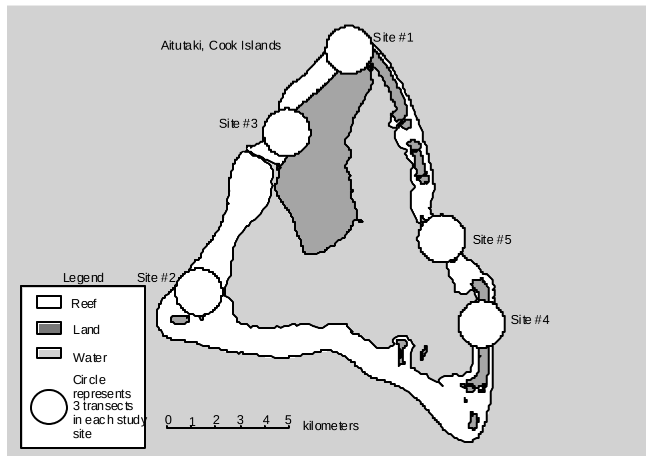

Aitutaki Site #2 Coral Coverage
Percent Coverage per quadrat
100
90
80
70
60
50
40
30
20
10
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

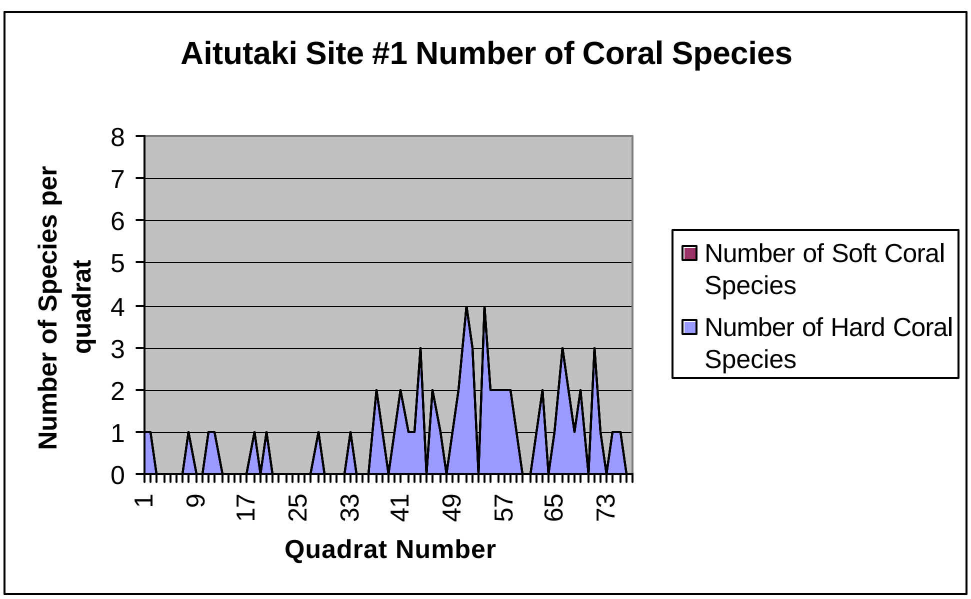

Aitutaki Site #3 Coral Coverage
Percent Coverage per quadrat
100
90
80
70
60
50
40
30
20
10
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

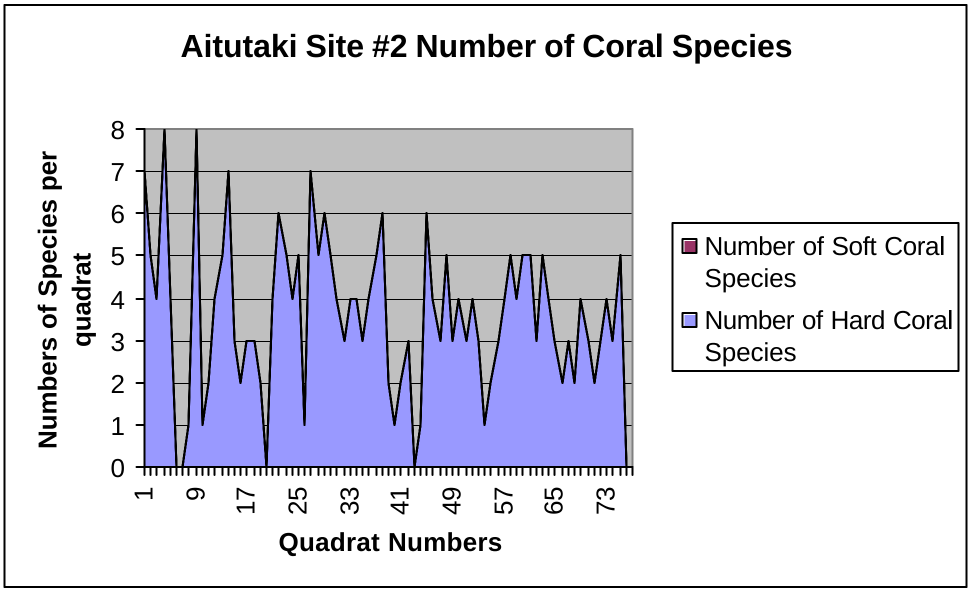

Aitutaki Site #4 Coral Coverage
Percent Coverage per quadrat
100
90
80
70
60
50
40
30
20
10
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

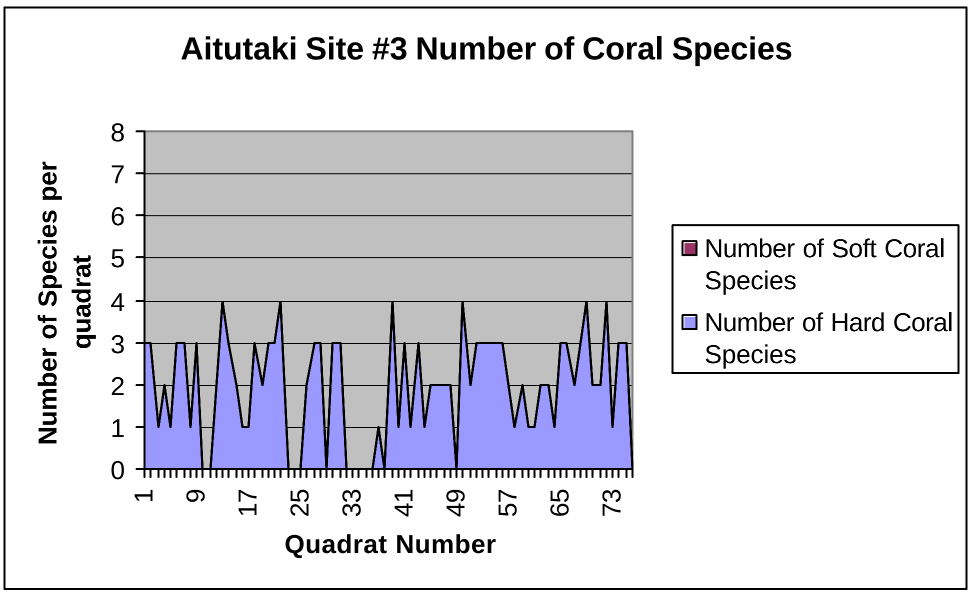

Aitutaki Site #5 Coral Coverage
Percent Coverage per quadrat
100
90
80
70
60
50
40
30
20
10
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

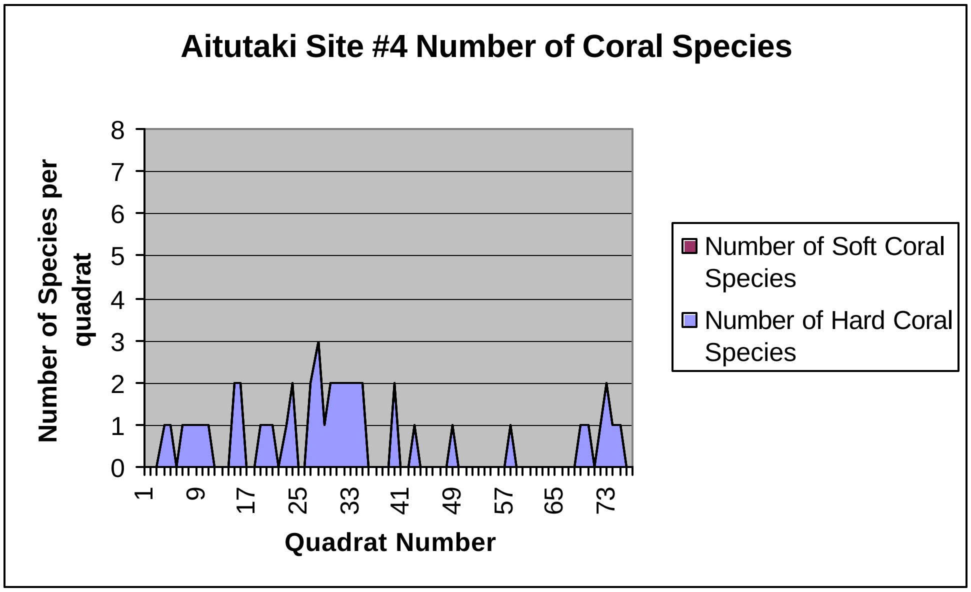
Graphs 4.6 – 4.10: Number of Coral Species, Aitutaki, Cook Islands

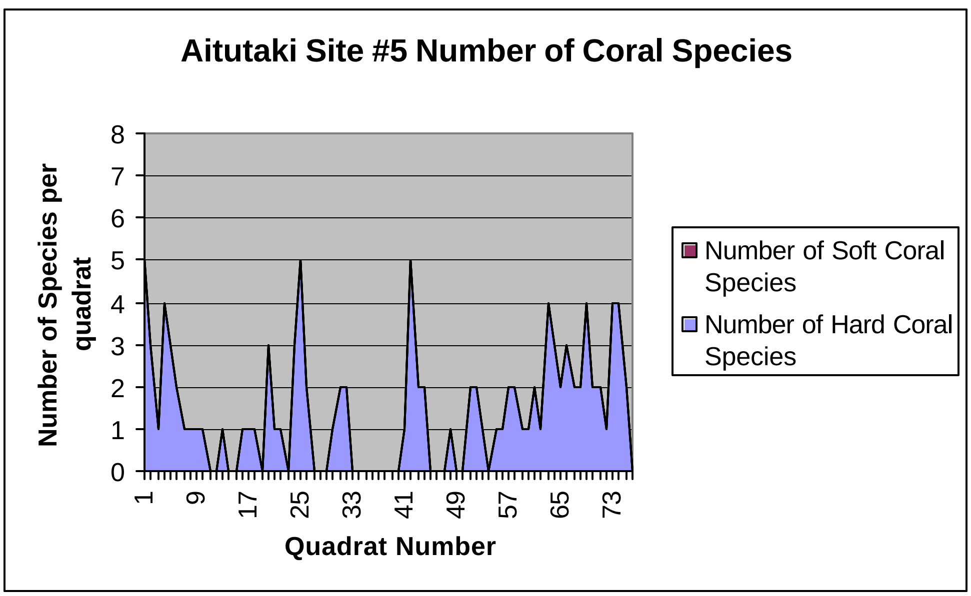




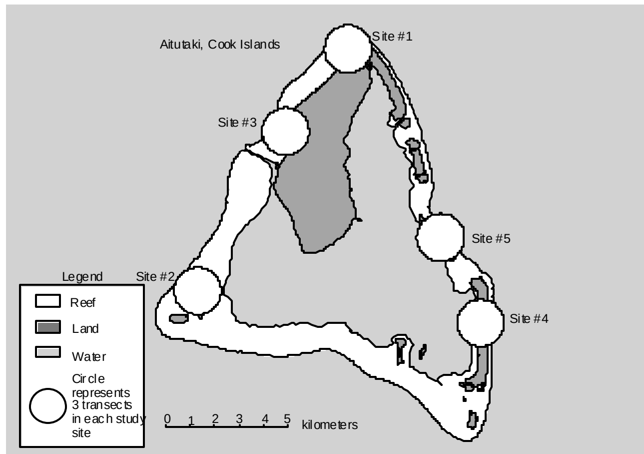

Aitutaki Site #2 Number of Coral Species
Numbers of Species per quadrat
8
7
6
5
4
3
2
1
0
1
9
17
25
33
41
49
57
65
73
Quadrat Numbers
Number of Soft Coral Species
Number of Hard Coral Species

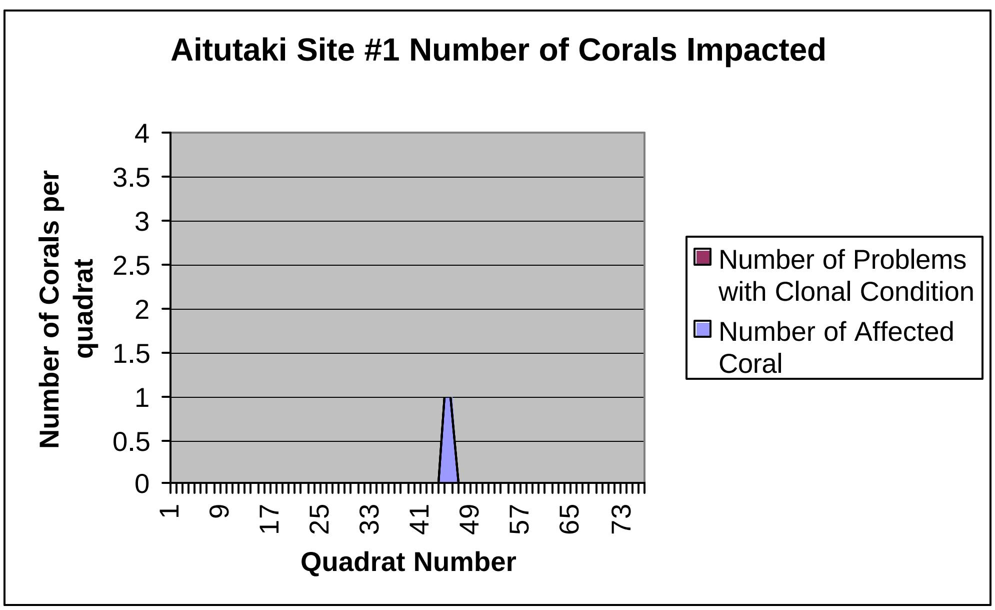

Aitutaki Site #3 Number of Coral Species
Number of Species per quadrat
8
7
6
5
4
3
2
1
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

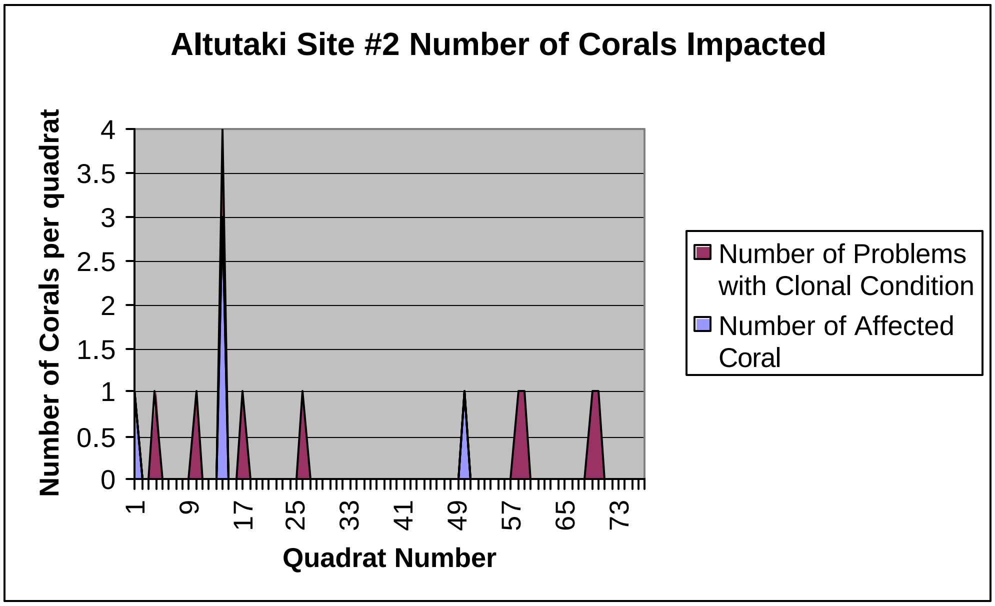

Aitutaki Site #4 Number of Coral Species
Number of Species per quadrat
8
7
6
5
4
3
2
1
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species


Aitutaki Site #5 Number of Coral Species
Number of Species per quadrat
8
7
6
5
4
3
2
1
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

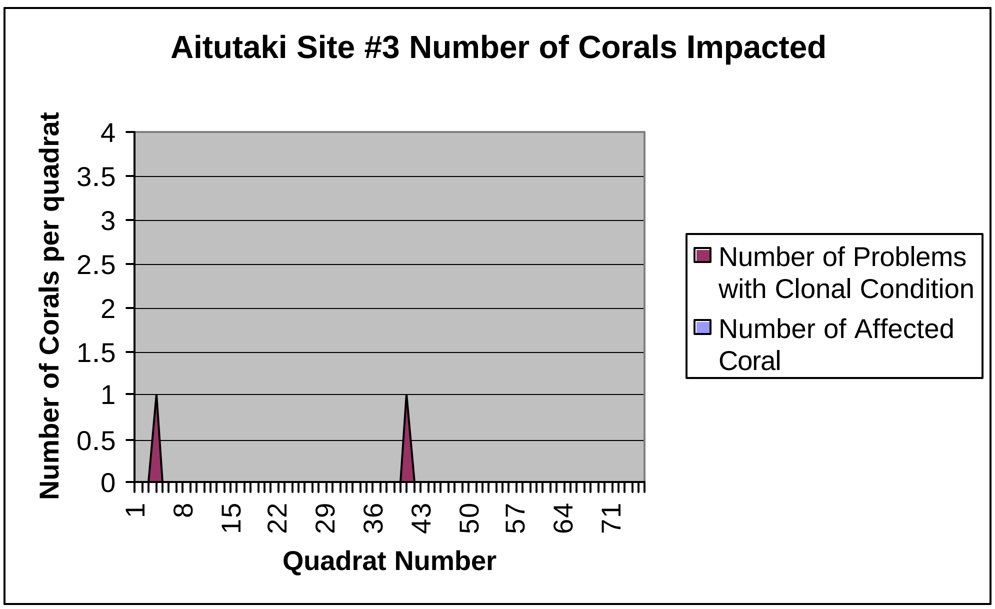
Graphs 4.11 – 4.15: Number of Coral Impacts, Aitutaki, Cook Islands



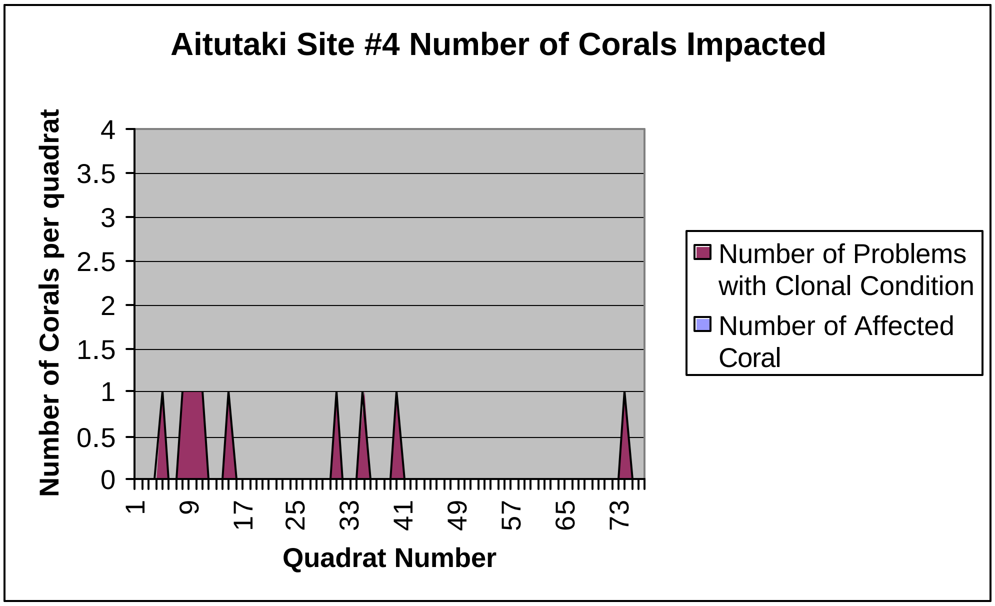


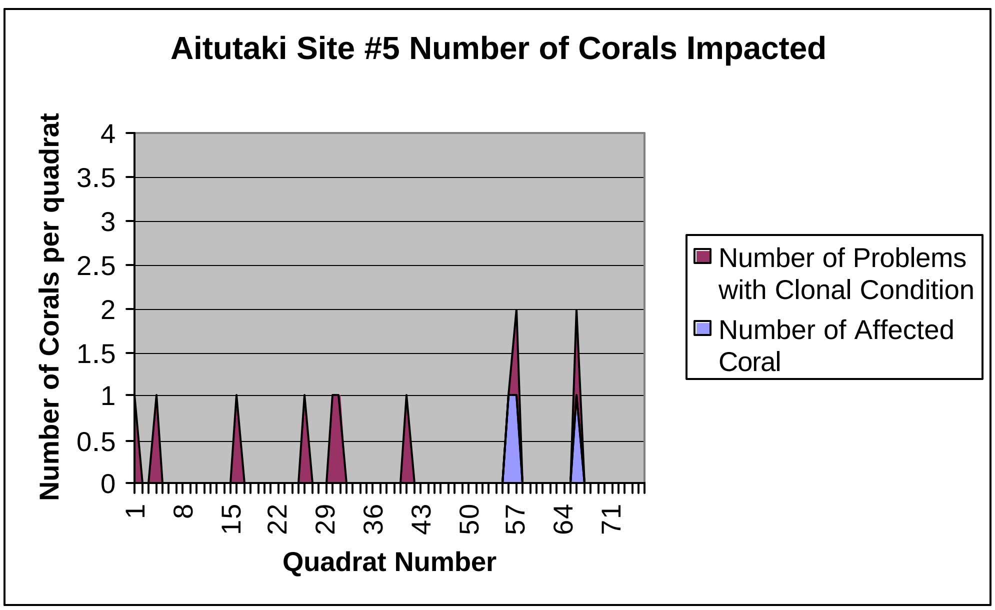


Altutaki Site #2 Number of Corals Impacted
Number of Corals per quadrat
4
3.5
3
2.5
2
1.5
1
0.5
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

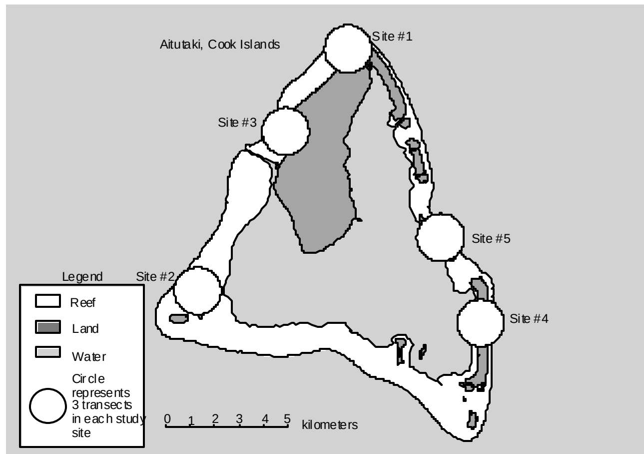


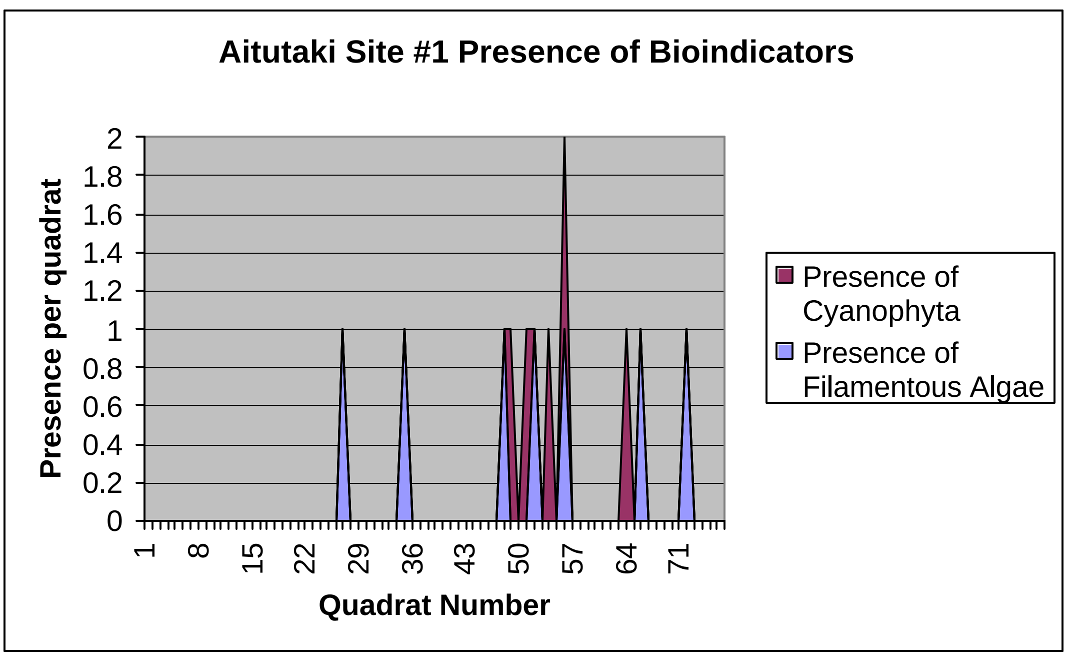
Aitutaki Site #3 Number of Corals Impacted
Number of Corals per quadrat
4
3.5
3
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

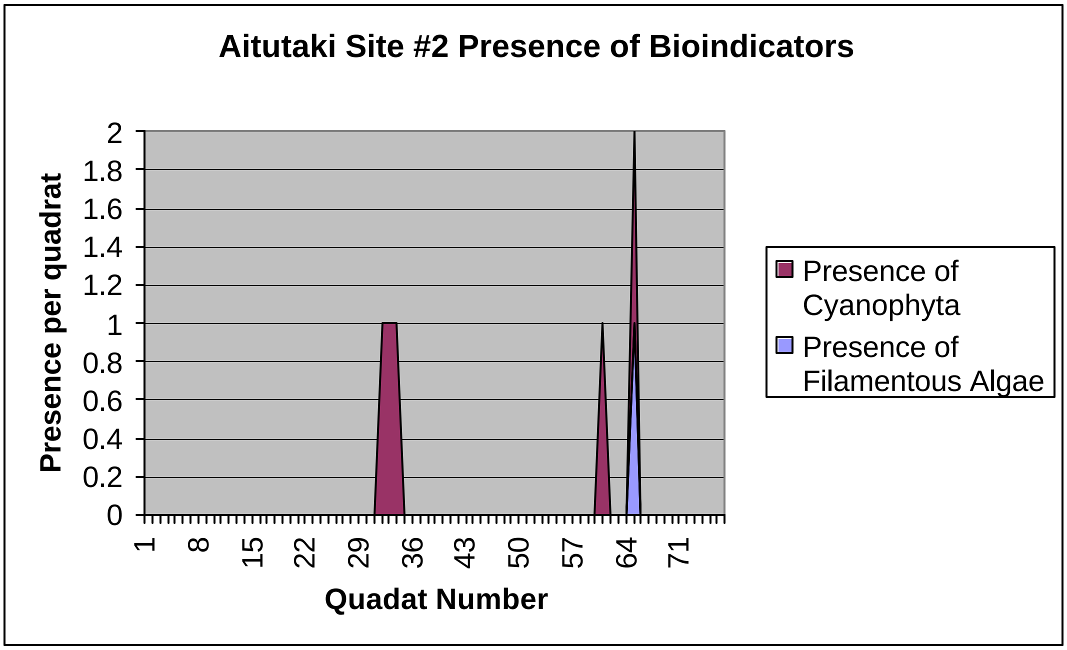

Aitutaki Site #4 Number of Corals Impacted
Number of Corals per quadrat
4
3.5
3
2.5
2
1.5
1
0.5
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

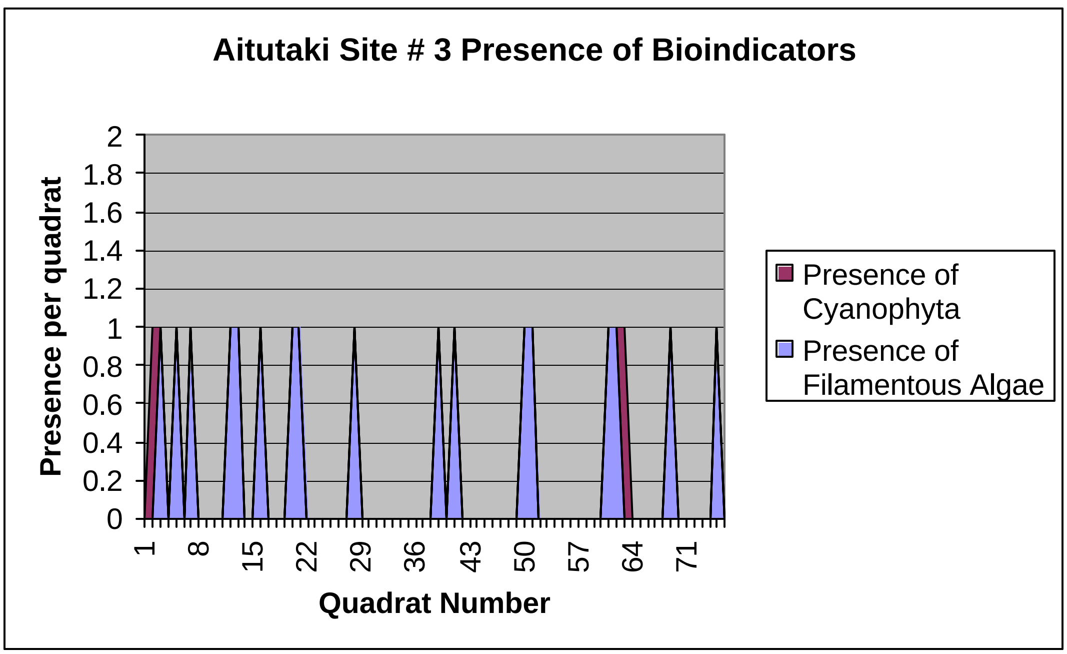

Aitutaki Site #5 Number of Corals Impacted
Number of Corals per quadrat
4
3.5
3
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

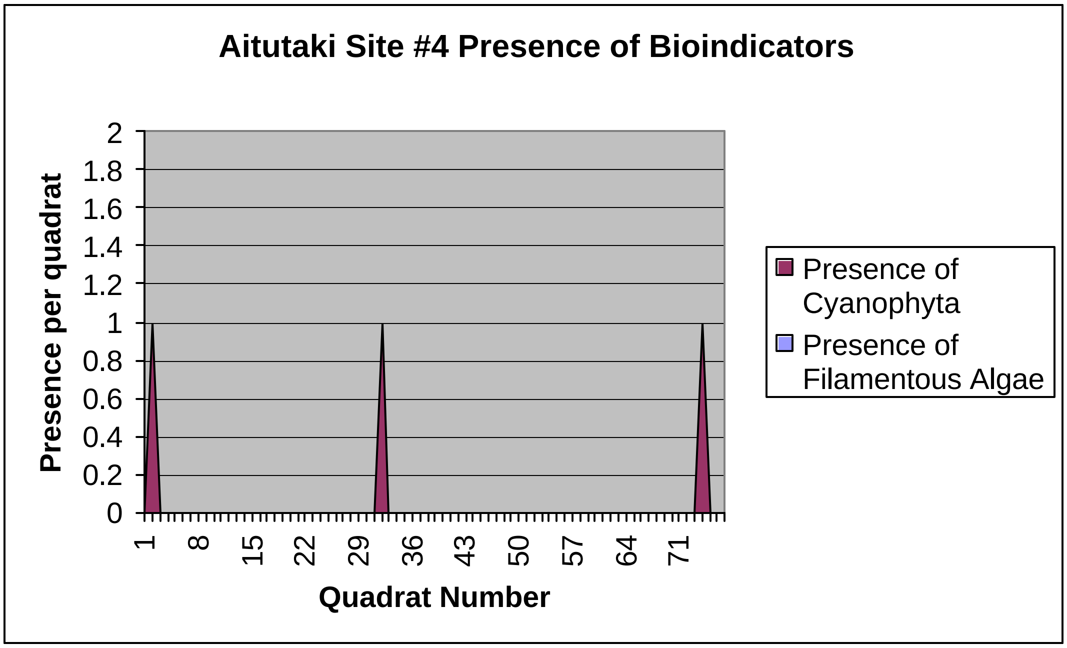
Graphs 4.16 - 4.20: Presence of Bioindicators, Aitutaki, Cook Islands

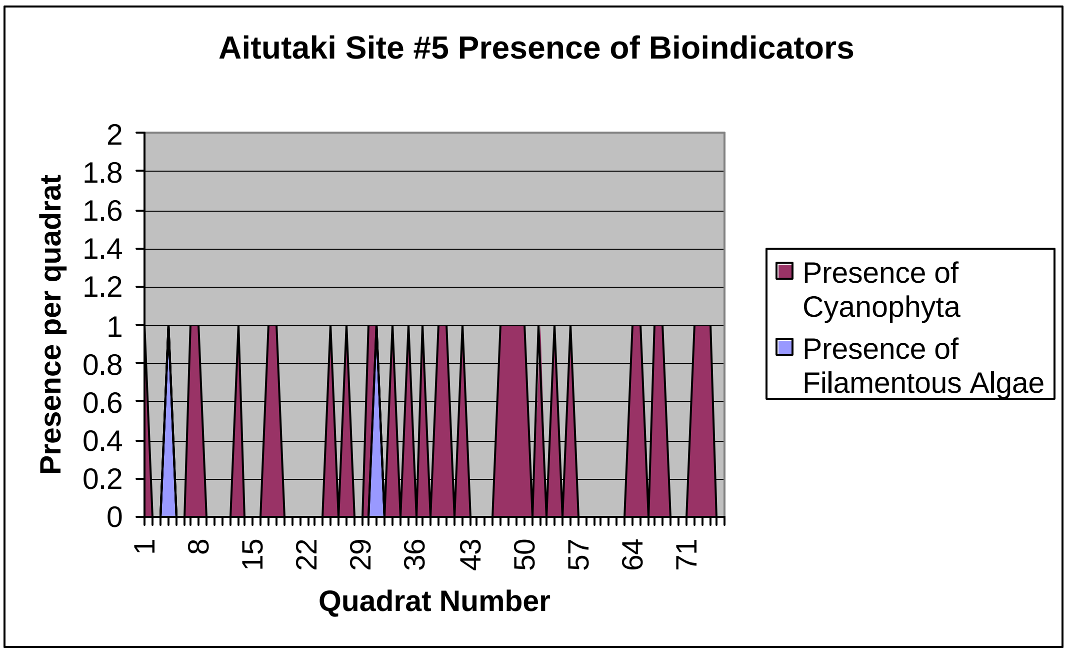




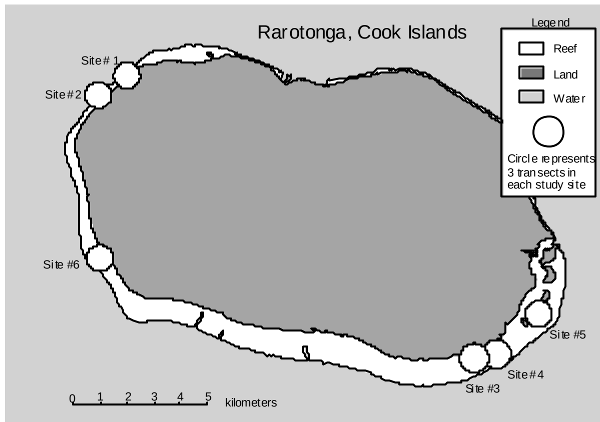

Aitutaki Site #2 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
8
15
22
29
36
43
50
57
64
71
Quadat Number
Presence of Cyanophyta
Presence of Filamentous Algae

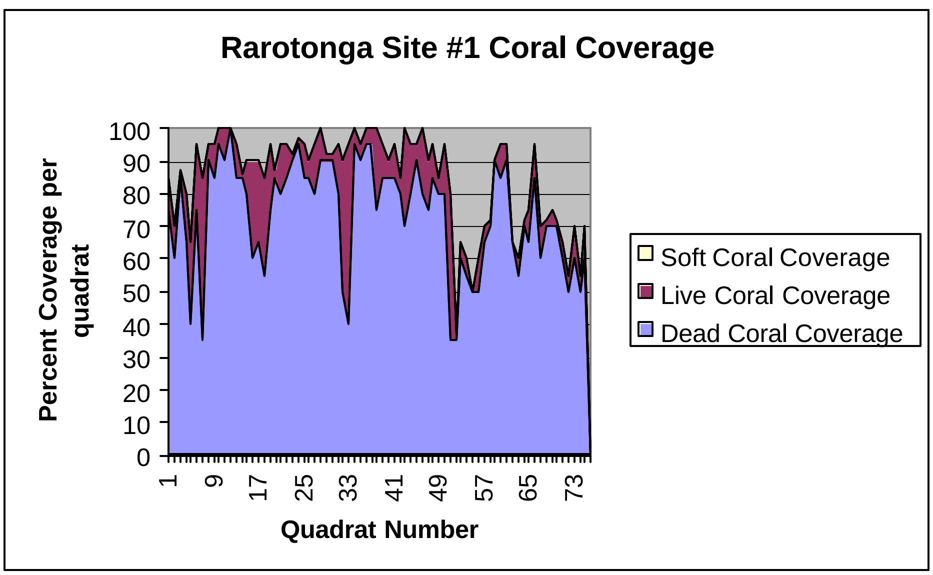

Aitutaki Site # 3 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae

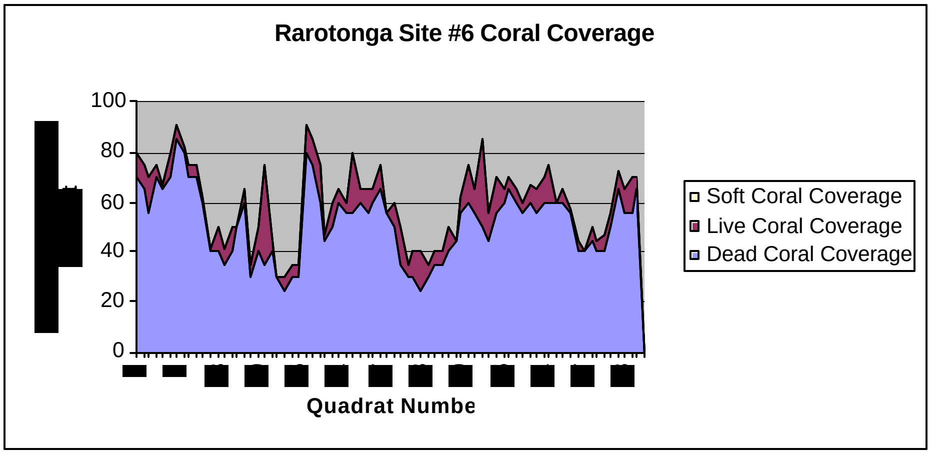

Aitutaki Site #4 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae

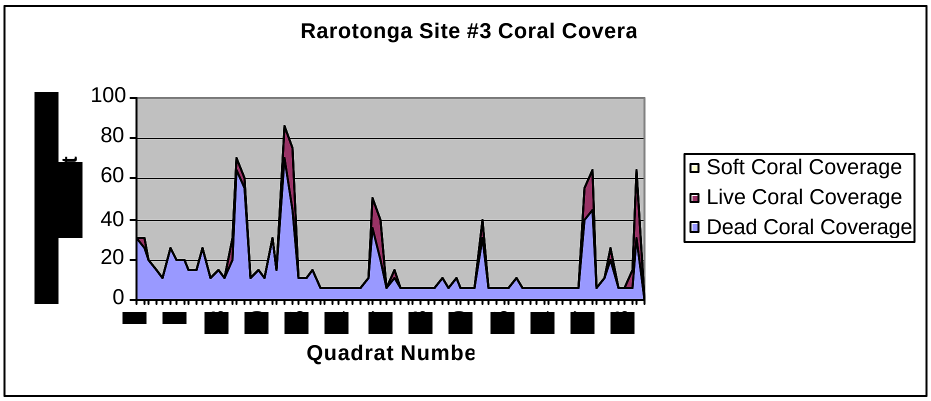

Aitutaki Site #5 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae

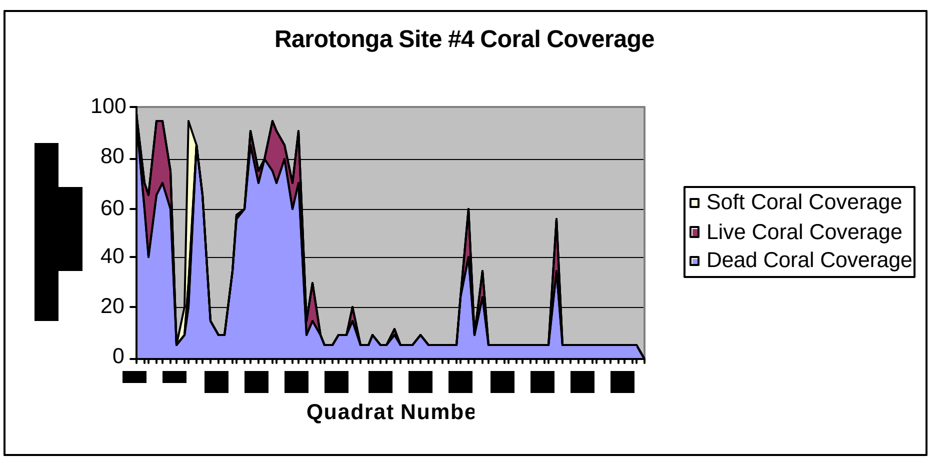
Graphs 4.21 – 4.26: Percent Coral Coverage, Rarotonga, Cook Islands

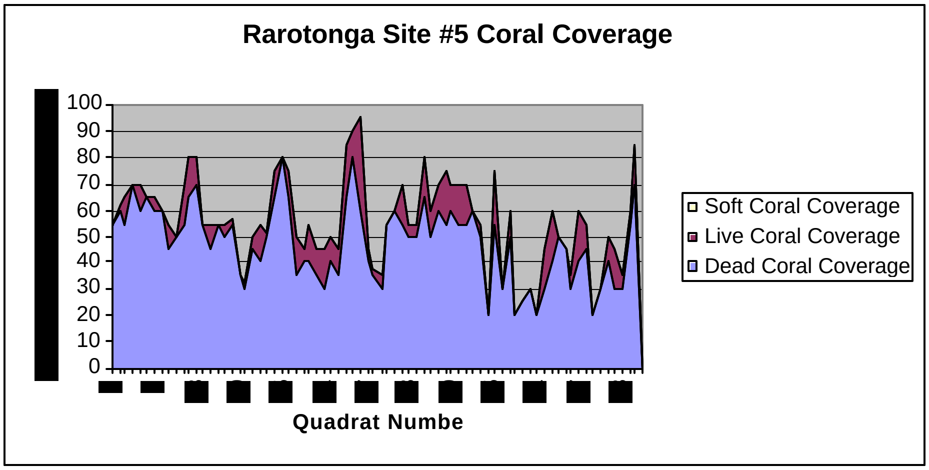


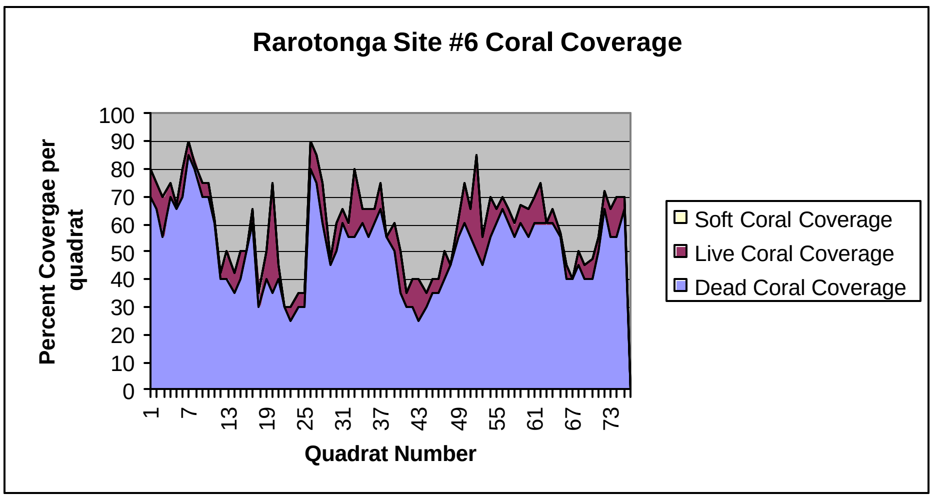



Rarotonga Site #6 Coral Coverage
100
80
60
40
20
0
Quadrat Numbe
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

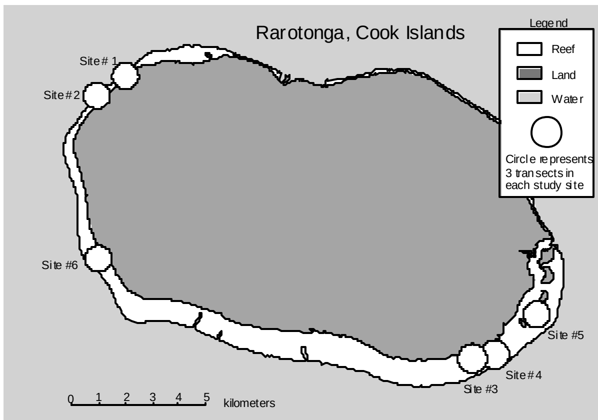

Rarotonga Site #3 Coral Covera
100
80
60
40
20
0
Quadrat Numbe
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

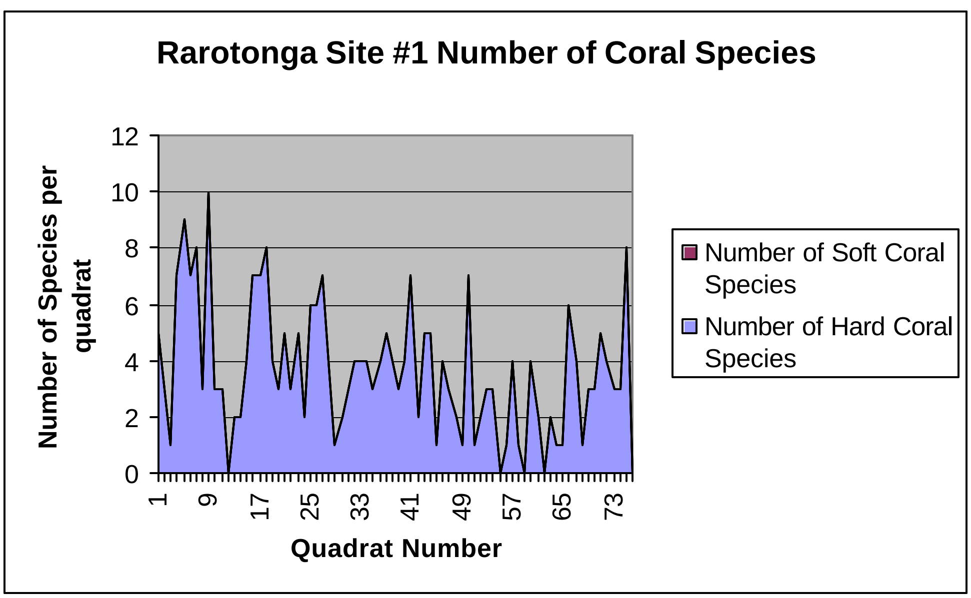

Rarotonga Site #4 Coral Coverage
100
80
60
40
20
0
Quadrat Numbe
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

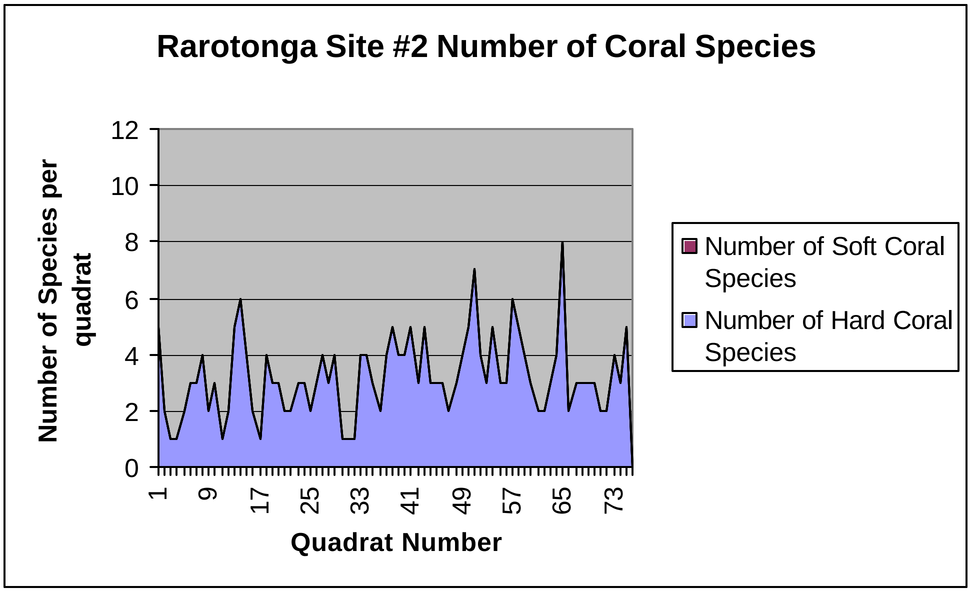

Rarotonga Site #5 Coral Coverage
[redacted]
100
90
80
70
60
50
40
30
20
10
0
[redacted]
Quadrat Numbe
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

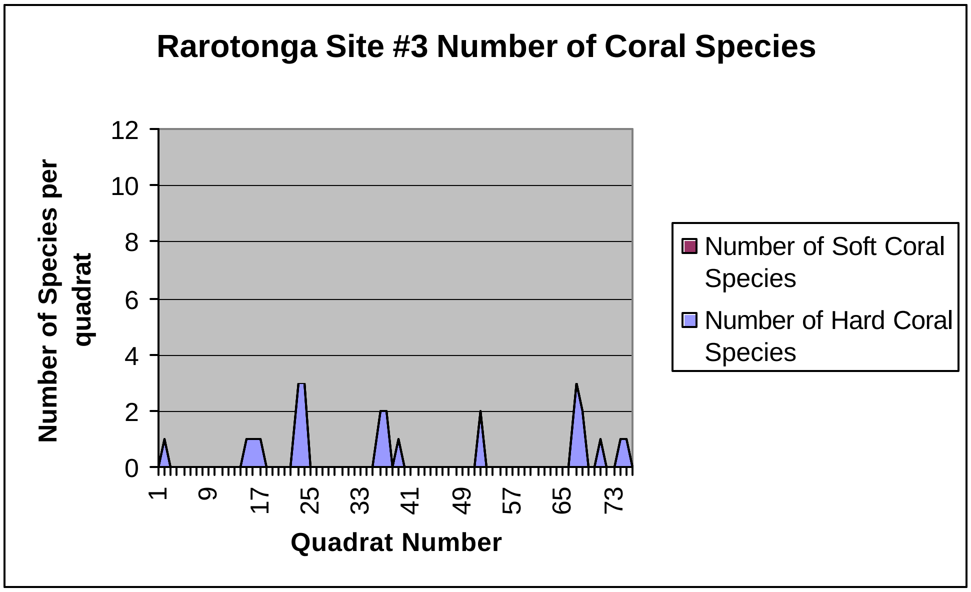

Rarotonga Site #6 Coral Coverage
Percent Covergae per quadrat
100
90
80
70
60
50
40
30
20
10
0
1
7
13
19
25
31
37
43
49
55
61
67
73
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

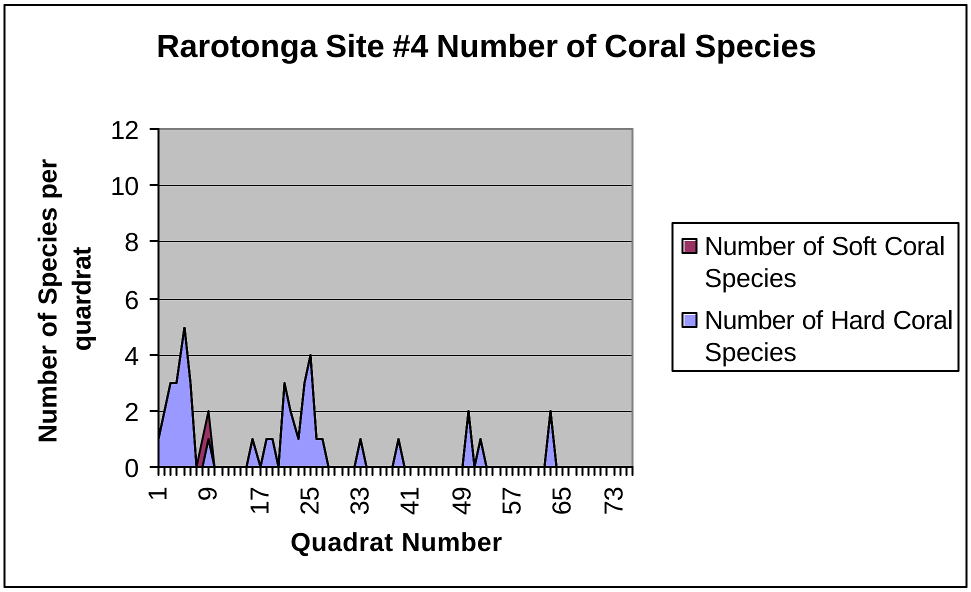
Graphs 4.27 – 4.32: Number of Coral Species, Rarotonga, Cook Islands

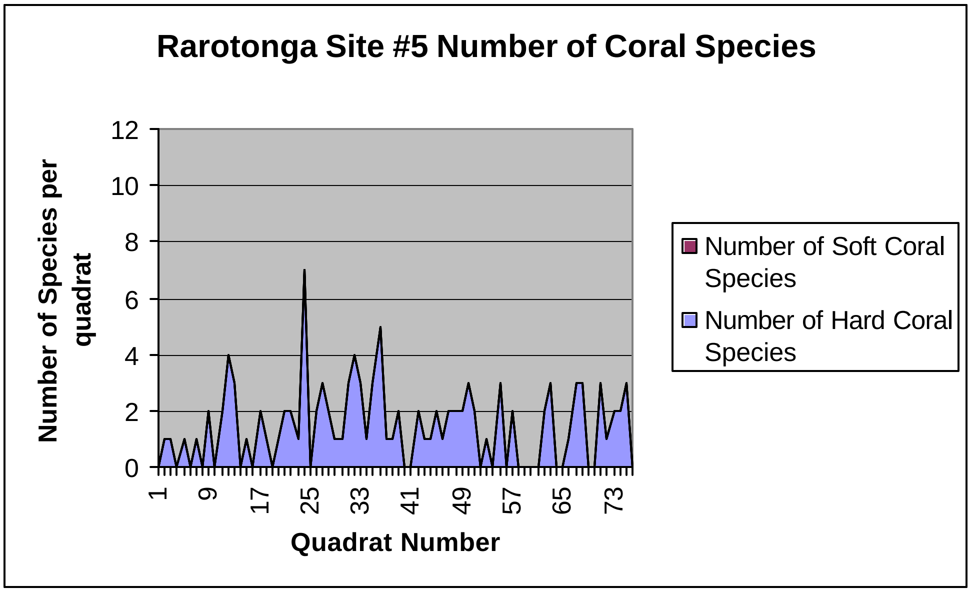




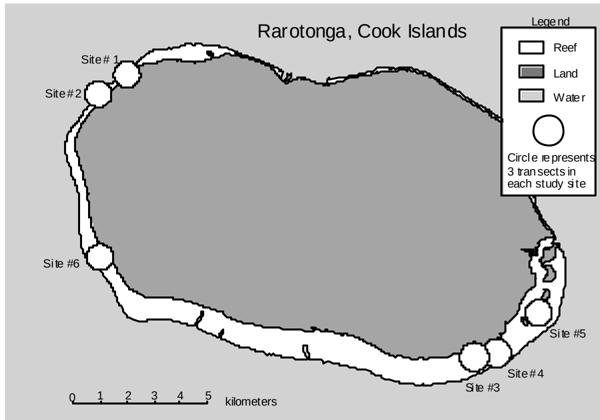

Rarotonga Site #2 Number of Coral Species
Number of Species per quadrat
12
10
8
6
4
2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

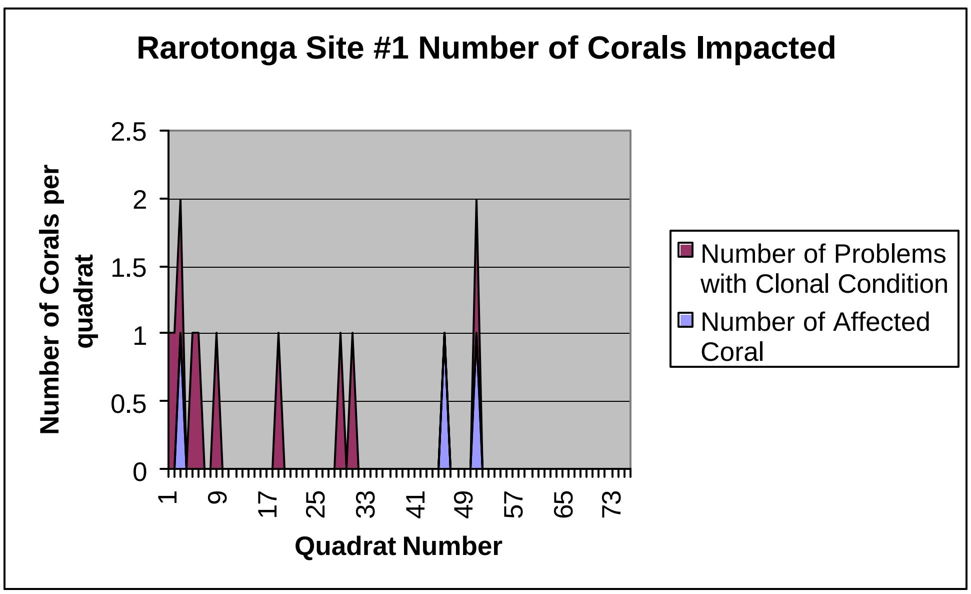

Rarotonga Site #3 Number of Coral Species
Number of Species per quadrat
12
10
8
6
4
2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

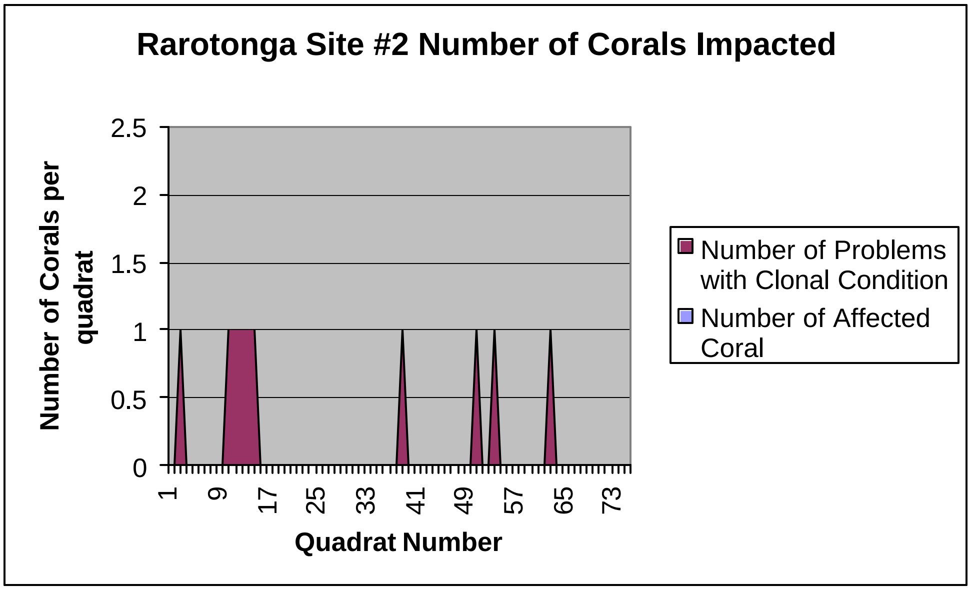

Rarotonga Site #4 Number of Coral Species
Number of Species per quardrat
12
10
8
6
4
2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

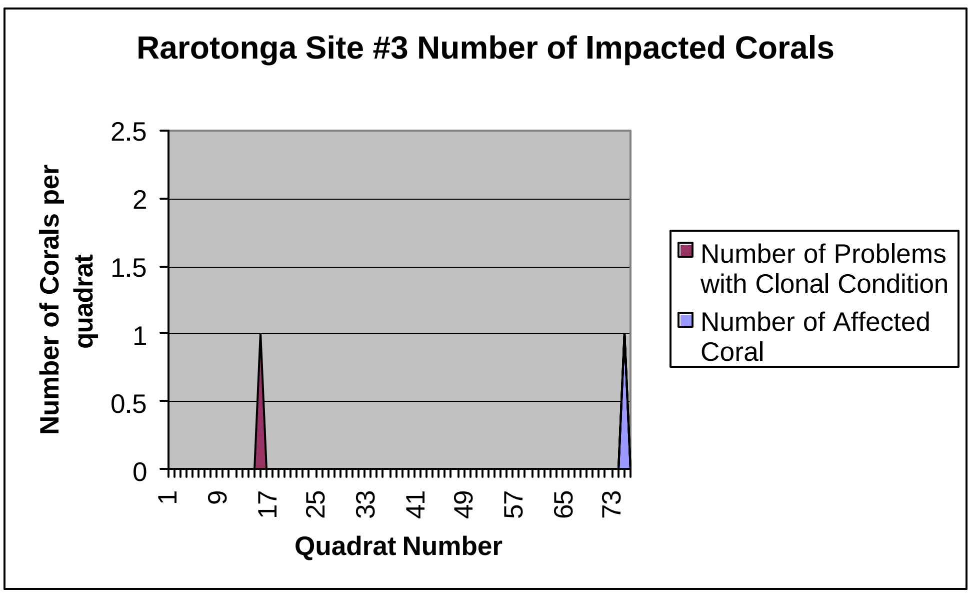

Rarotonga Site #5 Number of Coral Species
Number of Species per quadrat
12
10
8
6
4
2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

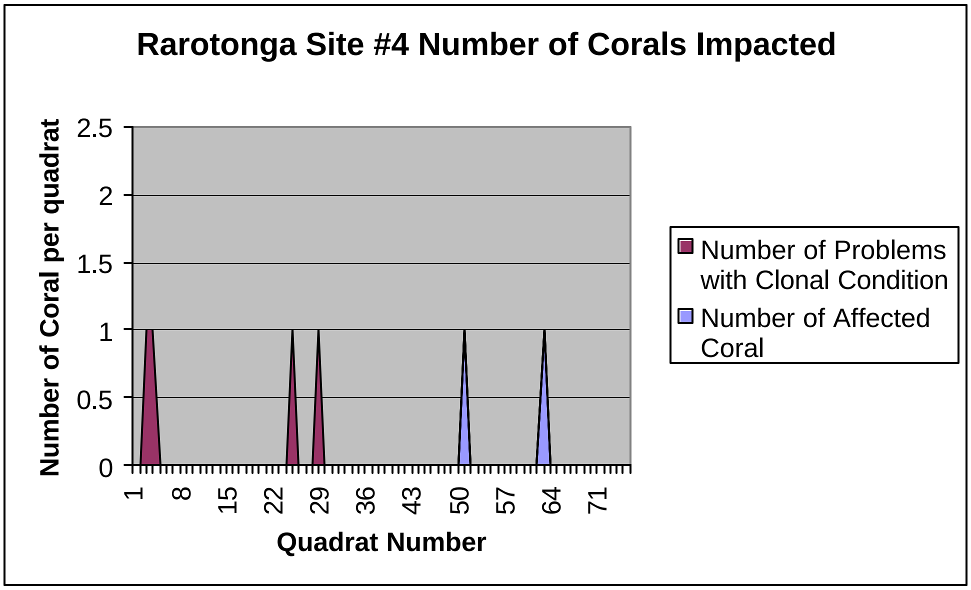
Graphs 4.33 – 4.38: Number of Coral Impacts, Rarotonga, Cook Islands

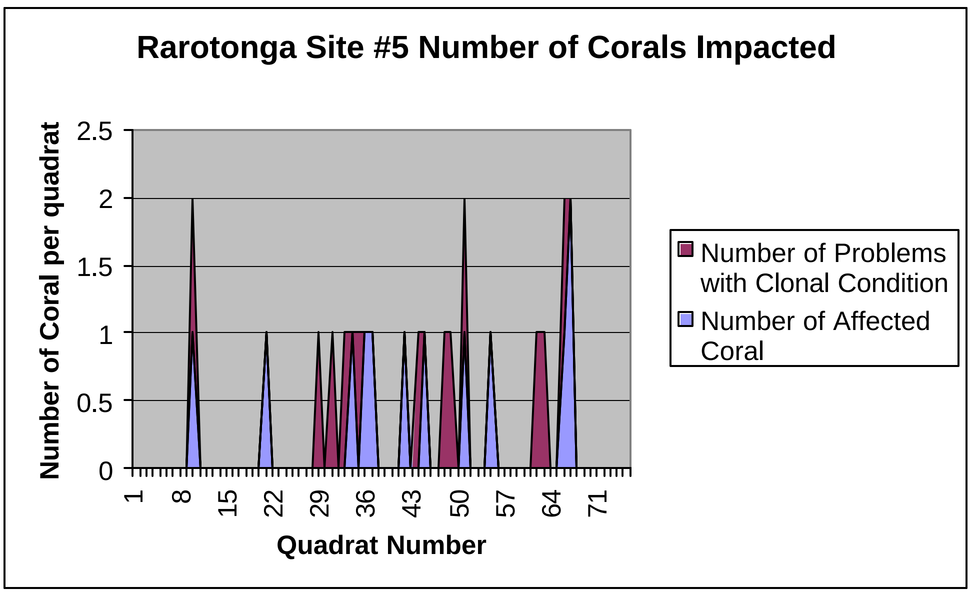




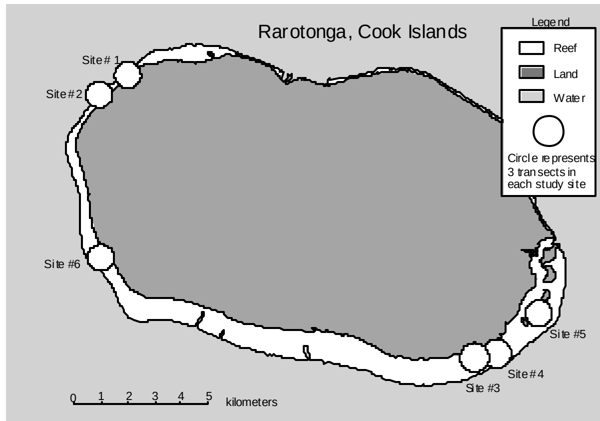

Rarotonga Site #2 Number of Corals Impacted
Number of Corals per quadrat
2.5
2
1.5
1
0.5
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

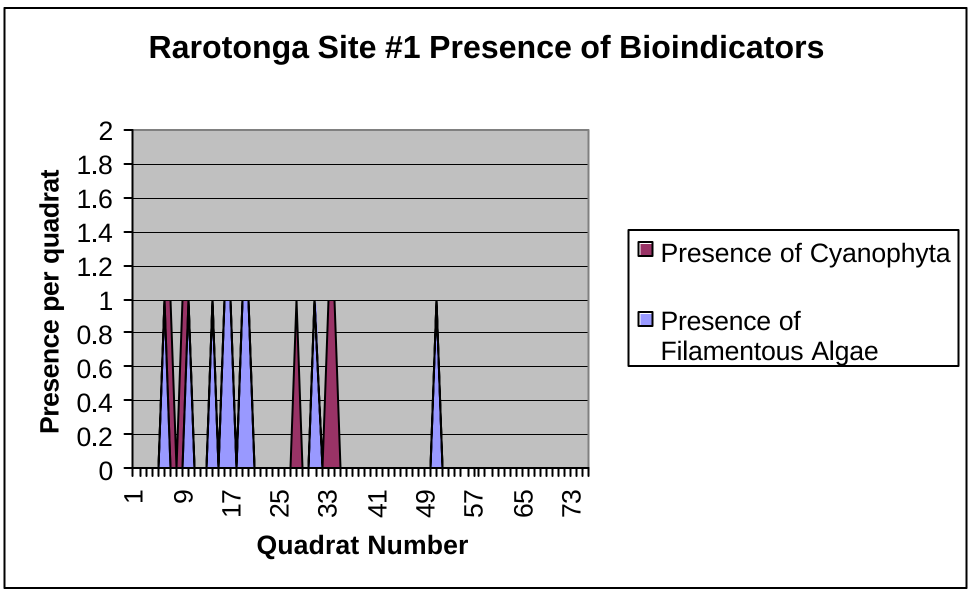

Rarotonga Site #3 Number of Impacted Corals
Number of Corals per quadrat
2.5
2
1.5
1
0.5
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

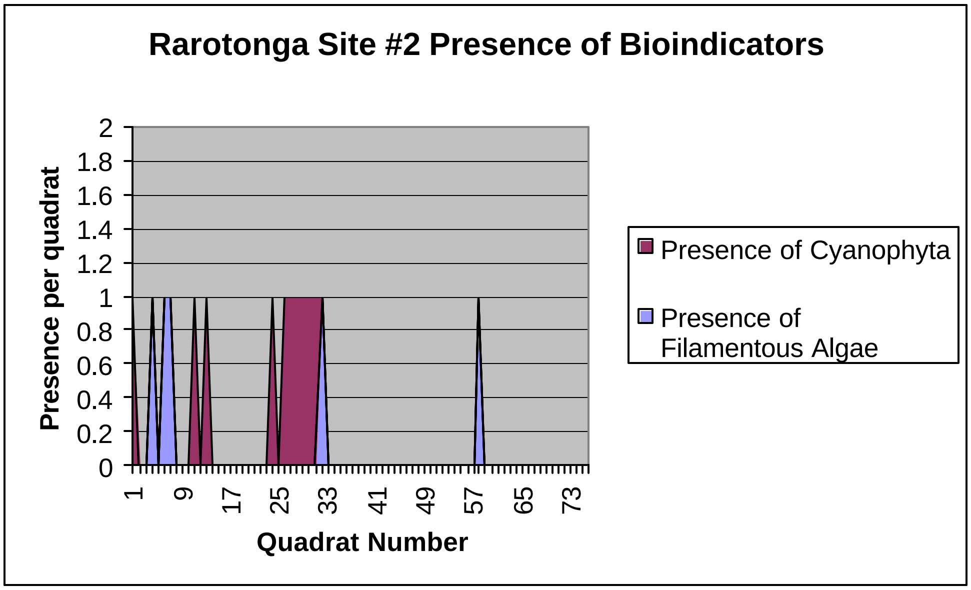

Rarotonga Site #4 Number of Corals Impacted
Number of Coral per quadrat
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

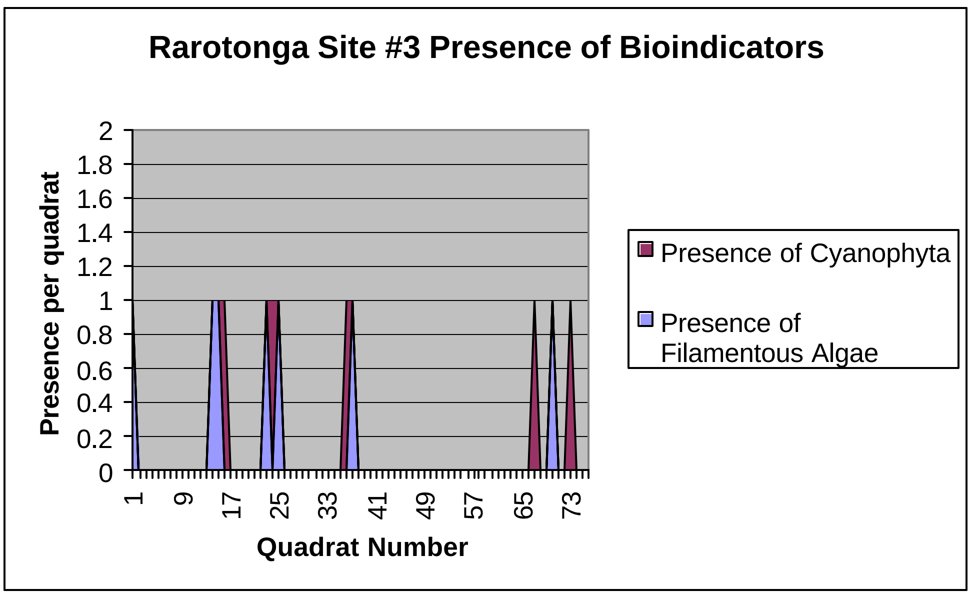

Rarotonga Site #5 Number of Corals Impacted
Number of Coral per quadrat
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

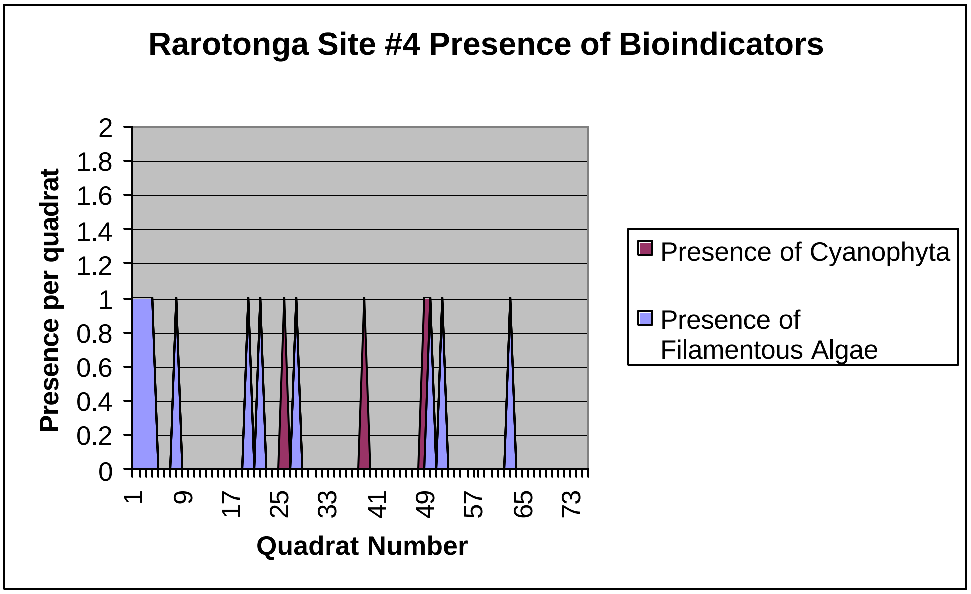
4.39 – 4.44: Presence of Bioindicators, Rarotonga, Cook Islands

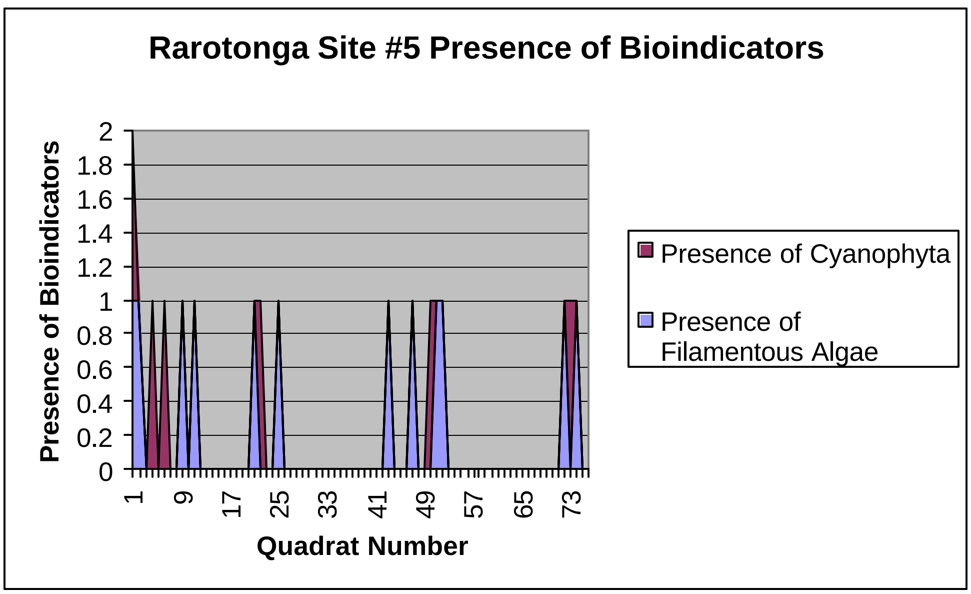


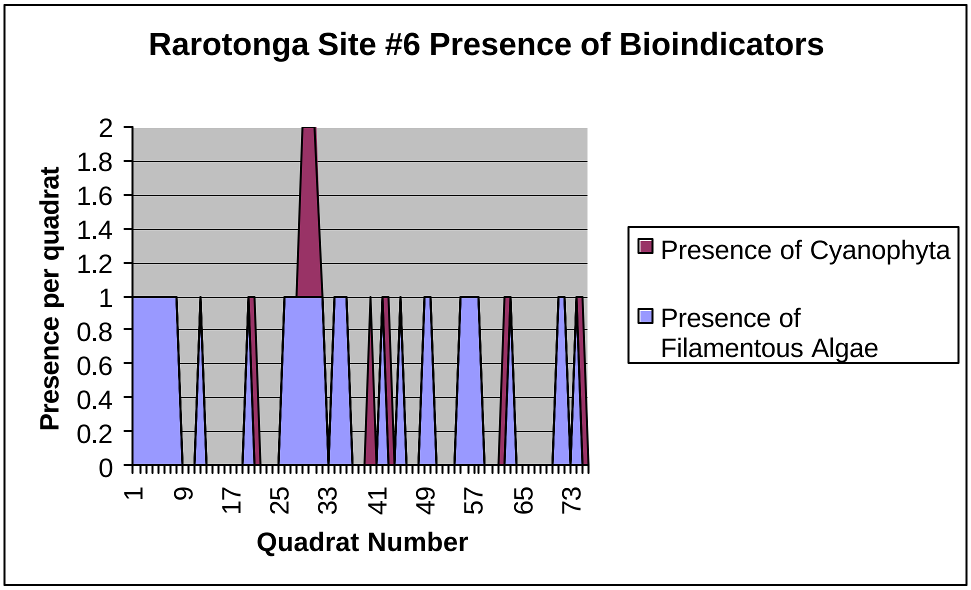



Rarotonga Site #2 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae

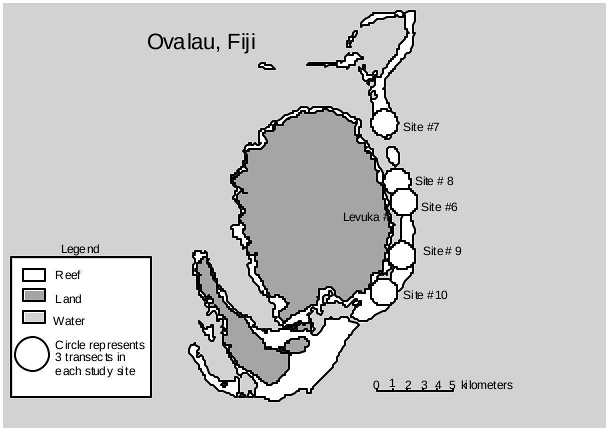

Rarotonga Site #3 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae

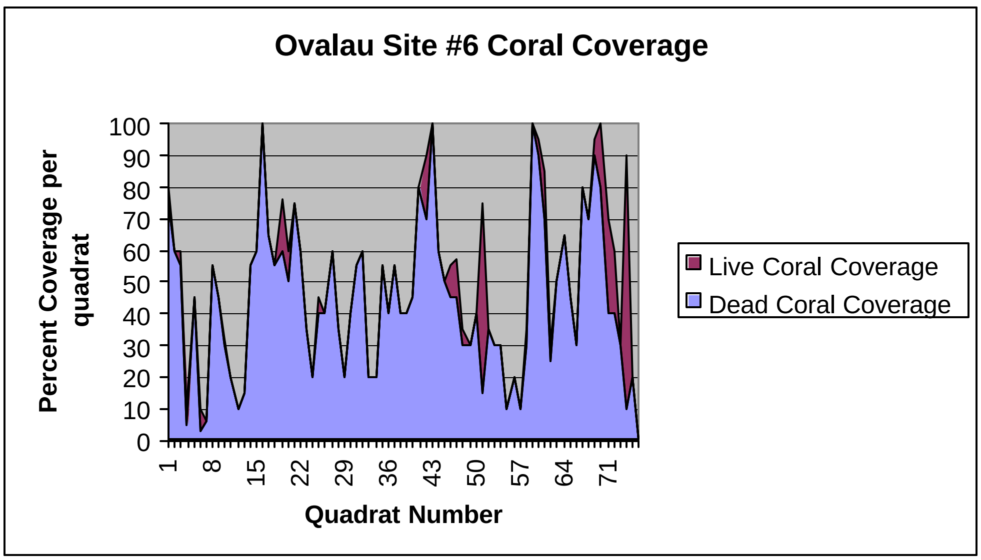

Rarotonga Site #4 Presence of Bioindicators
Presence per quadrat
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73

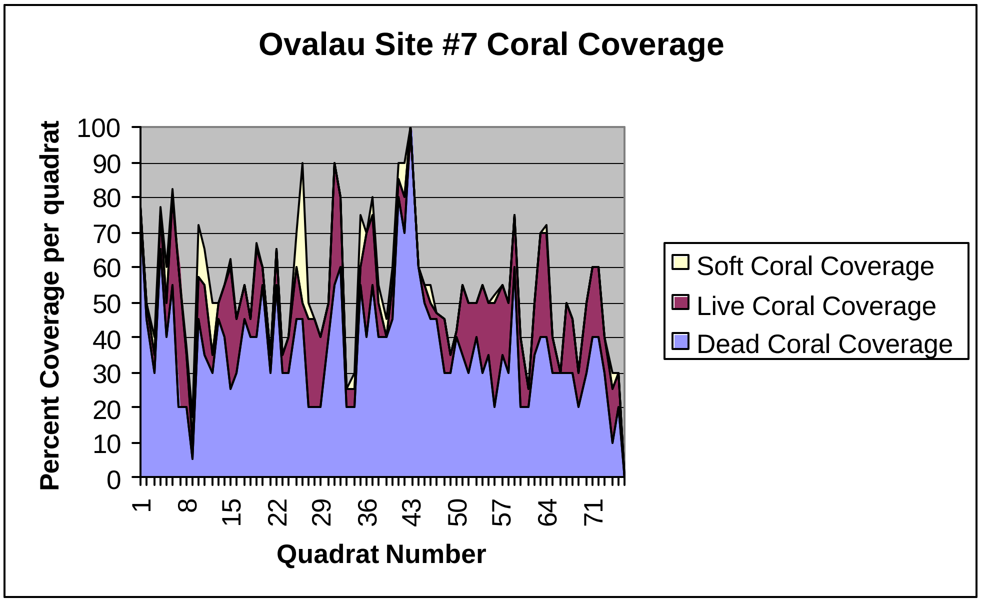

Rarotonga Site #5 Presence of Bioindicators
Presence of Bioindicators
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73

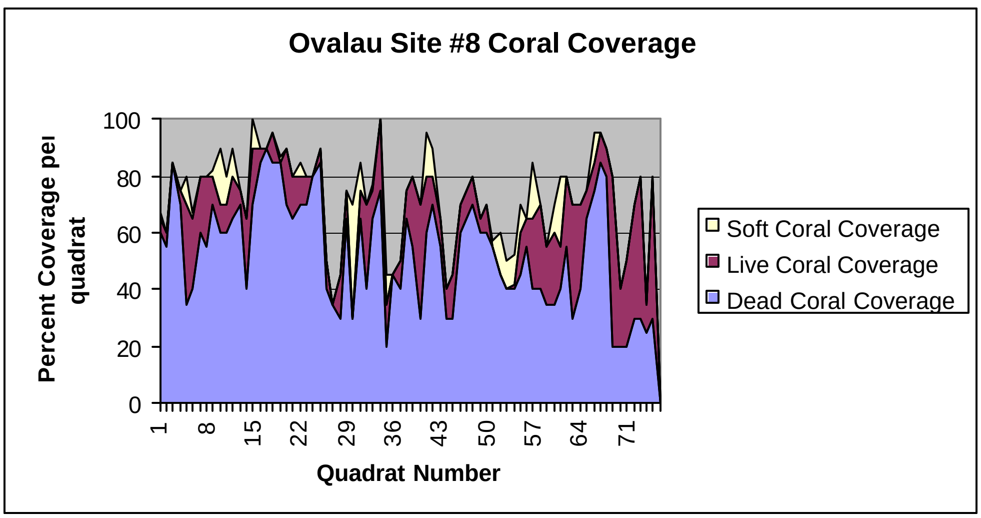

Rarotonga Site #6 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae

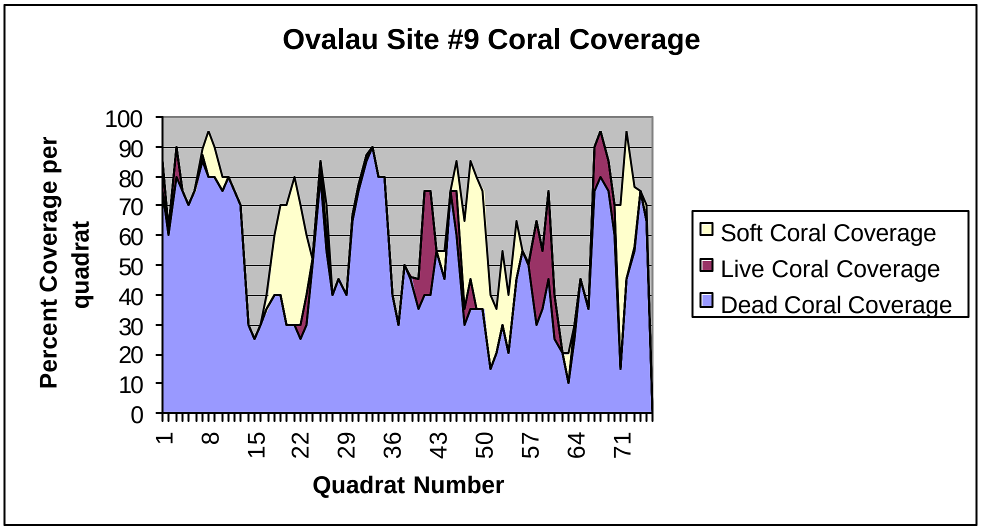
Graphs 4.45 – 4.49: Percent Coral Cover, Ovalau, Fiji

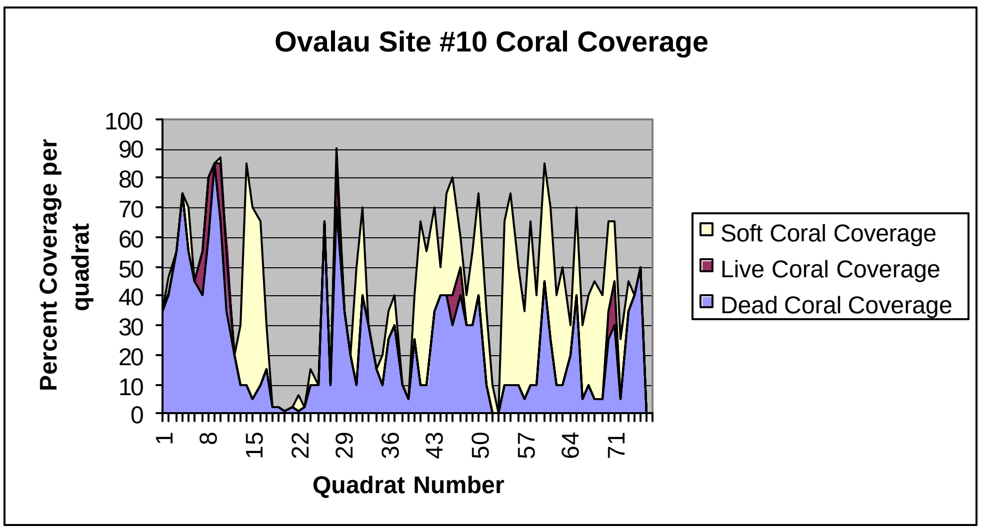




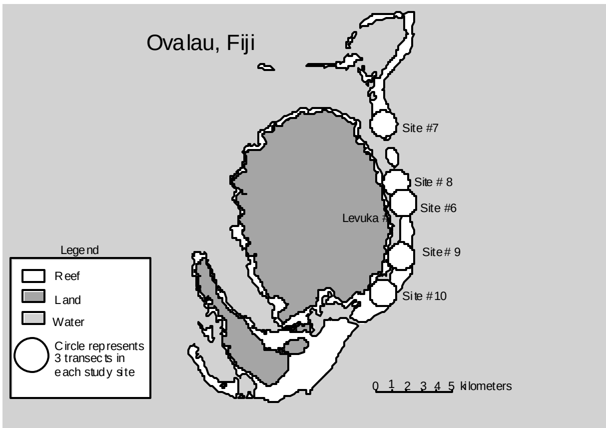

Ovalau Site #7 Coral Coverage
Percent Coverage per quadrat
100
90
80
70
60
50
40
30
20
10
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

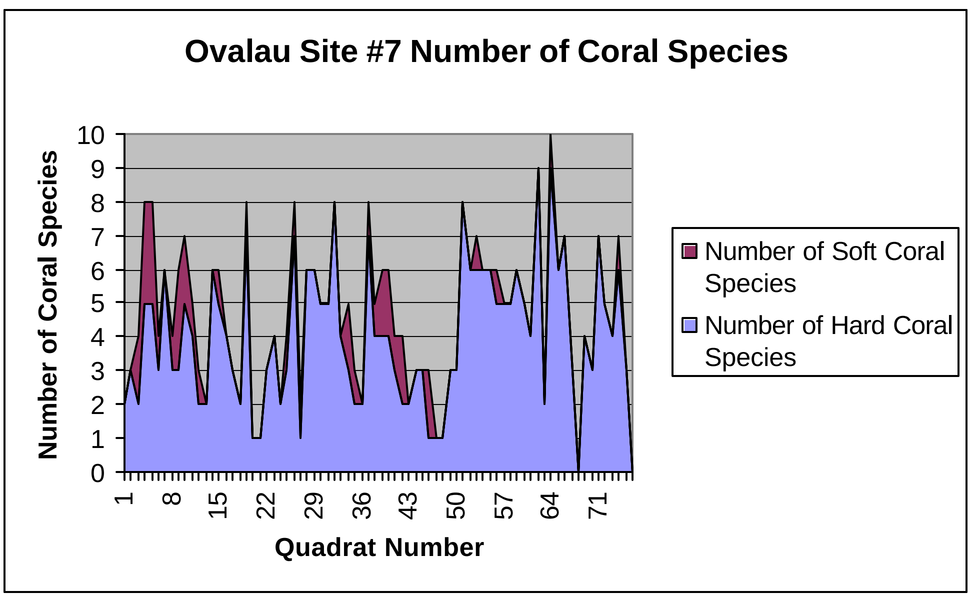

Ovalau Site #8 Coral Coverage
Percent Coverage pei quadrat
100
80
60
40
20
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

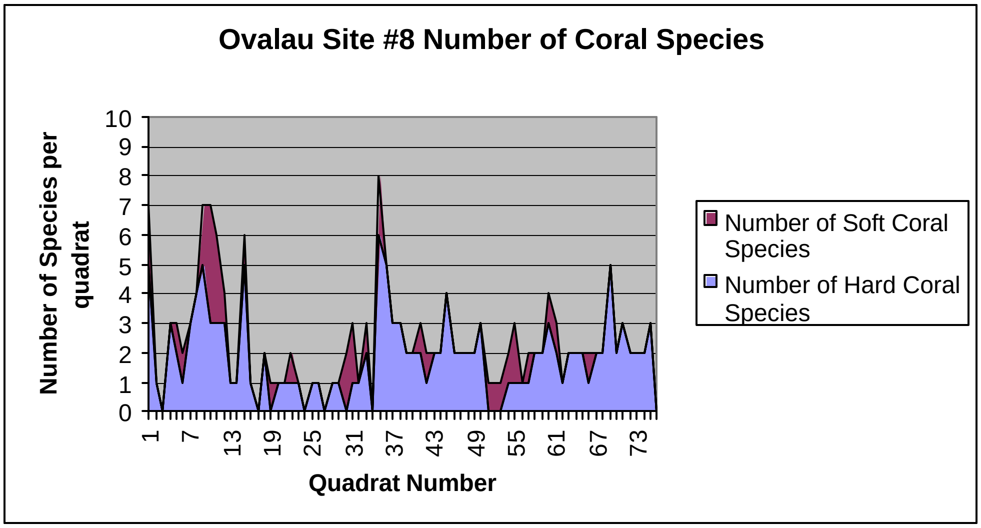

Ovalau Site #9 Coral Coverage
Percent Coverage per quadrat
100
90
80
70
60
50
40
30
20
10
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

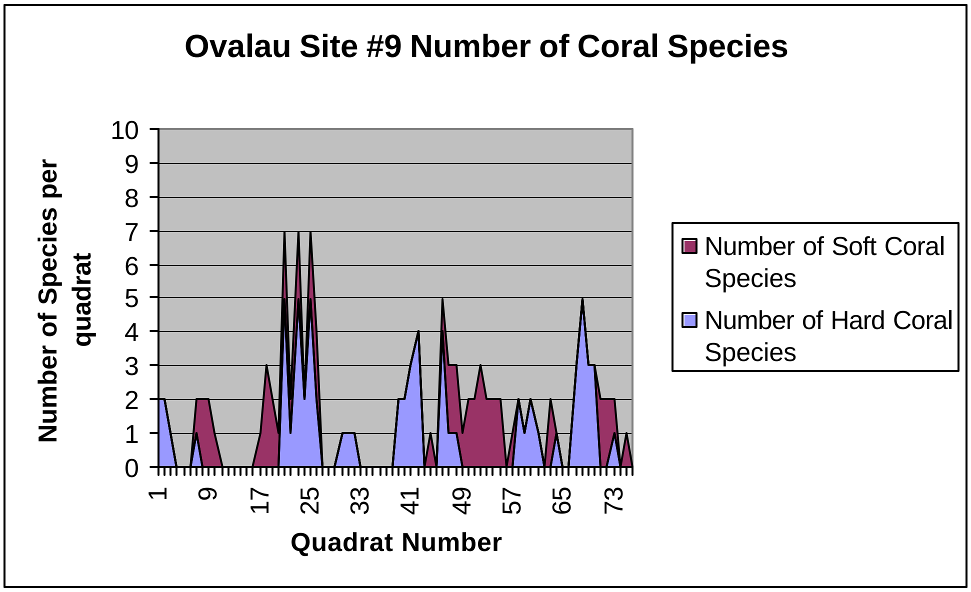

Ovalau Site #10 Coral Coverage
Percent Coverage per quadrat
100
90
80
70
60
50
40
30
20
10
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

Graphs 4.50 – 4.54: Number of Coral Species, Ovalau, Fiji

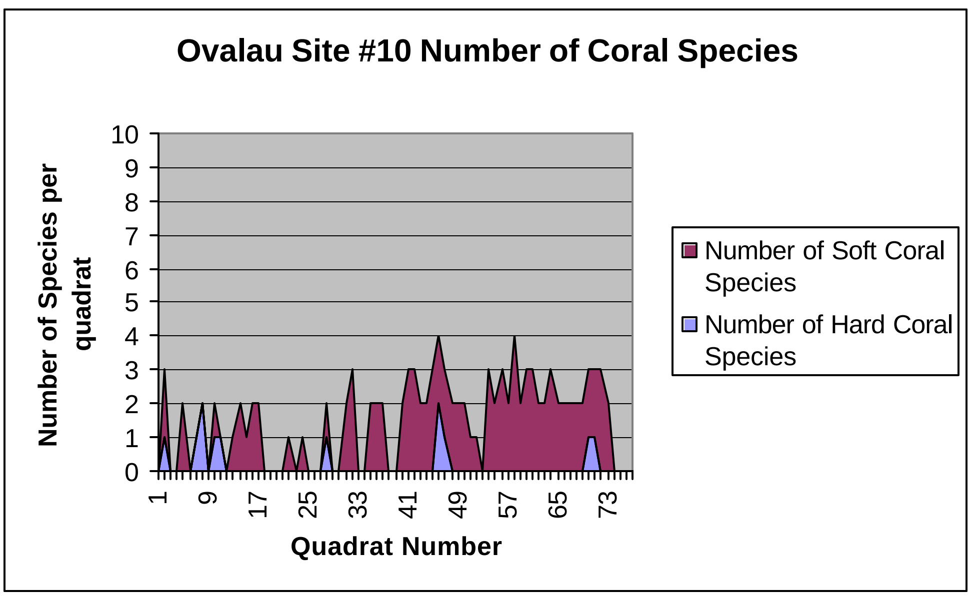





Ovalau Site #8 Number of Coral Species
Number of Species per quadrat
10
9
8
7
6
5
4
3
2
1
0
1
7
13
19
25
31
37
43
49
55
61
67
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

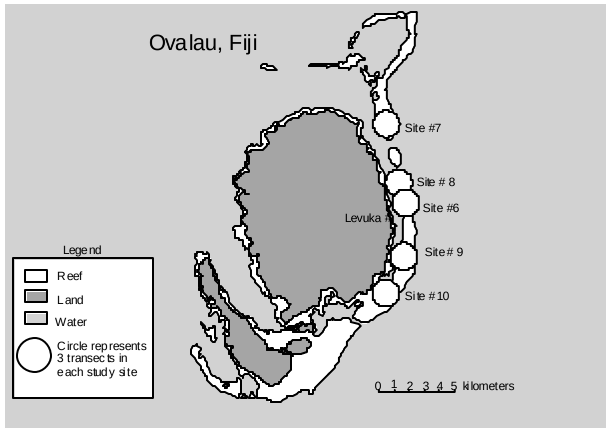


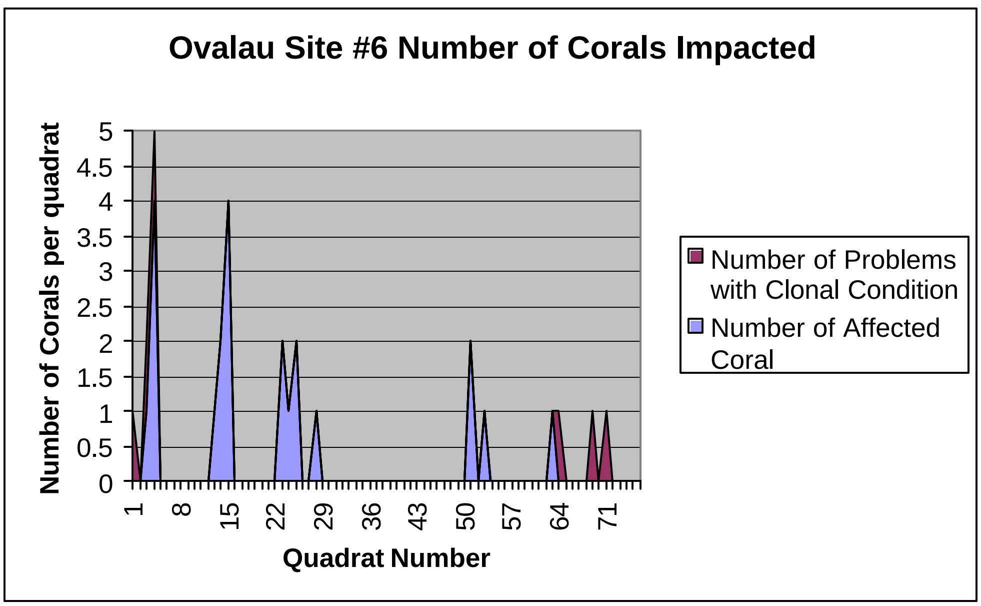
Ovalau Site #9 Number of Coral Species
Number of Species per quadrat
10
9
8
7
6
5
4
3
2
1
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

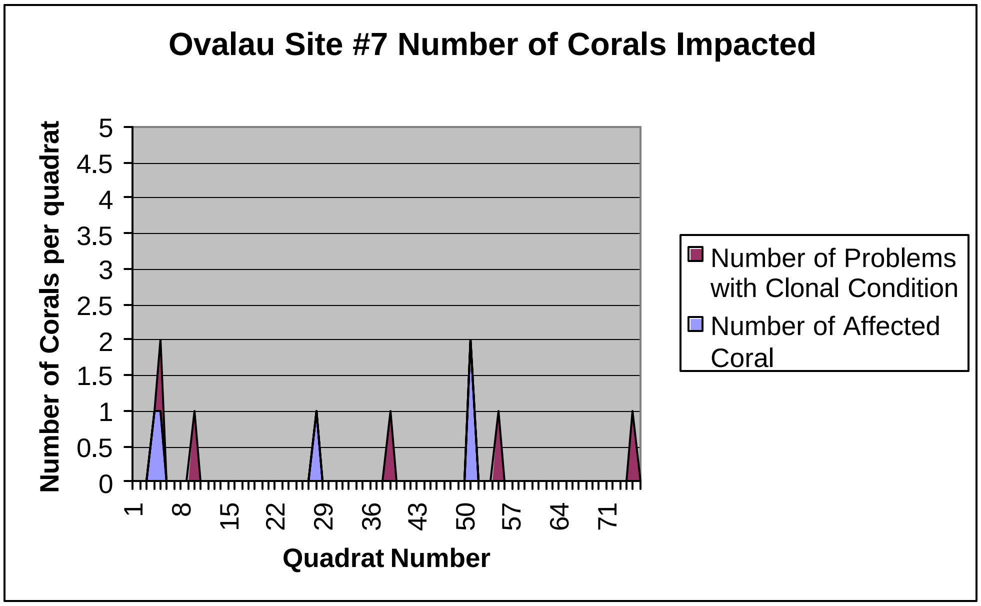


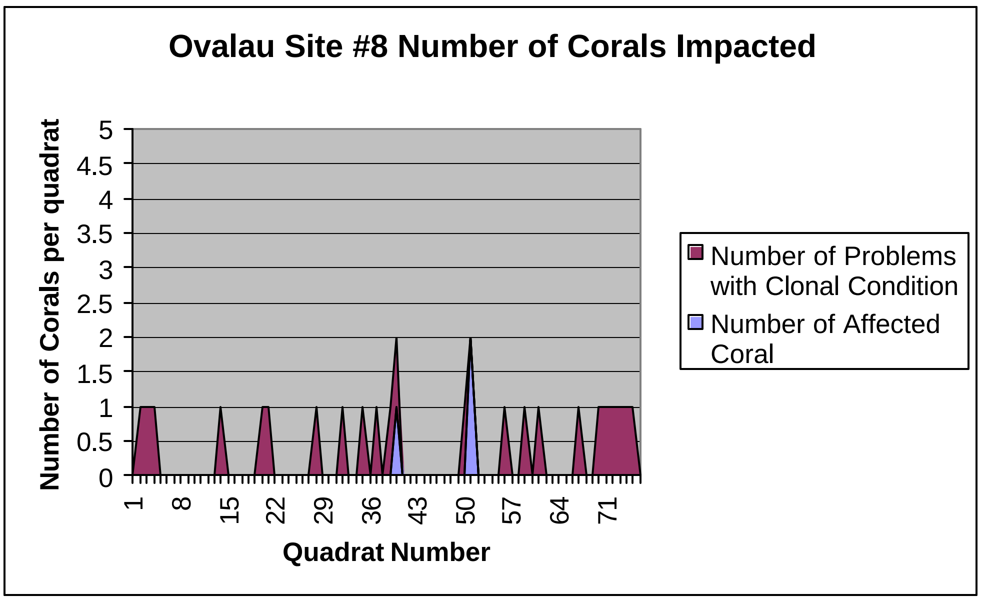
Ovalau Site #10 Number of Coral Species
Number of Species per quadrat
10
9
8
7
6
5
4
3
2
1
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

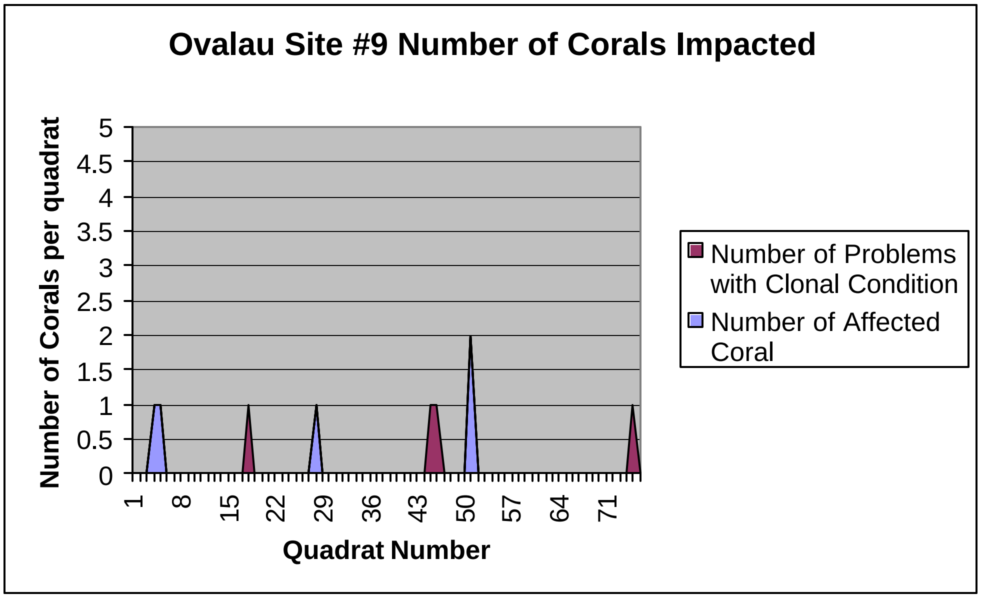
Graphs 4.55 – 4.59: Number of Coral Impacts, Ovalau, Fiji

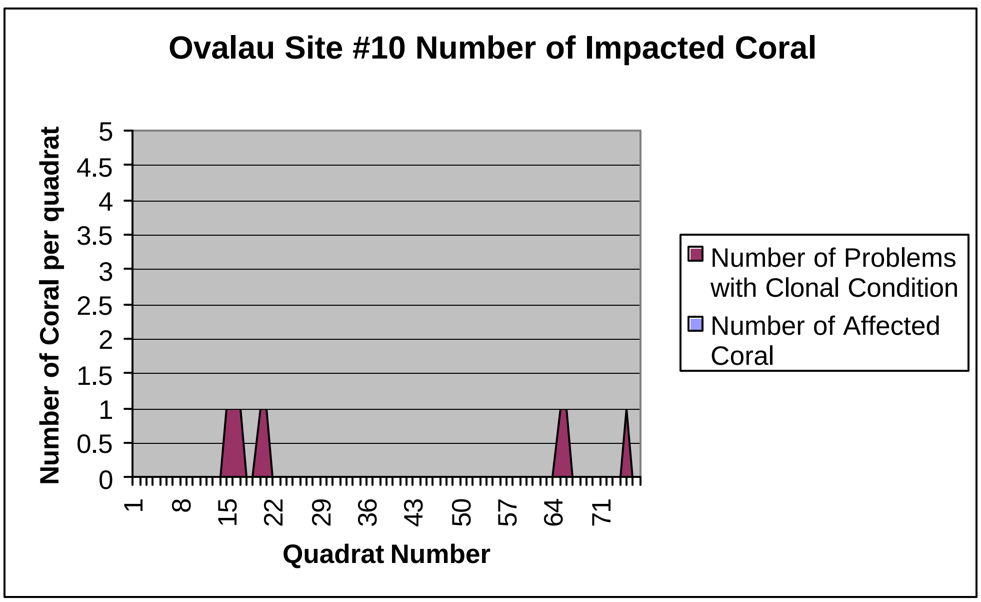




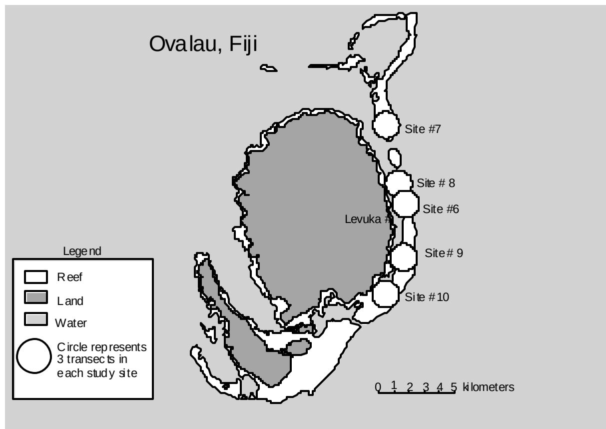

Ovalau Site #7 Number of Corals Impacted
Number of Corals per quadrat
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

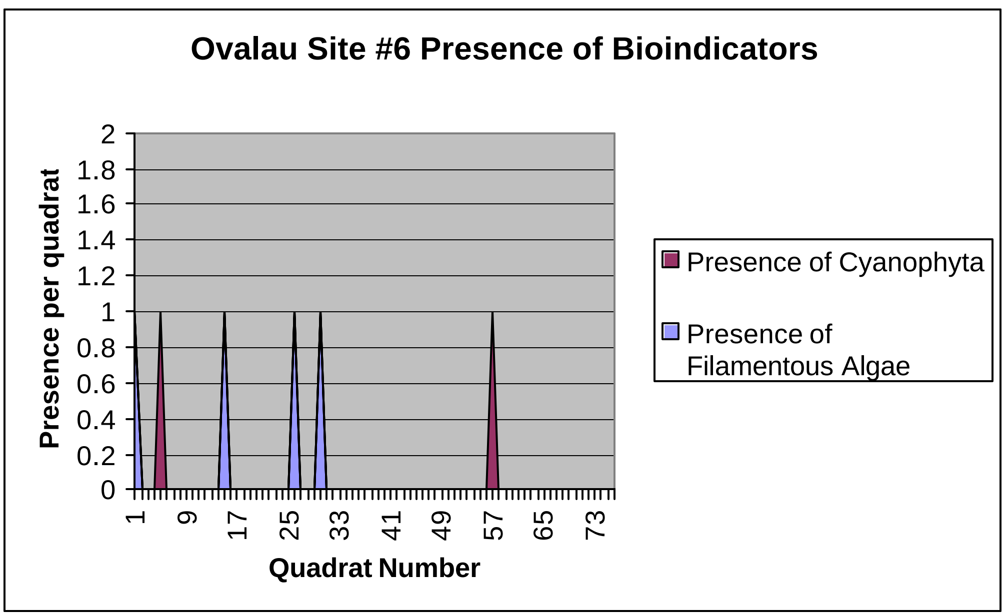

Ovalau Site #8 Number of Corals Impacted
Number of Corals per quadrat
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

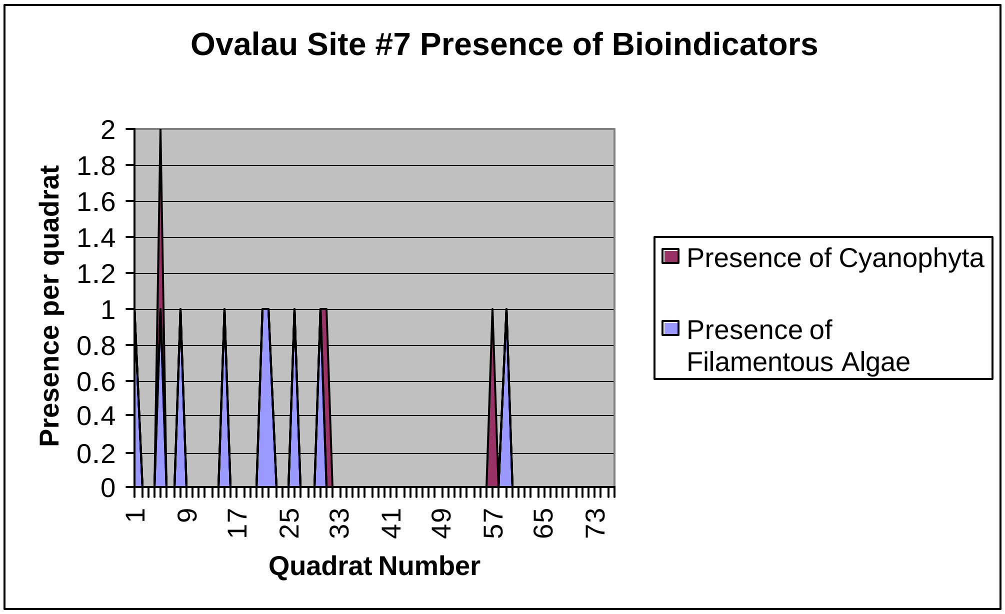

Ovalau Site #9 Number of Corals Impacted
Number of Corals per quadrat
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

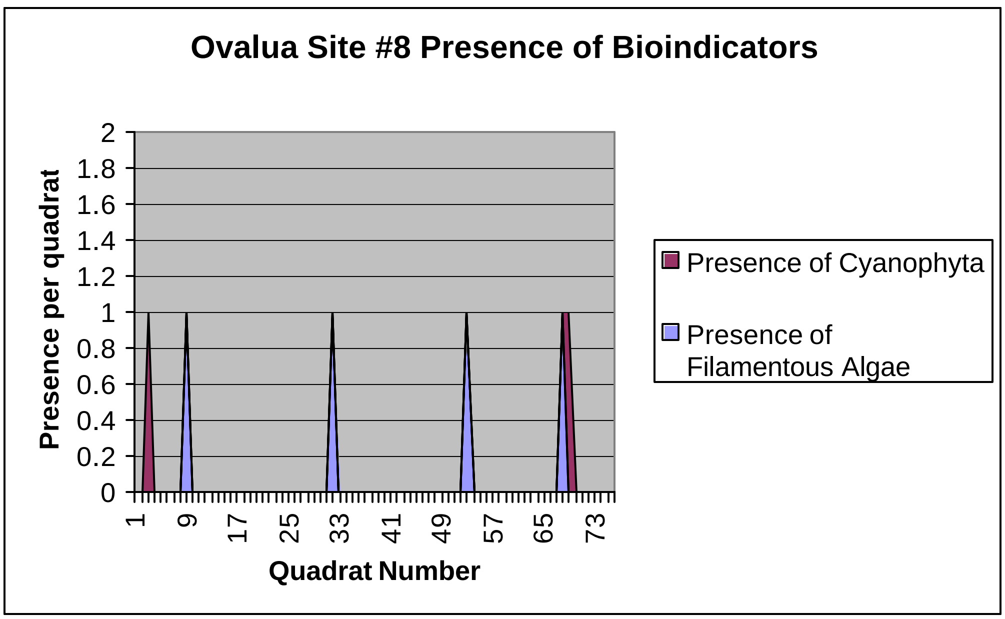

Ovalau Site #10 Number of Impacted Coral
Number of Coral per quadrat
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

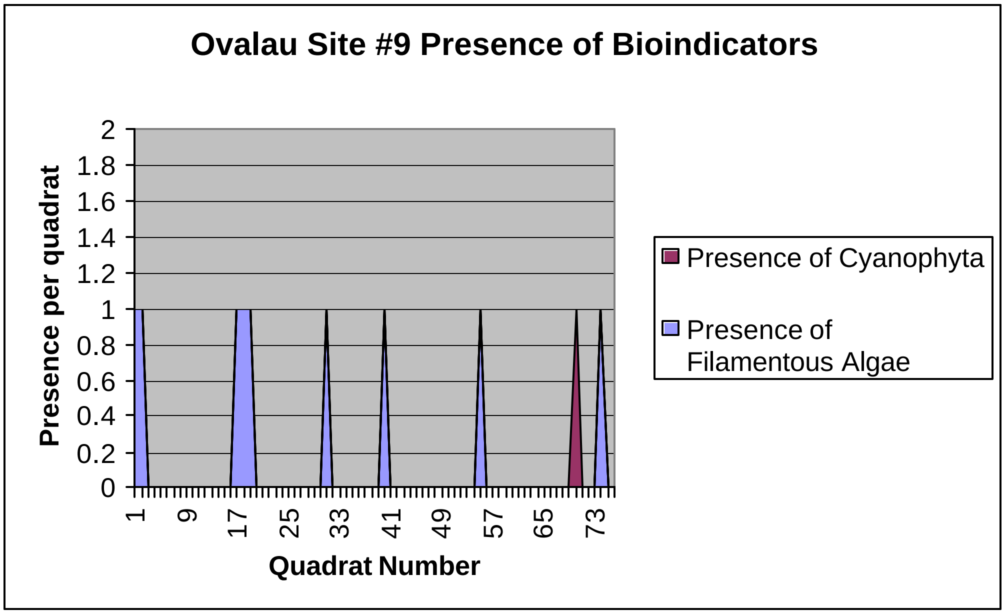
Graphs 4.60 – 4.64: Presence of Bioindicators, Ovalau, Fiji

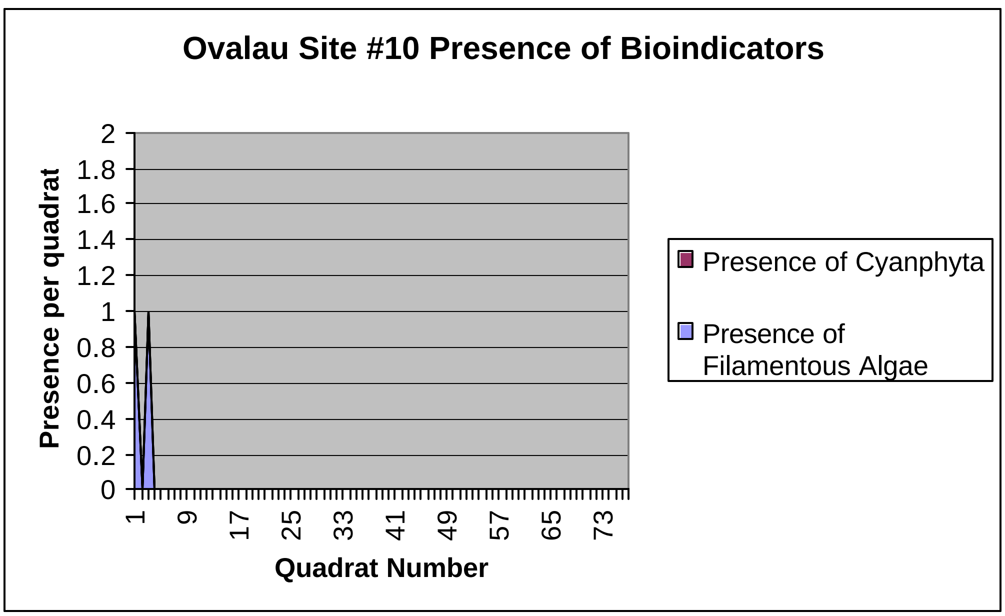




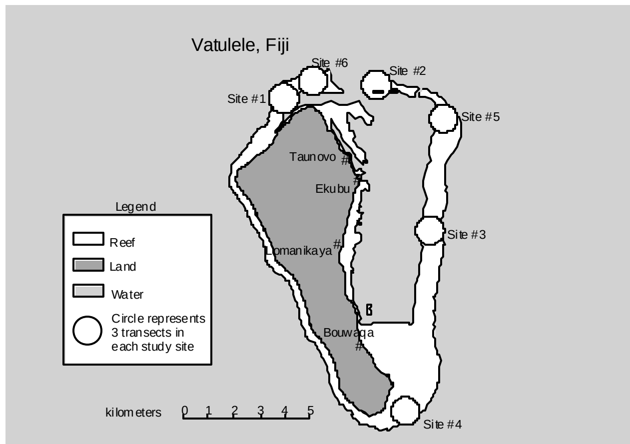

Ovalau Site #7 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae

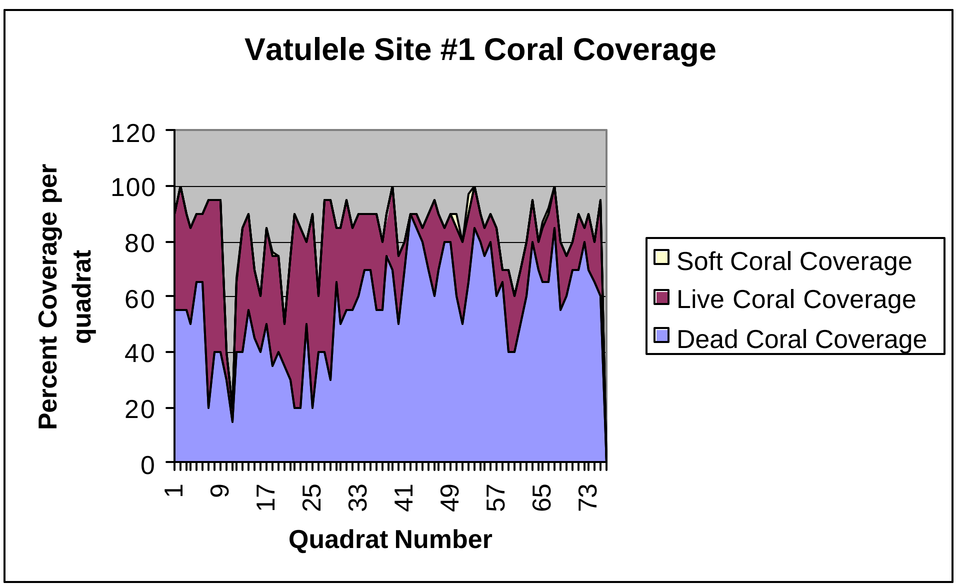

Ovalua Site #8 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae

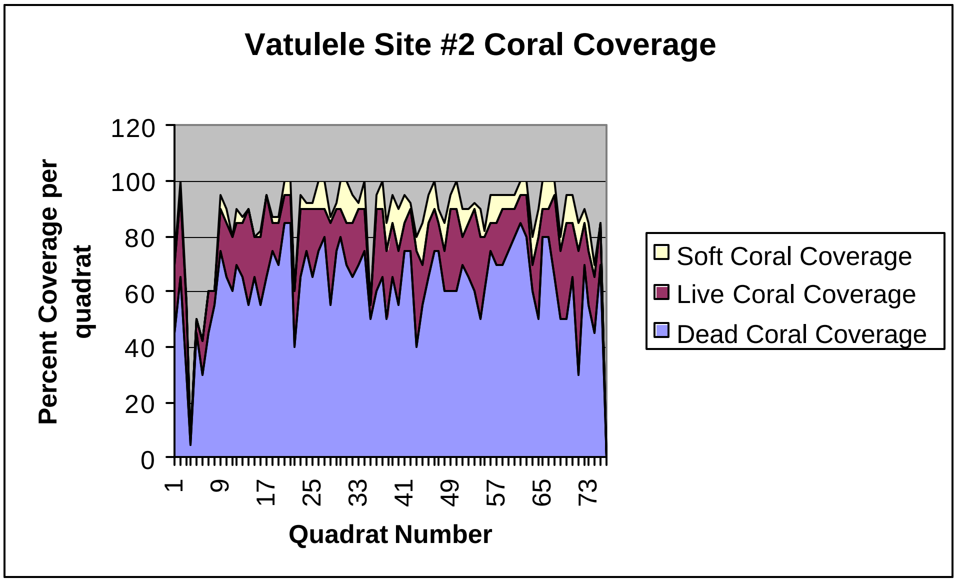

Ovalau Site #9 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae

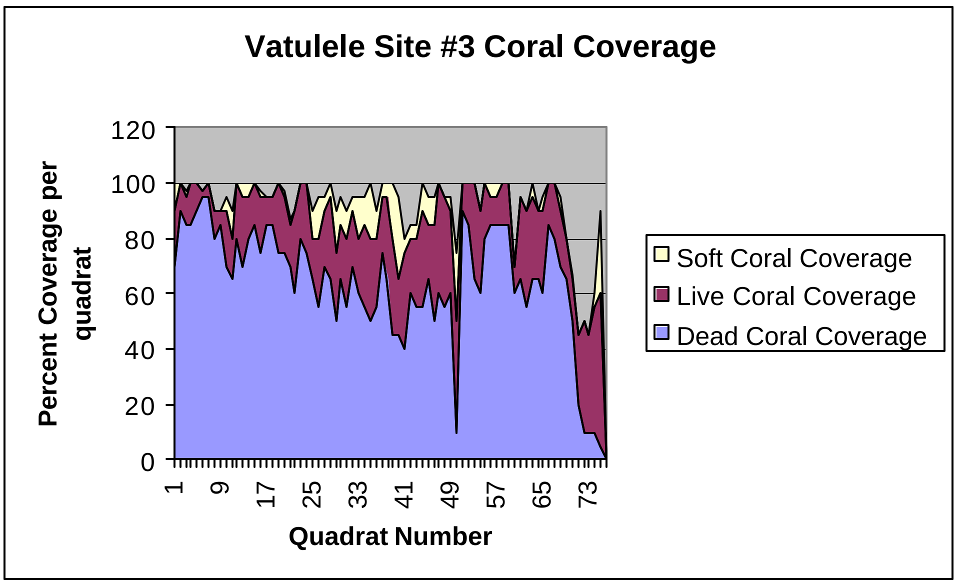

Ovalau Site #10 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanphyta
Presence of Filamentous Algae

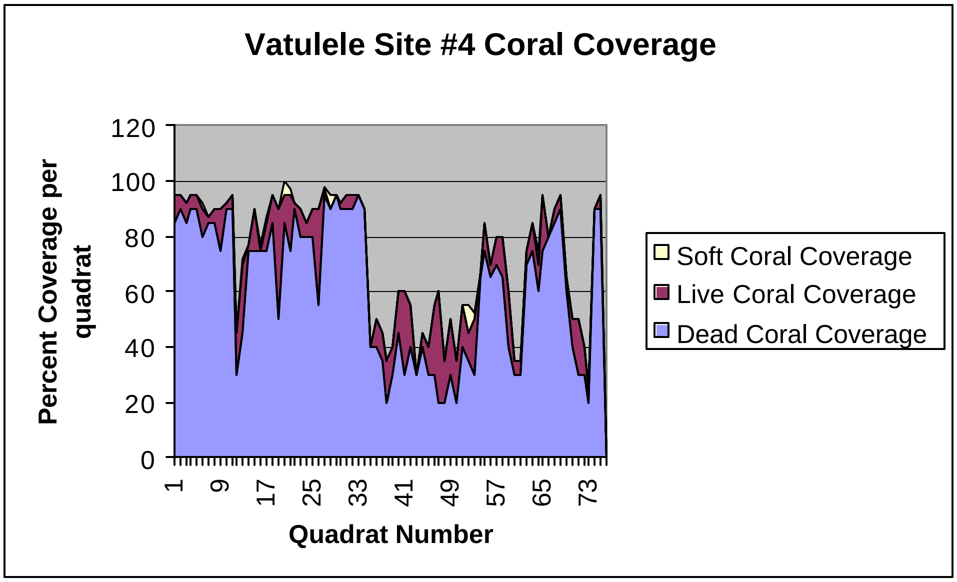
Graphs 4.65 – 4.70: Percent Coral Coverage, Vatulele, Fiji

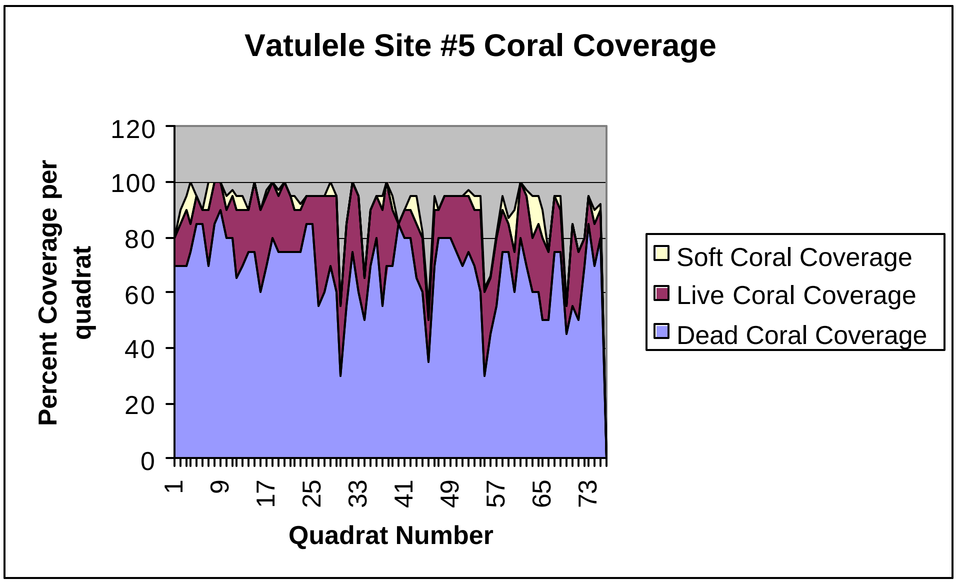


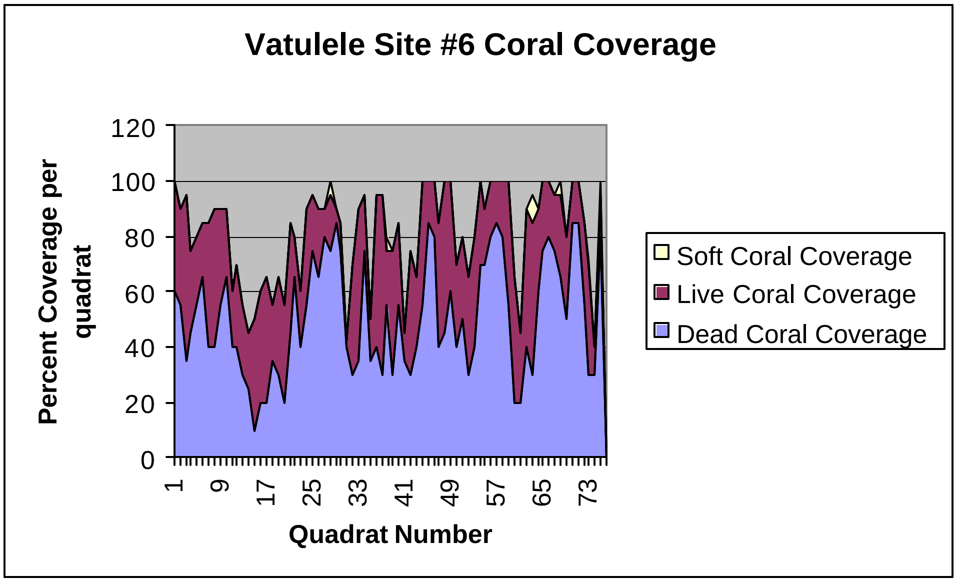



Vatulele Site #2 Coral Coverage
Percent Coverage per quadrat
120
100
80
60
40
20
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage


Vatulele Site #3 Coral Coverage
Percent Coverage per quadrat
120
100
80
60
40
20
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

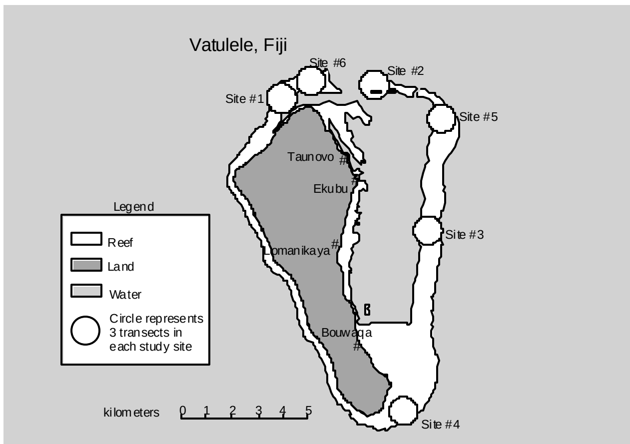

Vatulele Site #4 Coral Coverage
Percent Coverage per quadrat
120
100
80
60
40
20
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

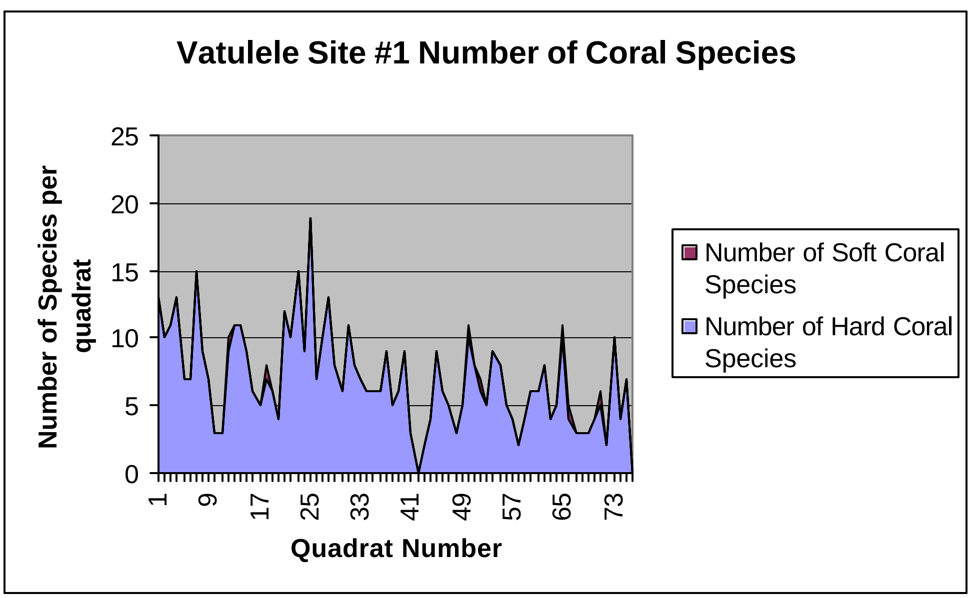

Vatulele Site #5 Coral Coverage
Percent Coverage per quadrat
120
100
80
60
40
20
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

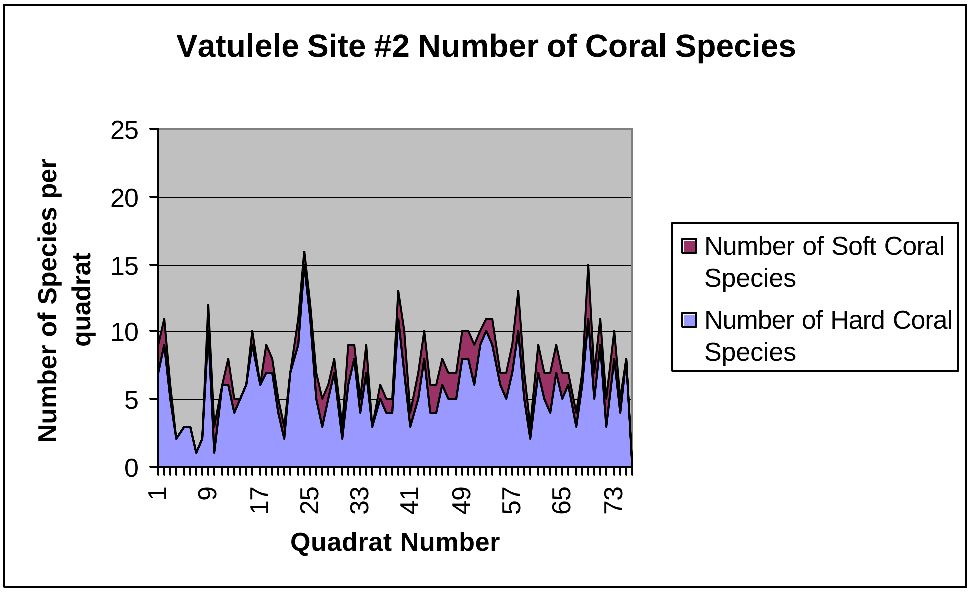


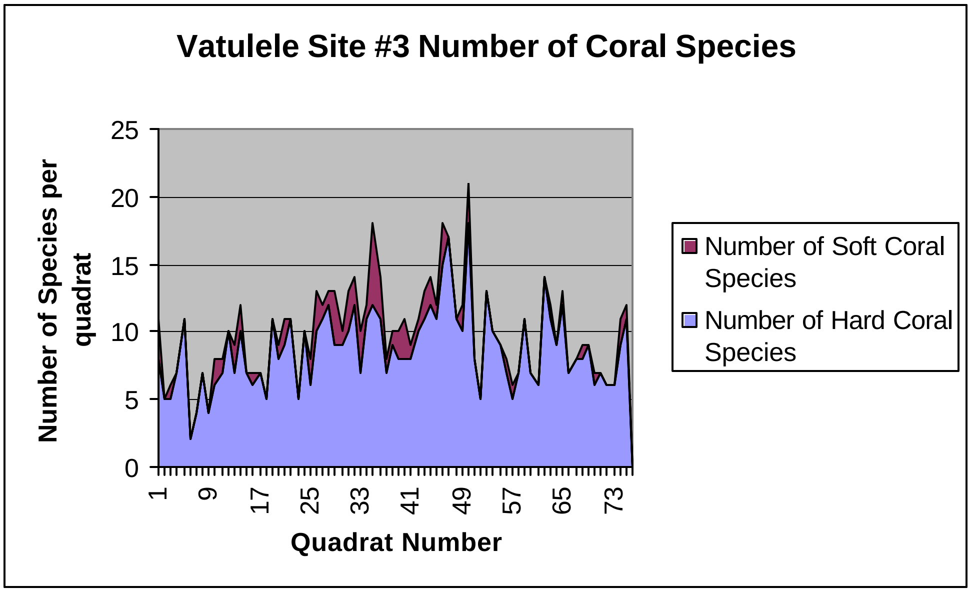
Vatulele Site #6 Coral Coverage
Percent Coverage per quadrat
120
100
80
60
40
20
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Soft Coral Coverage
Live Coral Coverage
Dead Coral Coverage

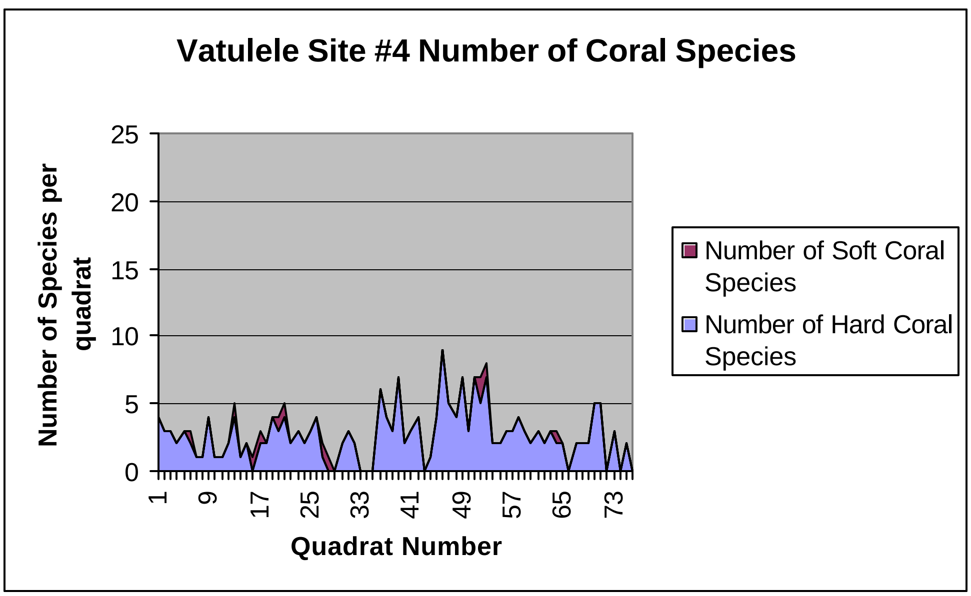
Graphs 4.71 – 4.76: Number of Coral Species, Vatulele, Fiji

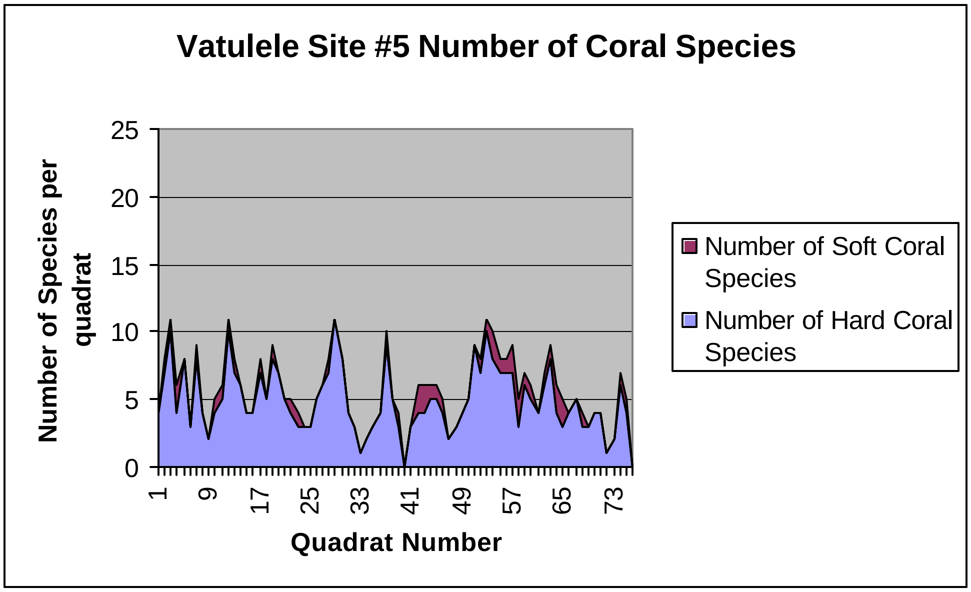




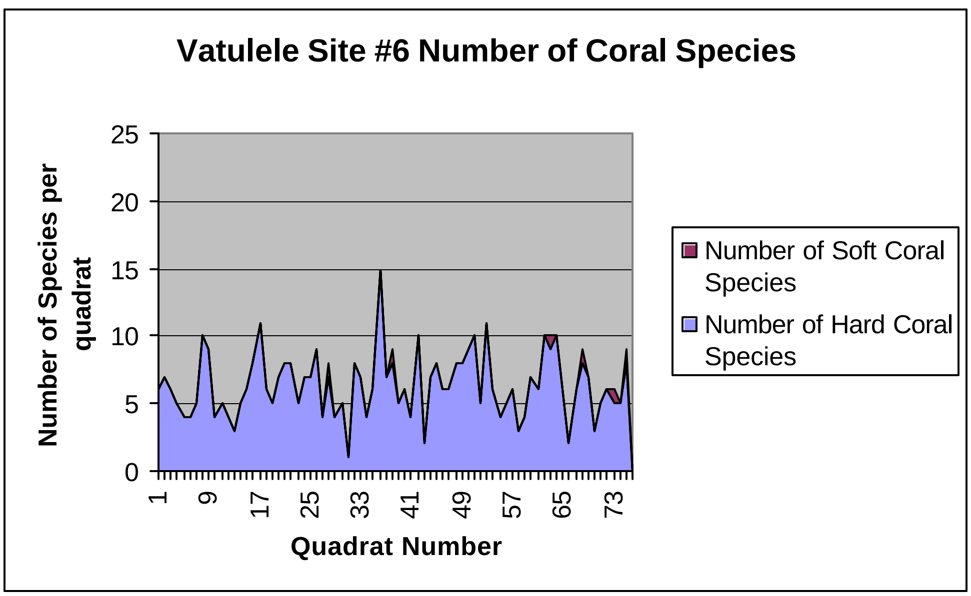

Vatulele Site #2 Number of Coral Species
Number of Species per quadrat
25
20
15
10
5
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species


Vatulele Site #3 Number of Coral Species
Number of Species per quadrat
25
20
15
10
5
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species


Vatulele Site #4 Number of Coral Species
Number of Species per quadrat
25
20
15
10
5
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

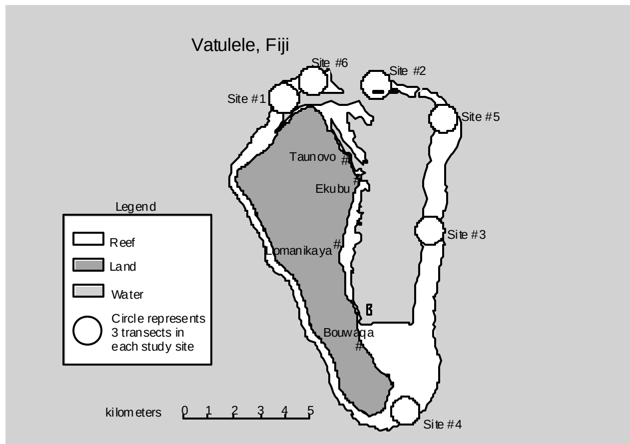


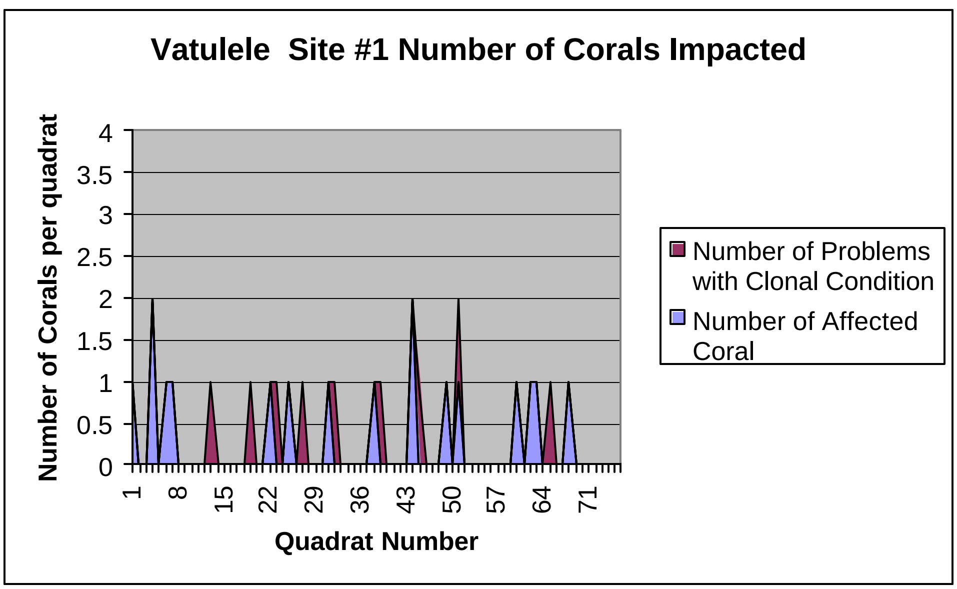
Vatulele Site #5 Number of Coral Species
Number of Species per quadrat
25
20
15
10
5
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

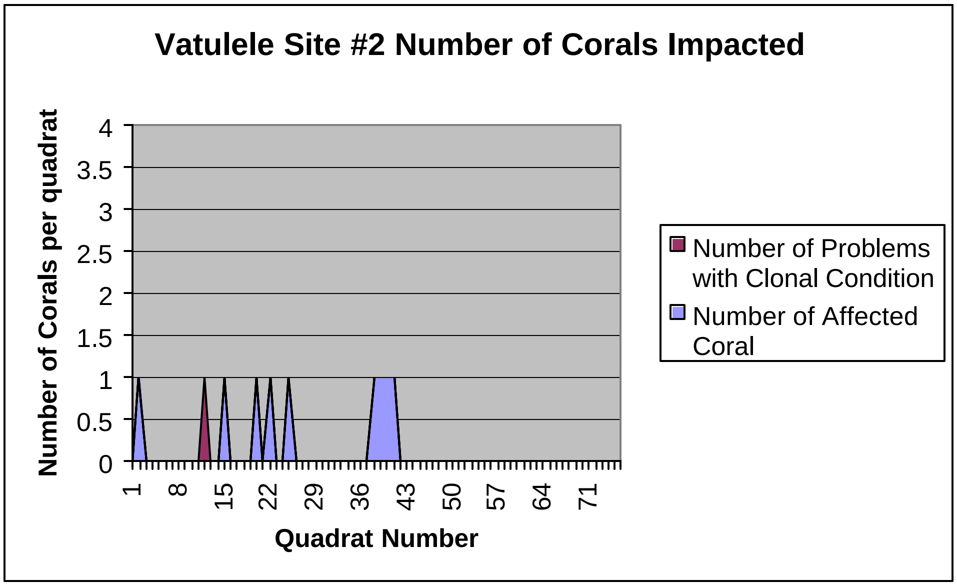


Vatulele Site #6 Number of Coral Species
Number of Species per quadrat
25
20
15
10
5
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Number of Soft Coral Species
Number of Hard Coral Species

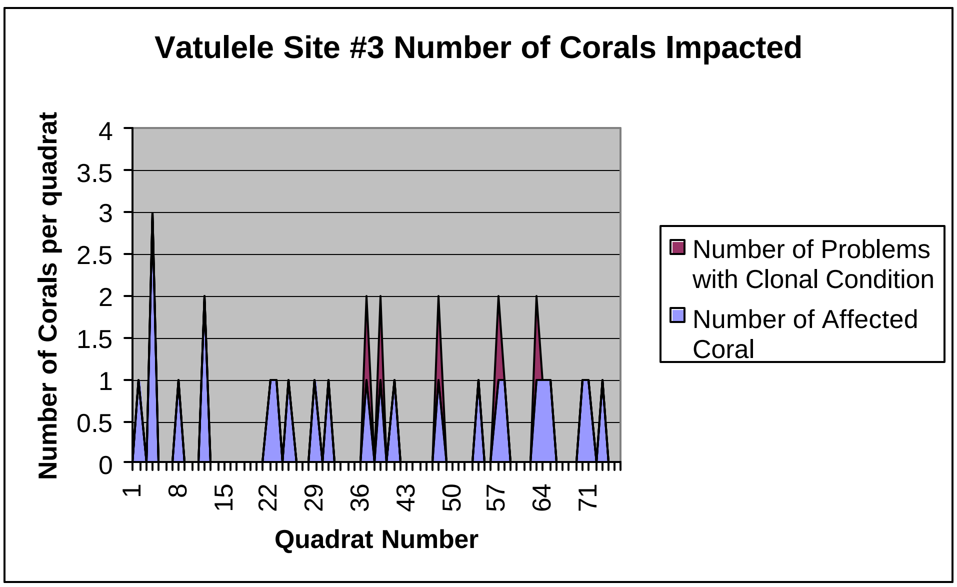
Graphs 4.77 – 4.82: Number of Coral Impacts, Vatulele, Fiji



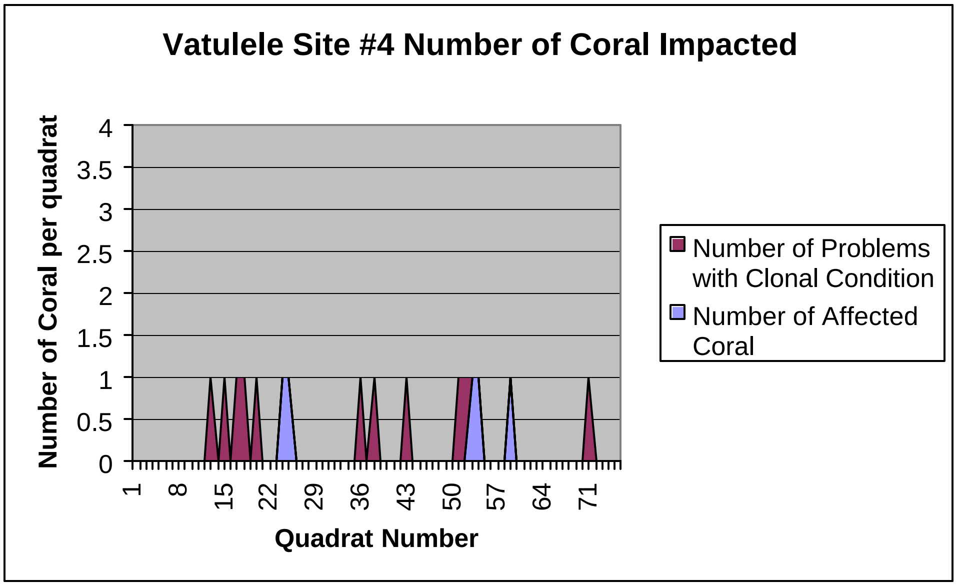


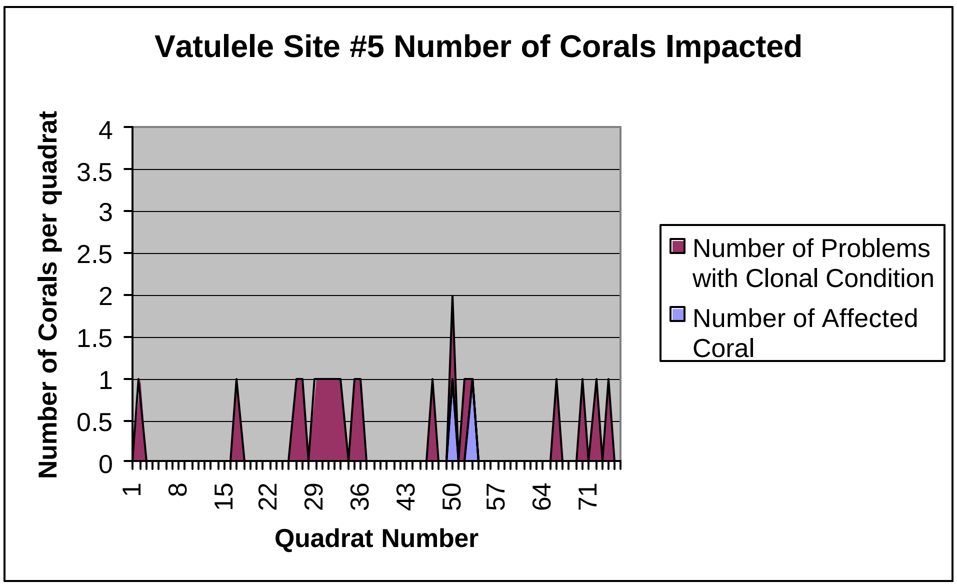


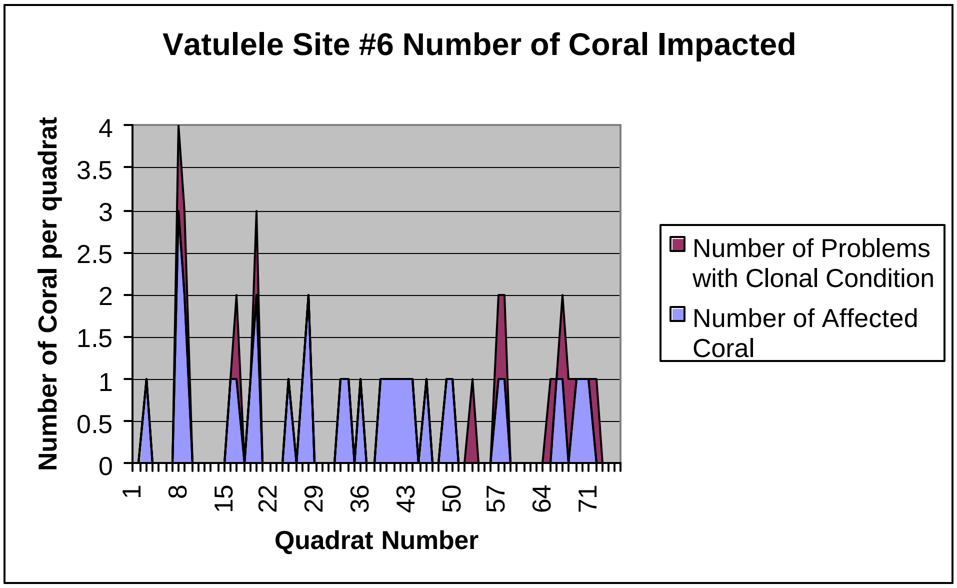
Vatulele Site #2 Number of Corals Impacted
Number of Corals per quadrat
4
3.5
3
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral



Vatulele Site #3 Number of Corals Impacted
Number of Corals per quadrat
4
3.5
3
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

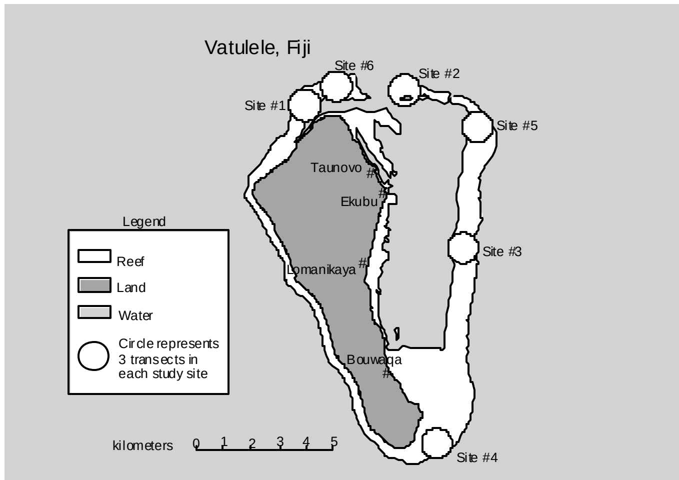

Vatulele Site #4 Number of Coral Impacted
Number of Coral per quadrat
4
3.5
3
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

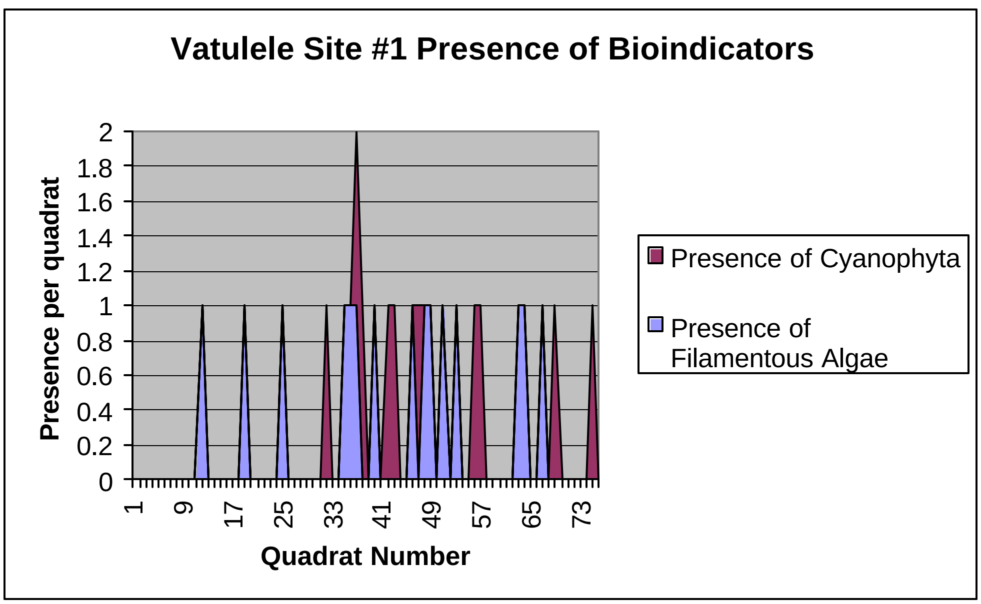

Vatulele Site #5 Number of Corals Impacted
Number of Corals per quadrat
4
3.5
3
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

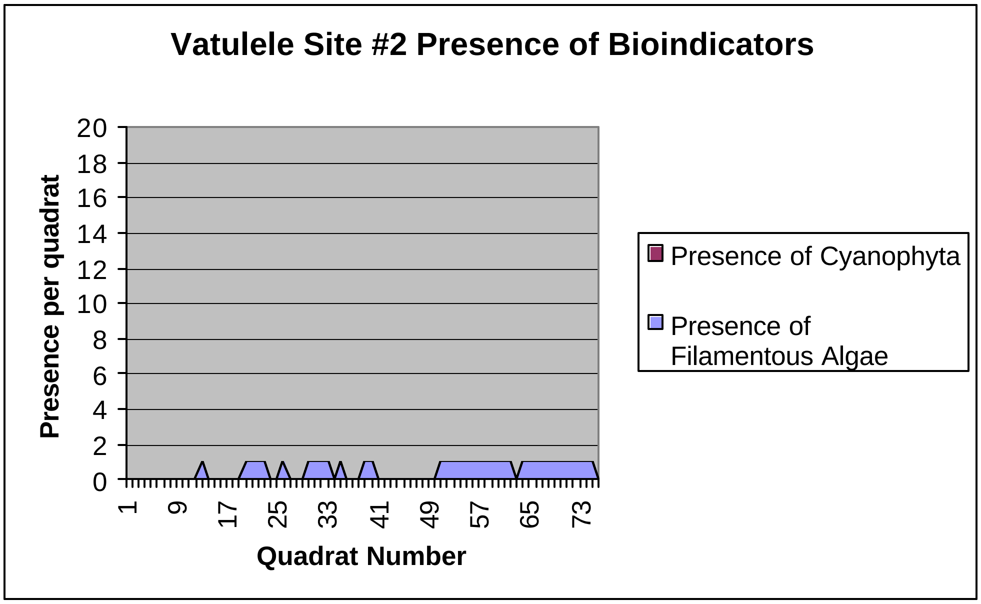


Vatulele Site #6 Number of Coral Impacted
Number of Coral per quadrat
4
3.5
3
2.5
2
1.5
1
0.5
0
1
8
15
22
29
36
43
50
57
64
71
Quadrat Number
Number of Problems with Clonal Condition
Number of Affected Coral

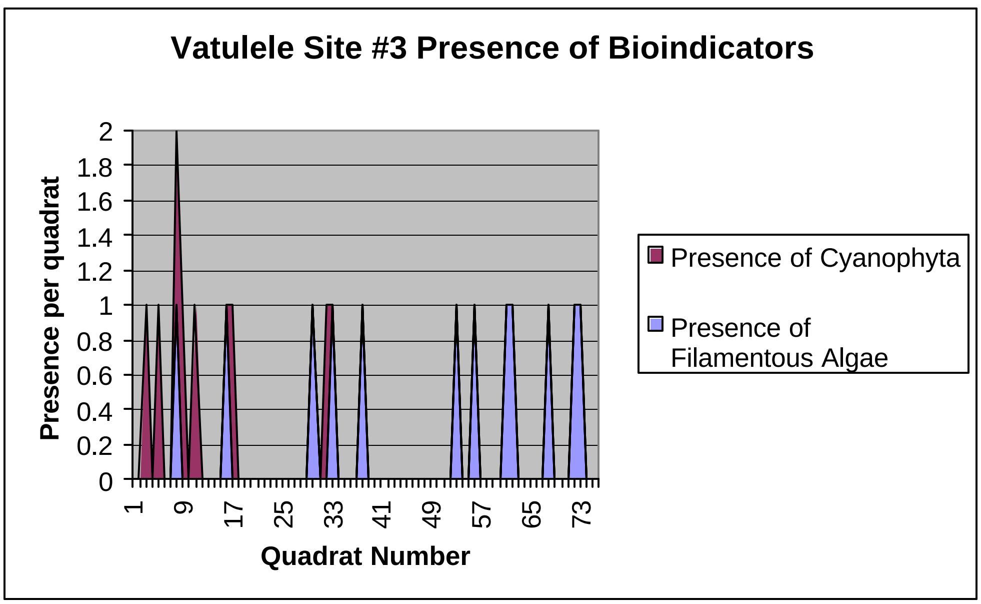
Graphs 4.83 – 4.88: Presence of Bioindicators, Vatulele, Fiji



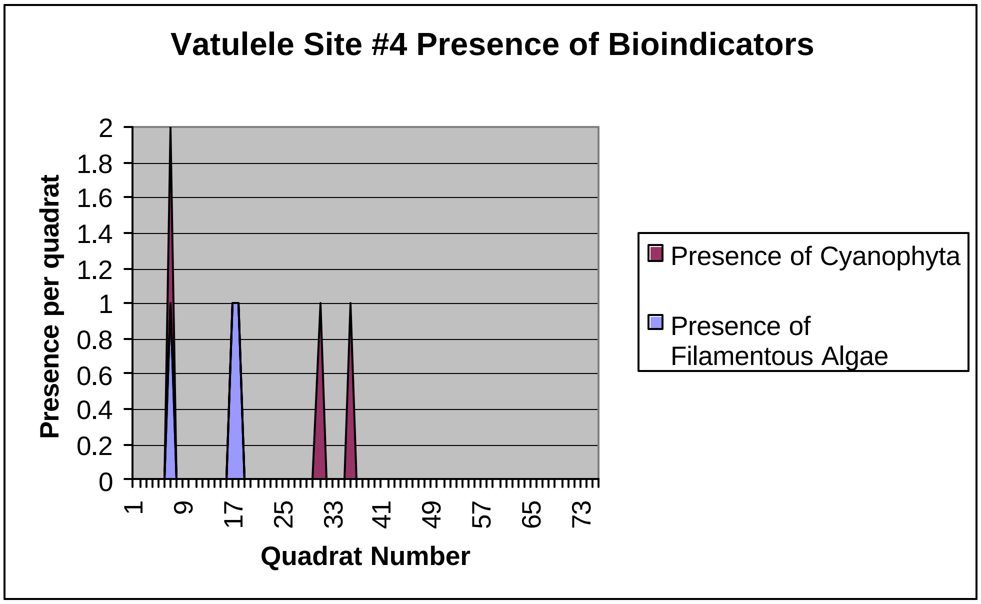


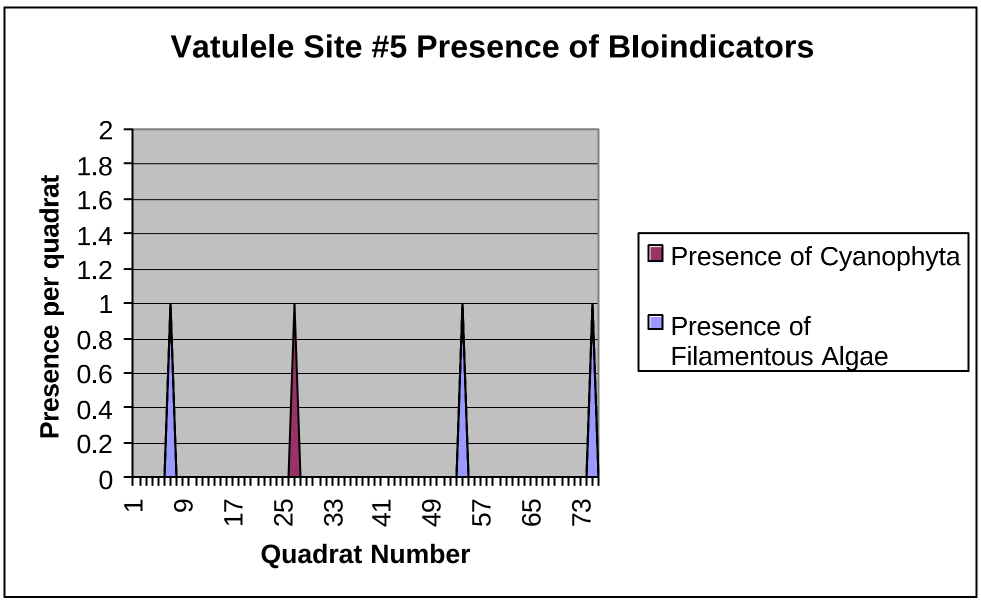


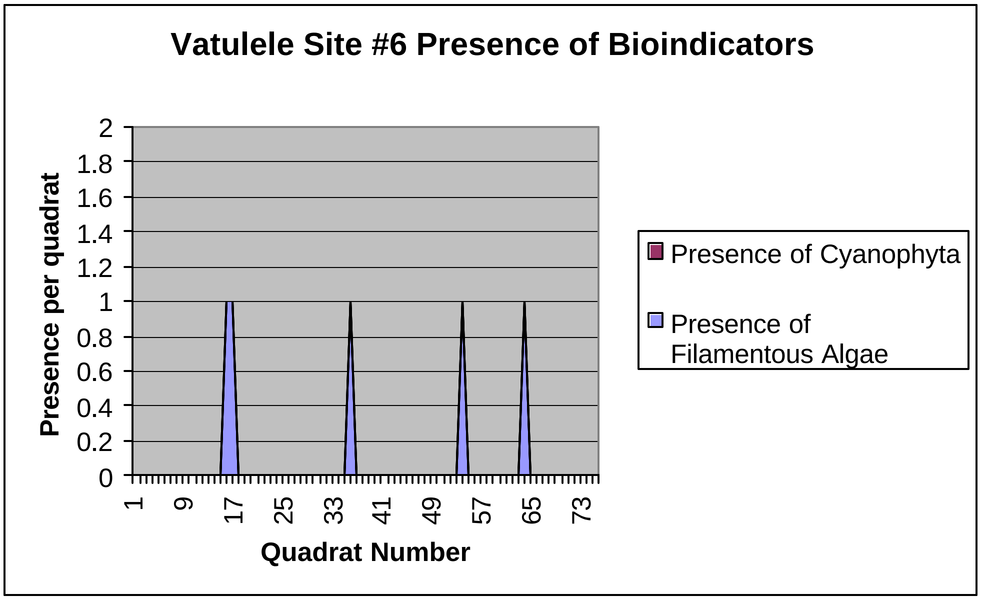
Vatulele Site #2 Presence of Bioindicators
Presence per quadrat
20
18
16
14
12
10
8
6
4
2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae



Vatulele Site #3 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae


Vatulele Site #4 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae


Vatulele Site #5 Presence of BIoindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae


Vatulele Site #6 Presence of Bioindicators
Presence per quadrat
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
9
17
25
33
41
49
57
65
73
Quadrat Number
Presence of Cyanophyta
Presence of Filamentous Algae

The Mortality Index was calculated Gomez (Gomez 1994) as:

$$MI = \frac{\text{dead coral coverage}}{\text{live coral coverage + dead coral coverage}}$$

Island and site means are described in the table below. Sites in Rarotonga and Ovalau have the highest MI values. Sites in Vatulele and Rarotonga have the highest hard coral species diversity and the largest number of corals affected by biotic factors such as parasites and disease, predators such as the Crown of Thorn Starfish, and parasites such *Plagioporus* spp. Futhermore, soft corals were predominant in Ovalau and Vatulele. The reefs in Ovalau have less soft coral diversity and site 9 and 10 had extremely high soft coral percent coverage. The coral clonal condition, bleaching, tissues loss and discoloration, and mucus production, had the highest number of corals with tissue discoloration and mucus in Ovalau and Vatulele. It is relevant to point out that Ovalau has significantly higher MI values than Vatulele. The presence of filamentous algae was higher in Rarotonga and Vatulele and Cyanophyta was high in Aitutaki.

Table 4.12: Means of Ecological Data for Study Sites on All Islands

	MI	Hard Coral Species Diversity	Number of Corals Affected by Biotic Factors	Percentage Soft Coral Coverage	Soft Coral Species Diversity	Coral Clonal Condition	Presence of Fila. Algae	Presence of Cyanophyta
Aitutaki								
Aitutaki Site 1	0.77	0.85	0.09	0	0	0	0.09	0.07
Aitutaki Site 2	0.73	**3.59**	0.07	0	0	0.12	0.02	0.07
Aitutaki Site 3	0.62	1.96	0	0	0	0.03	0.23	0.03
Aitutaki Site 4	**0.94**	0.63	0	0	0	0.13	0	0.04
Aitutaki Site 5	0.84	1.44	0.04	0	0	0.12	0.02	**0.39**
AITUTAKI ISLAND MEANS	**0.78**	**1.70**	**0.04**	**0**	**0**	**0.08**	**0.07**	**0.12**
Rarotonga								
Rarotonga Site 1	0.87	3.25	0	0	0	0.13	0.07	0.13
Rarotonga Site 2	0.83	3.69	0.67	0	0	0.13	0.12	0.07
Rarotonga Site 3	**0.94**	0.33	0.02	0	0	0.01	0.09	0.07
Rarotonga Site 4	**0.93**	0.57	0.04	1	0.16	0.05	0.15	0.04
Rarotonga Site 5	0.88	1.48	**0.77**	0	0	0.16	0.16	0.08
Rarotonga Site 6	0.87	1.96	0.34	0	0	0.16	**0.43**	0.11
RAROTONGA ISLAND MEANS	**0.89**	**1.88**	**0.31**	**0.17**	**0.03**	**0.11**	**0.17**	**0.09**
Ovalau								
Ovalau Site 6	0.92	--	0.29	--	--	0.08	0.05	0.03
Ovalau Site 7	0.73	**4.08**	0.07	2.61	0.53	0.07	0.12	0.04
Ovalau Site 8	0.77	1.89	0.04	3.63	0.48	0.31	0.05	0.03
Ovalau Site 9	0.93	0.91	0.07	**8.91**	0.68	0.05	0.12	0.01
Ovalau Site 10	0.94	0.16	0	**18.63**	1.36	0.11	0.03	0
OVALAU ISLAND MEANS	**0.86**	**1.76**	**0.10**	**8.45**	**0.76**	**0.12**	**0.07**	**0.02**
Vatulele								
Vatulele Site 1	0.68	7.06	1.14	0.25	0.09	0.12	0.2	0.13
Vatulele Site 2	0.77	5.92	0.58	5.71	1.44	0.01	0.49	0
Vatulele Site 3	0.72	**8.77**	1.55	4.93	1.01	0.07	0.16	0.09
Vatulele Site 4	0.83	2.72	0.87	0.51	0.16	0.15	0.04	0.04
Vatulele Site 5	0.78	5	0.12	2.56	0.59	0.24	0.04	0.01
Vatulele Site 6	0.62	6.35	1.5	0.43	0.08	0.15	0.07	0
VATULELE ISLAND MEANS	**0.73**	**5.97**	**0.96**	**2.40**	**0.56**	**0.12**	**0.17**	**0.05**

Data on the number of corals affected by biotic factors includes information on four variables: bleaching or an entire coral colony, the presence of COTS on the transect, the parasitic trematode *Plagioporus* spp., and CLOD, which affects coralline algae.

Table 4.13: Number of Corals Affected

	Bleaching of Entire Coral	COTS	Plagioporus spp.	CLOD
Aitutaki				
Aitutaki Site 1	0	0	2	0
Aitutaki Site 2	3	1	0	0
Aitutaki Site 3	0	0	0	0
Aitutaki Site 4	0	0	0	0
Aitutaki Site 5	2	0	0	0
Rarotonga				
Rarotonga Site 1	0	0	3	0
Rarotonga Site 2	0	0	0	0
Rarotonga Site 3	0	0	1	0
Rarotonga Site 4	0	0	1	0
Rarotonga Site 5	**8**	0	2	0
Rarotonga Site 6	3	0	1	0
Ovalau				
Ovalau Site 6	**22**	0	0	0
Ovalau Site 7	4	0	0	0
Ovalau Site 8	0	0	1	0
Ovalau Site 9	4	0	0	0
Ovalau Site 10	0	0	0	0
Vatulele				
Vatulele Site 1	**10**	0	0	**5**
Vatulele Site 2	6	0	0	**3**
Vatulele Site 3	6	0	**15**	0
Vatulele Site 4	4	0	1	0
Vatulele Site 5	0	0	2	0
Vatulele Site 6	5	0	0	**22**

Data in the chart below summarize categories described and discussed in Chapter 3. The following correlative analysis will compare and link relationships with ecological data displayed in chart 4.14 on island means and the geographic factors below.

Table 4.14: Island Site Geographic Categories

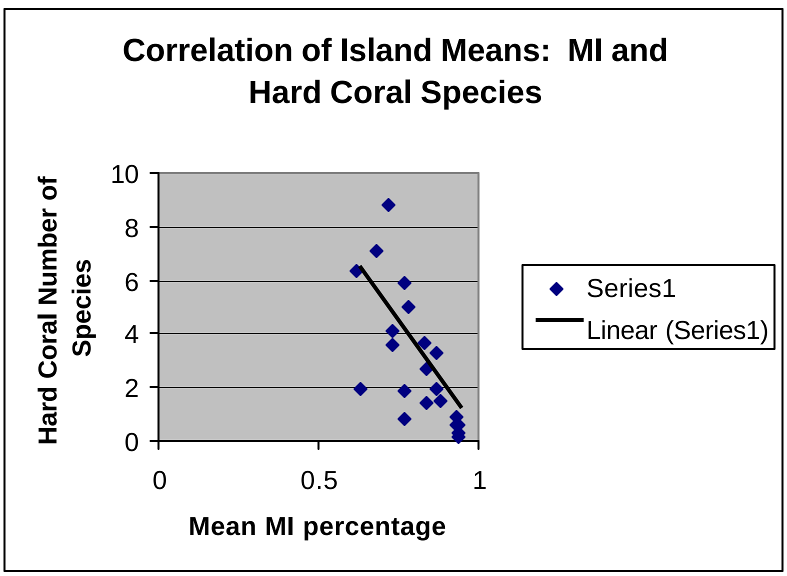
	Windward or Leeward	Reef Type	Property	Tourism Externalities	Harvesting Externalities	Agro-Industry Externalities	Externalities Total
Aitutaki							
Aitutaki Site 1	Windward	Fringing	Government	3	6	2	11
Aitutaki Site 2	Leeward	Barrier	Government	4	6	6	16
Aitutaki Site 3	Windward	Fringing	Government	4	6	7	17
Aitutaki Site 4	Leeward	Barrier	Government	3	6	7	16
Aitutaki Site 5	Leeward	Barrier	Government	3	6	7	16
AITUTAKI ISLAND MEANS				**3.4**	**6**	**5.8**	**15.2**
Rarotonga							
Rarotonga Site 1	Windward	Fringing	Traditional	1	0	9	10
Rarotonga Site 2	Windward	Fringing	Government	1	2	9	12
Rarotonga Site 3	Leeward	Fringing	Traditional	6	0	6	12
Rarotonga Site 4	Leeward	Fringing	Government	6	2	6	14
Rarotonga Site 5	Leeward	Barrier	Government	9	3	6	18
Rarotonga Site 6	Windward	Fringing	Traditional	2	0	6	8
RAROTONGA ISLAND MEANS				**4.17**	**1.17**	**7**	**12.33**
Ovalau							
Ovalau Site 6	Windward	Barrier	Government	4	3	9	16
Ovalau Site 7	Windward	Barrier	Traditional	3	2	6	11
Ovalau Site 8	Windward	Barrier	Government	4	3	8	15
Ovalau Site 9	Windward	Barrier	Government	4	3	9	16
Ovalau Site 10	Windward	Barrier	Traditional	2	2	8	12
OVALAU ISLAND MEANS				**3.4**	**2.6**	**8**	**14**
Vatulele							
Vatulele Site 1	Leeward	Fringing	Traditional	3	2	0	5
Vatulele Site 2	Leeward	Fringing	Traditional	1	2	0	3
Vatulele Site 3	Windward	Barrier	Traditional	1	2	0	3
Vatulele Site 4	Windward	Fringing	Traditional	0	2	0	2
Vatulele Site 5	Windward	Barrier	Traditional	1	2	0	3
Vatulele Site 6	Leeward	Barrier	Traditional	3	2	0	5
VATULELE ISLAND MEANS				**1.5**	**2**	**0**	**3.5**

Correlation is calculated using the non-parametric Spearman correlation coefficient. Only correlations with an absolute value of .50 or higher are recorded with a .05 or less significance.

Table 4.15: Correlation of All Island Means

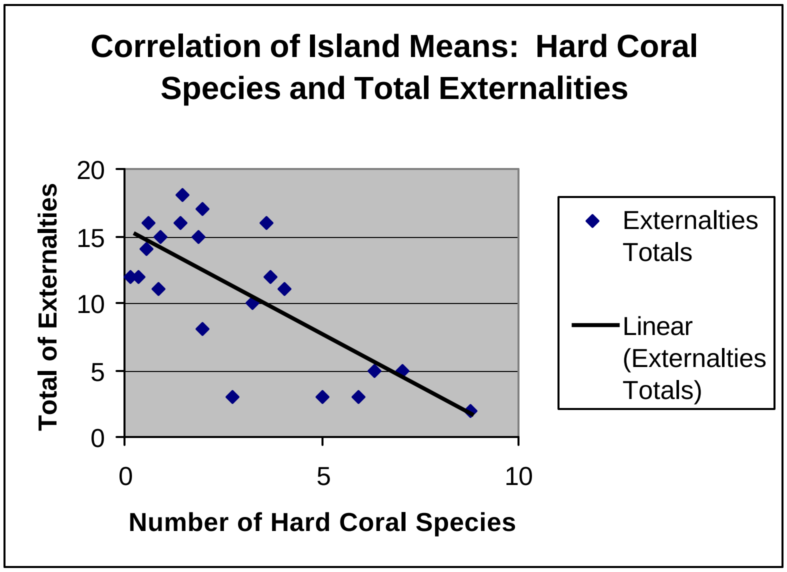
MI	Agro-Industry Externalities	.50
MI	Hard Coral Species Diversity	-.78
Hard Coral Species Diversity	Agro-Industry Externalities	-.52
Hard Coral Species Diversity	Total Externalities	-.60
Number of Coral Affected by Biotic Factors	Agro-Industry Externalities	-.60
Number of Coral Affected by Biotic Factors	Total Externalities	-.51
Number of Coral Affected by Biotic Factors	Hard Coral Species Diversity	.69
Presence of Filamentous Algae	Reef Type (Fringing)	.51
Presence of Cyanophyta	Percentage of Soft Coral Coverage	-.62
Presence of Cyanophyta	Soft Coral Species Diversity	-.59

The Mortality Index is positively correlated with agro-industry externalities. Mortality Index and hard coral species diversity were negatively correlated.



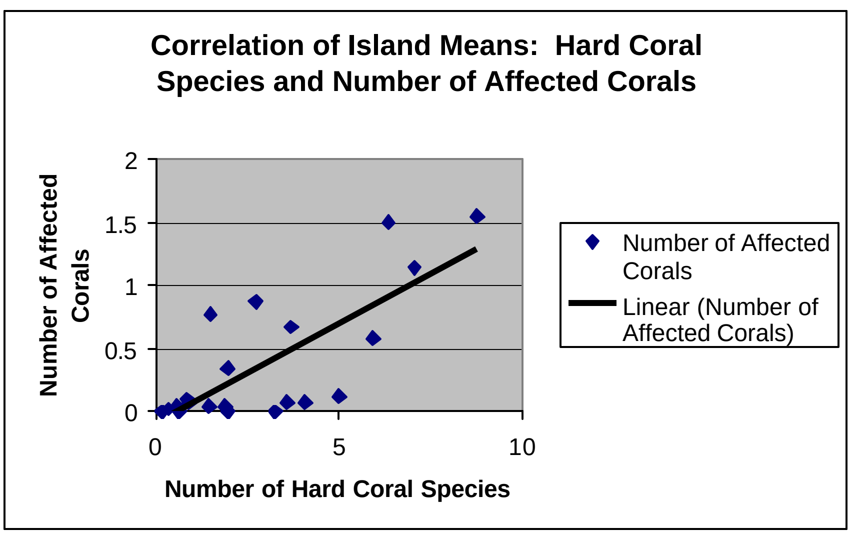
Graph 4.89: Correlation of -.78

Hard coral species diversity and agro-industry externalities and total externalities are negatively correlated.



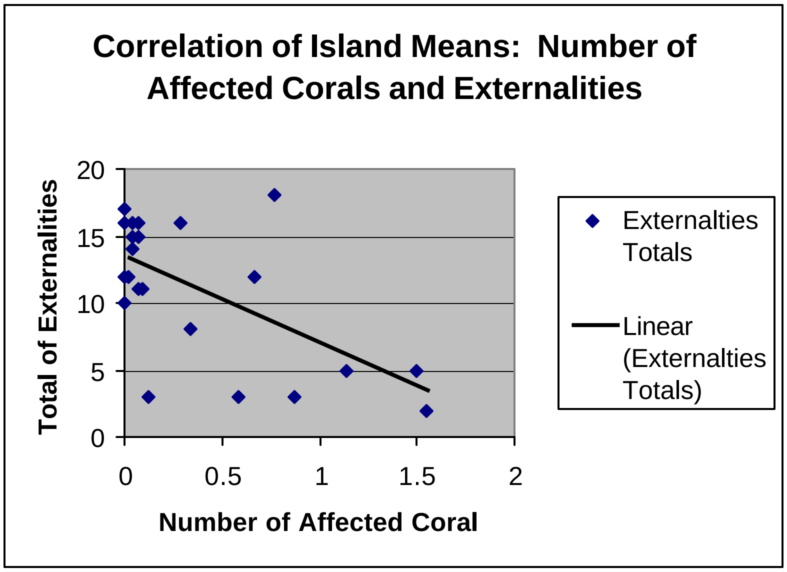
Graph 4.90: Correlation -.60

The number of corals affected by biotic factors is positively correlated with hard coral species diversity.



Graph 4.91: Correlation .69

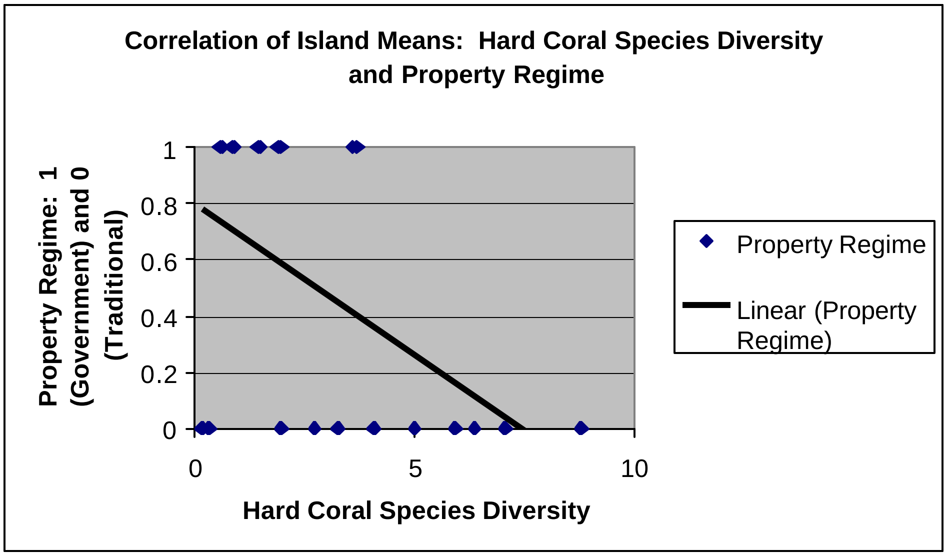
The number of coral affected by biotic factors is negatively correlated with agro-industry externalities and with total externalities.



Graph 4.92: Correlation -.51

The presence of filamentous algae and reef type were positively correlated. This means that there is a linear relationship with the presence of filamentous algae and with fringing reefs. The presence of Cyanophyta and percentage of soft coral coverage and the soft coral species diversity is negatively correlated.

Finally, the last correlation I would like to point out is a weak correlation, -.45, but with a high significance of .04 between the hard coral species diversity and the type of property regime. The negative correlation means that the higher the hard coral species diversity the more likely there is a relationship with a traditional system of management.



Graph 4.93: Correlation -.45

Intra –Island and Inter-Island Site Comparison

Islands and study sites were selected based upon differences in the property regimes and commodification of marine resources. Study sites are compared using a non-parametric statistical analysis, the Wilcoxon test, testing the difference between the variability and dispersion of two sample populations. Coral data will be reported as having a significant difference only when the p value is less than .05. Since coral data has natural variability, the variance in each site is extremely high and thus makes showing significant differences less likely.

Ovalau and Vatulele: Significance of Property Regimes and Agro-Industry

Vatulele Site #3 and #5 and Ovalau Site #8 and Site #9 are all study sites on the windward side of the island that have barrier reefs. Vatulele Site #3 and site #5 have traditional marine tenure regimes and little commodication of marine resources and thus low levels of externalities associated with the development of these markets. Ovalau Site #8 and Site #9 are in areas controlled by the Port Authority and are classified as government regulated reef areas. Furthermore, these two sites have high externalities associated with marine harvesting and agro-industry. The PAFCO effluent pipeline flows out into these sites. Ovalau Site #7 and Site #10 are under traditional marine tenure. Current patterns in the Ovalua reef system show that currents head south towards site # 9 and #10 (Lovell).

Table 4.16: Hard Coral Species Diversity

	Ovalau 7	Ovalau 8	Ovalau 9	Ovalau 10	Vatulele 3	Vatulele 5
Mean	**4.08**	**1.89**	**0.91**	**0.16**	**8.77**	**5**
Standard Error	0.24	0.16	0.17	0.06	0.34	0.27
Standard Deviation	2.05	1.38	1.43	0.44	2.93	2.33
Confidence Level (95.0%)	0.47	0.32	0.33	0.10	0.68	0.54

Ovalua sites #7, #8, #9, and #10 have lower means for hard coral species diversity than the two Vatulele study sites. Ovalau site #8 has a mean of 1.89 and site #9 has a mean of .91. Vatulele site #3 has a mean of 8.77 and Site #5 has a mean of 5. Hard coral species diversity is significantly different between Vatuele Site #5 and Ovalua Site #8 (Wilcoxon Score: 18.58 and p<.04). Vatulele site #5 and Ovalau site #9 are significantly different (Wilcoxon Score: 19.27 and p<.05). Furthermore, Ovalau site #7 has a mean of 4.08 and site #10 has a mean of .16 for hard coral species diversity. There is no significant difference between Ovalau site #7 and the two Vatuele sites, but there is a significant difference between Ovalau site #10 and Vatulele site #3 (Wilcoxon Score: 24.84 and p<.04). There is no significant difference between the four Ovalau sites. Site #7 is higher and Site #10 is significantly lower than Ovalau sites #8 and #9.

Table 4.17: Coral Mortality Index

	Ov 7MI	Ov 8MI	Ov 9MI	Ov 10MI	Vat 3MI	Vat 5MI
Mean	**0.73**	**0.77**	**0.93**	**0.94**	**0.72**	**0.78**
Standard Error	0.02	0.02	0.02	0.02	0.02	0.01
Standard Deviation	0.16	0.18	0.13	0.18	0.18	0.10
Confidence Level (95.0%)	0.04	0.04	0.03	0.04	0.04	0.03

The MI for Ovalau sites #9 and #10 have higher values than Vatulele sites #3 and sites #5. Both of Ovalau sites #9 and #10 are south of the PAFCO pipeline. Thus the water from the PAFCO effluent follows the current patterns inside the barrier reef system and goes south.

Table 4.18: Percentage Soft Coral Coverage

	Ov 7%soft	Ov 8%soft	Ov 9%soft	Ov10%soft	Vat3%soft	Vat5%soft
Mean	**2.61**	**3.63**	**8.91**	**18.63**	**4.93**	**2.56**
Standard Error	0.67	0.82	1.73	2.32	0.80	0.44
Standard Deviation	5.80	7.11	14.97	20.05	6.92	3.77
Confidence Level (95.0%)	1.34	1.64	3.44	4.61	1.59	0.87

The percentage of soft coral coverage is higher in Ovalau sites #9 and #10 with means of 8.91 and for the latter 18.63. Soft coral species diversity is significantly different between Vatulele #5 and Ovalau #10 (Wilcoxon Score: 6.65 and $p<.04$).

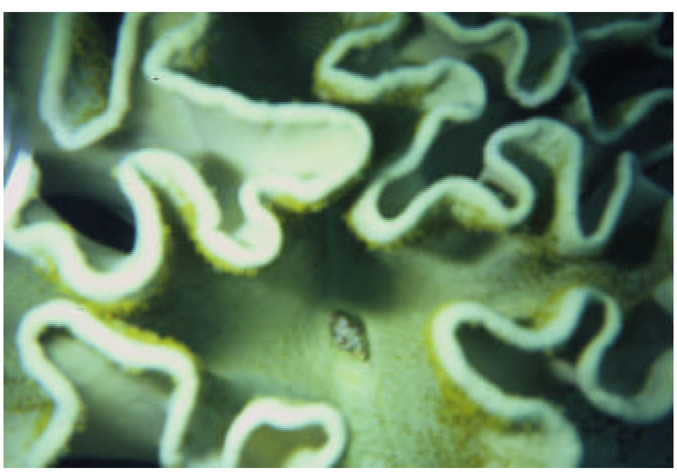

Picture 4.10: Soft Coral, Ovalau

Table 4.19: Soft Coral Species Diversity

	Ov 7	Ov 8	Ov 9	Ov 10	Vat 3	Vat 5
Mean	**0.53**	**0.48**	**0.68**	**1.36**	**1.013**	**0.59**
Standard Error	0.10	0.09	0.11	0.13	0.14	0.08
Standard Deviation	0.83	0.81	0.92	1.13	1.22	0.68
Confidence Level (95.0%)	0.19	0.19	0.21	0.26	0.28	0.16

Table 4.20: Number of Affected Corals by Biotic Factors

	Ov 7	Ov 8	Ov 9	Ov 10	Vat 3	Vat 5
Mean	**0.07**	**0.04**	**0.07**	**0**	**0.33**	**0.03**
Standard Error	0.04	0.03	0.04	0	0.07	0.02
Standard Deviation	0.30	0.26	0.30	0	0.58	0.16
Sample Variance	0.09	0.07	0.09	0	0.33	0.03
Confidence Level (95.0%)	0.07	0.06	0.07	0	0.13	0.04

Data for the affected corals, clonal condition, presence of filamentous algae, and Cyanophyta are all related to the MI. Vatulele site #3 has a high species diversity and low MI, but also has the highest values for number of corals affected by biotic factors, the presence of Cyanophyta and filamentous algae. Vatulele Site #5 has the highest number of values documenting the clonal condition. The MI for Ovalau site #9 and site #10 is extremely high. There is a significant difference between the number of affected corals Ovalau site #9 and Vatulele site #3 (Wilcoxon Score: 18.19 and $p<.004$) and Ovalau site #7 and Vatulele site #3 (Wilcoxon Score: 6.65 and $p<.0004$). The reef in Vatulele had incidence of CLOD.

Table 4.20: Coral Clonal Condition

	Ov 7	Ov 8	Ov 9	Ov 10	Vat 3	Vat 5
Mean	**0.07**	**0.31**	**0.05**	**0.11**	**0.07**	**0.24**
Standard Error	0.03	0.05	0.03	0.04	0.03	0.05
Standard Deviation	0.25	0.46	0.23	0.31	0.25	0.43
Confidence Level (95.0%)	0.06	0.11	0.05	0.07	0.06	0.10

There are no significant differences in the coral clonal condition.

Table 4.21: Presence of Cyanophyta

	Ov 7	Ov 8	Ov 9	Ov 10	Vat 3	Vat 5
Mean	**0.04**	**0.03**	**0.01**	**0**	**0.09**	**0.01**
Standard Error	0.02	0.02	0.01	0	0.03	0.01
Standard Deviation	0.20	0.16	0.12	0	0.29	0.12
Confidence Level (95.0%)	0.05	0.04	0.03	0	0.07	0.03

Ovalau site #8 and Vatulele site #3 have a significant difference in the presence of Cyanophyta (Wilcoxon Score: 3.96 and $p<.05$) and in the presence of filamentous algae (Wilcoxon Score: 3.59 and $p<.05$).

Table 4.22: Presence of Filamentous Algae

	Ov 7	Ov 8	Ov 9	Ov 10	Vat 3	Vat 5
Mean	**0.12**	**0.05**	**0.12**	**0.03**	**0.16**	**0.04**
Standard Error	0.04	0.03	0.04	0.02	0.04	0.02
Standard Deviation	0.33	0.23	0.33	0.16	0.37	0.20
Confidence Level (95.0%)	0.08	0.05	0.08	0.04	0.09	0.05

Rarotonga and Aitutaki: The Significance of Property Regimes and Marine Harvesting Externalities

Rarotonga Sites #1 and #6 and Aitutaki Sites #3 are both sites with fringing reefs on the windward side of the island. The Rarotonga sites are both Ra'ui that are closed to harvesting marine resources. All three sites have high levels of agro-industry development and tourism development. The data below highlights the differences among these three sites.

Table 4.23: Hard Coral Species Diversity

	Raro1	*Raro 6*	*Ait 3*
Mean	**3.69**	**1.96**	**1.96**
Standard Error	0.27	0.12	0.14
Standard Deviation	2.30	1.05	1.25
Confidence Level (95.0%)	0.53	0.24	0.29

Hard coral species diversity mean is higher in Rarotonga Site #1, 3.69, and the values are equal with Rarotonga site #6 and Aitutaki site #3 at 1.96 species per quadrat.

Table 4.24: Coral Mortality Index

	Raro 1 MI	*Raro 6 MI*	*Ait 3MI*
Mean	**0.87**	**0.87**	**0.62**
Standard Error	0.02	0.01	0.03
Standard Deviation	0.13	0.10	0.26
Confidence Level (95.0%)	0.03	0.02	0.06

The MI on Aitutaki is lower than the sites of Rarotonga.

Table 4.25: Number of Affected Corals by Biotic Factors

	Raro 1	Raro 6	Ait 3
Mean	**0.04**	**0.07**	**0.00**
Standard Error	0.02	0.04	0.00
Standard Deviation	0.20	0.30	0.00
Confidence Level (95.0%)	0.05	0.07	0.00

The number of affected corals by biotic factors, the coral clonal condition, and the presence of Cyanophyta have higher values in both Rarotongan study sites compared with the Aitutaki site. There is no significant difference in any of these data.

Table 4.26: Coral Clonal Condition

	Raro1	Raro 6	Ait 3
Mean	**0.13**	**0.16**	**0.03**
Standard Error	0.04	0.04	0.02
Standard Deviation	0.34	0.37	0.16
Confidence Level (95.0%)	0.08	0.09	0.04

Table 4.27: Presence of Cyanophyta

	Raro 1	Raro 6	Ait 3
Mean	**0.07**	**0.11**	**0.03**
Standard Error	0.03	0.04	0.02
Standard Deviation	0.25	0.31	0.16
Sample Variance	0.06	0.10	0.03
Confidence Level (95.0%)	0.06	0.08	0.04

Table 4.28: Presence of Filamentous Algae

	Raro 1	Raro 6	Ait 3
Mean	**0.12**	**0.43**	**0.23**
Standard Error	0.04	0.06	0.05
Standard Deviation	0.33	0.50	0.42
Confidence Level (95.0%)	0.08	0.12	0.10

The presence of filamentous algae has a mean of .43 in Rarotonga site #6, which is higher than Aitutaki site #3. Rarotonga site #1 has a lower level of filamentous algae than Aitutaki site #3.

Rarotonga and Aitutaki: The Significance of Tourism Externalities

Rarotonga site #5 and Aitutaki Site #2 are study sites on the leeward side of the island with a barrier reef. Both have high levels of marine harvesting and agro-industry. Rarotonga Site #5 has a high density of tourist facilities and activities and Aitutaki Site #2 does not. Neither of these sites have soft coral coverage.

Table 4.29: Hard Coral Species Diversity

	Raro 5	*Ait 2*
Mean	**1.48**	**3.59**
Standard Error	0.16	0.21
Standard Deviation	1.38	1.82
Confidence Level (95.0%)	0.32	0.42

Aitutaki site #2 has a higher mean, 3.59 than Rarotonga site #5, 1.48 for hard coral species diversity. Aitutaki site #2's MI is also lower than Rarotonga site #5.

Table 4.30: Coral Mortality Index

	Raro 5 MI	*Ait 2MI*
Mean	**0.88**	**0.73**
Standard Error	0.01	0.02
Standard Deviation	0.11	0.15
Confidence Level (95.0%)	0.03	0.03

Furthermore, the number of corals affected by biotic factors, the coral clonal conditions, presence of Cyanophyta, and presence of filamentous algae are all variables that have higher values on Rarotonga site #5, even though the MI is higher, than Aitutaki site #2.

Table 4.31: Number of Affected Corals by Biotic Factors

	Raro 5	Ait 2
Mean	**0.16**	**0.07**
Standard Error	0.05	0.04
Standard Deviation	0.40	0.38
Confidence Level (95.0%)	0.09	0.09

Table 4.32: Coral Clonal Condition

	Raro 5	Ait 2
Mean	**0.16**	**0.12**
Standard Error	0.04	0.04
Standard Deviation	0.37	0.33
Confidence Level (95.0%)	0.09	0.08

Table 4.33: Presence of Cyanophyta

	Raro 5	Ait 2
Mean	**0.08**	**0.07**
Standard Error	0.03	0.03
Standard Deviation	0.27	0.25
Confidence Level (95.0%)	0.06	0.06

Table 4.34: Presence of Filamentous Algae

	Raro 5	Ait 2
Mean	**0.16**	**0.01**
Standard Error	0.04	0.01
Standard Deviation	0.37	0.12
Confidence Level (95.0%)	0.09	0.03

Discussion: Reef Health and Change, Commodification, and Property Regimes

Island study sites were selected based upon similar physical characteristics and different human geographic factors. These four islands and this approach were used to gain further insight into the causes of the decline in reef health.

All Island Means and Correlation Analysis

Ovalau

The reefs surrounding Ovalau have been affected by the PAFCO effluent and harbor surrounding Levuka. All sites, #6, #9, and #10, that are south of the effluent have higher MI means of .92, .93, and .94. The Ovalau sites north of the pipeline have MI means of .73 and .77. This pattern is also the same for hard coral species diversity. The sites in the north have higher values than the sites south. Sites #9 and #10 have means of .91 and .16, while sites #7 and #8 have means of 4.08 and 1.89. The data describing the number of affected coral, coral clonal condition, presence of Cyanophyta, and presence of filamentous algae are high in sites #6, #9, and #10 compared to sites #7 and #8 due to the high MI. Site # 6 had twenty-two bleached corals while having a MI of .92. Although, there are no significant differences according to the Wilcoxon score, there is a significant relationship when doing a Spearman correlation coefficient for all of the Fijian study sites. The Spearman correlation coefficient shows a strong positive correlation of .64 with a probability of .03 between the MI and the externalities associated with agro-industry. Furthermore, the hard coral species diversity and the agro-industry correlation have an even stronger relationship with a negative correlation of -.82 and a probability of .004. Finally, the soft coral percent coverage is positively correlated, .63 with a probability of .05, with agro-industry. Based upon this data patterns have emerged on the reefs of Ovalau. The reefs have been heavily affected by the waters in the Levuka area and are carried south. Thus the hard corals of the south have died, but are recovering. This recovery is dominated by soft coral. This “phase shift” is a common pattern seen in degraded reefs (Done 1997).

Vatulele

The reefs of Vatulele have much lower MI values and much higher hard coral species diversity than the reefs of Ovalau. Some quadrats had up to twenty different species of coral. Site #4 has a much higher MI and lower hard coral species diversity due to the location of the study site. This site is heavily influenced by big waves. The reefs of Vatulele have many biotic factors affecting the corals and coralline algae. Vatulele island resort, at the time of doing the research was collecting up to 200 COTS a day, and while surveying, CLOD was documented at all of the sites on the leeward side of the island. Site #6 had twenty-two coralline algae with CLOD. It has been suggested by locals that plume from the Sigatoka river is the cause for this increase in biotic factors affecting the reefs of Vatulele.

Picture 4.11: Plume from the Sigatoka River, Fiji

Aitutaki

The reefs on the east part of the island versus the reefs on the west side of the island have higher MI's and overall lower hard coral species diversity. Aitutaki site #4 and #5 on the east side of the island are on the leeward side of the island and runoff from the past agro-industry and present plantations affects these two sites due to the current patterns in the lagoon. MI's for site #4 and #5 are .94 and .84 and hard coral species diversity is .63 and 1.44. By contrast sites #1, #2, and #3 have lower MI's of .77, .73, and .62 and overall higher values of hard coral species diversity of .85, 3.59, and 1.96. Site #1 is hit by heavy waves and is next to the airport, it still has lower MI and higher species diversity than site #4. Furthermore, site #5 was covered with the Cyanophyta.

Rarotonga

Rarotongan reefs have high levels of *Plagioporus* spp. affecting *Porites* spp. This is correlated with sewage (Aeby 1991). Partial bleaching of corals and the presence of filamentous algae were also affecting the corals. Sites #3, #4, and #5 have high levels of tourism development and the externalities associated with tourism. Sites #3, #4, and #5 have mean MI's of .94, .93, and .88, while sites #1, #2, and #6 have mean MI's of .87, .83, and .87. Hard coral species diversity is lower for sites #3, #4 and #5 with values of .33, .57, and .1.48. Sites #1, #2, and #3 all have higher values of hard coral species diversity, which are 3.25, 3.69 and 1.96. These sites, #3, #4, and #5, have the highest MI's on the island as well as the highest levels of filamentous algae. This is unusual because leeward sides of islands generally have 15-20 percent more species diversity that windward side of island because of wave energy and reef formations and structure (Edinger et al. 1998). Perhaps the windward reefs have higher hard coral species diversity because of the flushing of fresh ocean water upon the reef environment, cleansing the habitat from pollutants.

Correlation of Island Means

Despite the high variability of coral data there were some strong correlative relationships with geographic factors seen in the data. The correlative relationships found in the data suggest that agro-industry is strongly related to the death of hard corals. Furthermore, reefs with agro-industry within a close proximity also have much lower hard coral species diversity. Hard coral species diversity is also lower in areas with higher total externalities. The relationship between property and hard coral species diversity must be discussed. There is a strong relationship considering that Ra'ui have only been in place for at most two years in Rarontonga and that the reefs of Ovalau have been heavily affected by pollutants in the areas not owned by the communities. The presence of filamentous algae and the fringing reef was also a strong positive correlation. This is not surprising, since fringing reefs are closer to the shoreline, which are areas where there are more nutrients usually in the water column. A weak positive correlation also exists between the tourism market and the fringing of .43 with a probability of .05.

The remainder of the relationships are between the ecological variables. There is strong relationship between the MI and hard coral species diversity, which is negatively correlated at -.78. There is also a strong positive correlation of .69 between hard coral species diversity and the number of affected coral by biotic factors. This would explain the negative correlative relationships between agro-industry externalities and total externalities with the number of coral affected by biotic factors. The final negative correlative relationship is between soft coral species diversity and soft coral percent cover and the presence of Cyanophyta. I would suggest that these two organisms are competing to re-colonize degraded reefs.

Intra-Island and Inter-Island Site Comparison

Ovalau and Vatulele: Significance of Property Regimes and Agro-Industry

As already discussed in the above section, the impact of the upstream PAFCO effluent upon Ovalau sites #9 and #10 may have increased the MI, lowered the hard coral species diversity, and created a "phase shift" from hard coral species to soft coral species (Done 1992). This shift is a change from a community dominated by reef building organisms to one dominated by non-reef building organisms such as soft coral and fleshy algae.

Rarotonga and Aitutaki: The Significance of Property Regimes and Marine Harvesting Externalities

No significant differences were identified between any of these sites with any of the ecological variables. The data shows, however, higher mean values in the hard coral species diversity in the Ra'ui sites than in the Aitutaki. This is interesting because an almost atoll is older and has a more developed reef, as well as higher coral diversity (Paulay 1988). The Ra'ui will be further investigated and discussed in Chapter 5.

Rarotonga and Aitutaki: The Significance of Tourism Externalities

No significant differences were identified between these two sites, but every variable tested has a higher or lower value in the Rarotongan site, suggesting poorer health. The MI is higher in Rarotonga and the hard coral species diversity is lower, while the number of affected corals, coral clonal condition, presence of Cyanophyta, and presence of filamentous algae are all higher on the Rarotonga site #5. Coral reef systems are sensitive to changes in the physical and chemical environment, and this is well documented in the literature (Pastorok and Bilyard 1985:) (Dubinsky and Stambler 1996). The impact of sewage upon the coral reef system depends upon the current patterns and flushing rates of the lagoon. Eutrophication as a result of sewage discharge can give rise to increased algal bloom and biomass and reduced diversity of invertebrates. Furthermore, the increase in coral mortality has been attributed to algal growth because of the direct smothering of colonies by fast growing algae that is stimulated by the additional nutrients or through the indirect competition for space (Walker 1982).

Conclusions and Outcomes

Key findings from this research suggest:

- As discussed in Chapter 3, there is a correlation with traditional systems of marine resource management and lower market development and the externalities associated with market development. In other words, there are more traditional systems of reef management and use when the market development is a level 1 or 2 according to the scale in Chapter 3. In the cases of Ovalau and Rarotonga, where there are combined types of marine tenure regimes on the island, non-point and point source pollutants upcurrent still affect traditional areas downcurrent. Ovalau site #10 and site #7 perfectly illustrates this example.
- Agro-Industry versus tourism and marine harvesting externalities have the biggest impact upon the MI and hard coral species diversity.
- Biotic factors affecting corals, such as disease and predators, occur naturally in a coral reef system. If this variable is solely used to assess reef change and health, Vatulele would have had the highest prevalence of coral affected by biotic factors.

Thus this confirms the need for a whole reef perspective when assessing reef health.

- Using a whole reef perspective and examining the environmental history of development and geographic factors is crucial to unraveling causes of degradation. Especially since reefs are extremely complex systems, it is difficult to carry-out large-scale studies on the health of the reef and causes of degradation. High variability in data and the uniqueness of each reef make large-scale studies inaccurate.
- Local peoples, including head fishermen, divers, as well as resource managers have insightful observation on the current status of reef health.
- Furthermore, reefs with traditional systems of marine management such as in the case of Rarotonga help control harvesting of marine resources. More studies need to be done for longer periods of time to understand the effect upon the habitat the Ra'ui may have. These data suggest that there is relationship between these Ra'ui areas and new coral growth. This will be discussed in more detail in the next chapter on the resurgence of the Ra'ui.

These four islands are a small sample of thousands of islands in the South Pacific. Thus more studies will be needed to assess reef health throughout the Pacific to make more general statements about reef health in the South Pacific and the relationship with market developed and property regimes.

Chapter 5: The Re-implementation of the Ra'ui in Rarotonga

> Ra'ui has no fishing and collecting, and it is helping the ecosystem. Herbivorous and carnivorous fish [are] getting back into balance (Interview #1, Rarotonga).

In the past two years the local communities on Rarotonga, Cook Islands have tried to stop Islanders from fishing in some coral reefs areas by creating traditional no-fishing zones, known to the locals as Ra'ui. The Ra'ui primarily protects the reef from many people walking and collecting shellfish, octopus, and other organisms, and therefore helps restock the lagoon fish. Locals want to maintain the restricted areas for conservation purposes.

In this chapter I will introduce an anomalous among the four island case studies. This island case study of Rarotonga documents an alternative model of the property institutions in place, which changes access to resources and regulation of marine areas. Although Rarotonga has heavy reef commodification, as described in Chapter 3, the local people and the government have simultaneously re-invented traditional marine institutions to regulate access and harvesting of the reef. I will review the history of the Ra'ui and will discuss the process of its re-introduction in 1998, and investigate whether or not the Ra'ui around Nikao Beach has changed any aspect of the basic reef ecology. I will show that the re-introduction of "traditional" marine social institutions, as exemplified in this case study, has increased the diversity of corals. Other researchers show that it has increased marine invertebrates and fish species diversity and evenness as well (Ponia April 1999; Ponia March 1998; Raumea and al. January 2000). Using the methods described in Chapter 1, I will compare one study site in a Ra'ui with another comparable site.

Cook Island Customary Marine Tenure and the Ra'ui

In many Pacific countries, laws and customary practices relating to conservation and use of natural resources are an essential component in policy making. In the past century, as legislative systems have begun to incorporate environmental laws, the question of integrating customary concepts and practices into the Western legal framework has come to the attention of many researchers and resource managers (Pulea 1985). Customary law has been found throughout the Pacific in written and unwritten form (Boer 1996). These types of laws can be social, such as marriage, or economic, such as the numerous customary practices of traditional fishing. Pacific people abide by such laws or the social laws which may be considered ritual, or process by which society conforms, and, if violated, will invoke coercive procedures (Boer 1996). According to Reti (1993), the incorporation of customary law has been controversial concerning the protection of the Pacific Islands' environment:

> …custom and traditional law have in the past had some success in the protection of the natural resources and environment of countries in the Pacific. However, some customs and laws have lost the degree of respect they use to command and are not as effective today as they were some years ago…Both the written and unwritten laws can contribute positively to the protection of the environment of the Pacific. The unwritten law which has its basis in the traditional customs and practices can bring together local communities to observe and to pay respect to policies and principles set under the written law for the protection of the environment. The legal system must also respect the local traditions and practices if it is to gain support and cooperation of the local people (Reti 1993: 59-60).

The customary laws and practices, i.e. patterns of behavior and social norms that have developed in the Cook Islands are based upon a system originating from Eastern Polynesia. These practices have been modified over the years, especially since European contact. Since 1965, the Cook Islands has been a self-governing state in free association with New Zealand. The formal ties to New Zealand beginning in 1901 significantly influenced the Cook Islands legal system. Laws written at this time are still in practice. For example, on issues related to land rights and ownership the following law is still in place. The Cook Islands Act of 1915 gives recognition to native customs and makes the following provision in relation to land:

> Every title to and interest in customary land shall be determined according to ancient custom and usage of the Natives of the Cook Islands (Boer 1996: 30).

However, all land lying below high water mark was declared by The Cook Islands Act of 1915 to be Crown Land, thus annulling the indigenous pattern of rights to reef and lagoon waters (Boer 1996: 30). Furthermore, the 1986/87 Conservation Act declares all foreshores and soil under the water to be owned by the Crown (Boer 1996). This Act further protects the foreshore by prohibiting the removals of silt, sand, gravel, coral, cobble, and boulders from foreshore and coastal waters without permission from the Conservation Council. These three laws are crucial to the issue surrounding reef health and the re-implementation of the Ra'ui.

Prior to European contact, rights to the lagoon, like land, were controlled by the dominant social lineages. According to Crocombe, "rights to the lagoon and its products were generally exercised by the *matakeinanga* occupying the *tapere*[30]." Although demarcation of the areas were often unclear, court cases documented people referring to coral rocks as boundary marks (Crocombe 1964: 41). In addition to reef access, reef

[30] *Matakeinanga* is the local group occupying a *tapere*, and composed of the residential core of a major lineage and other permitted members. *Tapere* is a sub-district, normally headed by a *Mataiapo*, a chief of a major lineage. Each *mataiao* was titular head of a *tapere* of land and the people who resided thereon, and

passages from the lagoon to the open ocean were associated with the senior title of the major lineage of the *tapere* in which they were found. In the past, it was the right of the title-holder to be given a part of the catch by any fisherman using the passage.

Access to land, preservation of supplies of certain crops, protection of lagoon fish, and even a walking path could be controlled by the use of a Ra'ui, or customary prohibition, enforced by the appropriate chief. The Cook Islands Maori Dictionary defines a Ra'ui as:

> 1. A sign, *usu*, leaves on a branch set in place by the owner of a piece of land or water reserving it or its produce for his own or some special use; a prohibition. 2. Erect a ra'ui restricting the picking of fruit etc.

The Ra'ui would be marked with a sign, such as a coconut leaf tied around a tree bordering the prohibited area. This prohibition was not permanent and would usually last for a season to restock food sources for a celebration or feast, or to protect a species while spawning (Interview #15, Rarotonga). The area was patrolled and no one was allowed to enter the demarcated area (Interview #14, Rarotonga). This area had supernatural power, *tapu*. If a person were to break the Ra'ui he/she would be punished with both secular and supernatural sanctions.

> Ra'ui areas are policed by *mana*, power – traditional leadership, king, and social pressure. And hurt person if disobey (Interview, #3, Rarotonga).

The Ra'ui had spiritual significance. Prior to colonization, not only would poaching cause a person harm through supernatural forces, but the person would be punished by

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occupied by *mataakeinanga* Crocombe, R. G. (1964). *Land Tenure in the Cook Islands*, Oxford University Press, Melbourne, Australia..

the village and be beaten, fined, or perhaps even chased out of the village (Interview #18, Rarotonga).

In the nineteenth century when European missionaries arrived, and in 1888 when the Cook Islands was officially declared a British Protectorate, the Ra'ui was used as an important technique to control the export of cash crops. A person could not harvest any coconuts until the Ra'ui was lifted. In order for the Ra'ui to be lifted, the *ariki* would negotiate with a trader the best price for the crop for the entire district. The system was "used to reduce theft and ensure the best possible price for produce" (Crocombe 1964: 93). However, an unfair chief could take advantage of this power. A principal function of the subsistence economy had been to ensure food supplies, but since the resources were perishable, and thus rapidly consumed, all the people enjoyed the fruits of their labor. The chief would not take a larger share than anyone else, just perhaps the best piece. But, as the export agricultural market developed the chief could use a Ra'ui to increase his cash income.

As land laws changed under The Cook Islands Act of 1915, land and sea ownership became segmented and clans' control and ownership of the land and sea diminished. By the 1970s, the Ra'ui system was not being used on the island of Rarotonga. If an elder placed a coconut leaf on a stake to protect the coconuts for feast, people would just rip off the leaves (Interview #12, Rarotonga). Local people were becoming less and less dependent upon the land and, in addition, had less access to it (Interview #12, Rarotonga). Prior to the re-implementation of the Ra'ui in 1998, the last time one community leader remembers a Ra'ui was in the early 1970s.

> My grandmother or other elder, put a Ra'ui on in the 1970s during the time period the Rock Cod was spawning. No fishing and she would tie a

> coconut leaf on a stick and place it in the water and this would mean do not fish there (Interview #12, Rarotonga).

In the Northern Group of Islands, the major lineages demarcated and created claims and ownership of the lagoon. This changed when the Cook Islands was incorporated into New Zealand yet traditional claims have persisted. For example, local people still respect traditional ownership of the reef if the family owns beach front property and there is no alternative way to access the waters except through the family's land (Interview #19, Rarotonga). Presently, on the remote islands and atolls, beach front access and ownership is of great importance, especially as cultivation of artificial pearls is becoming a more developed industry (Boer 1996). In one of the southern islands, Rarotonga, the Ra'ui system was reinstated in 1998, and other islands such as Aitutaki re-implemented the Ra'ui in 2000. Koutu Nui is suggesting the Ra'ui system to the other islands.

Access and Control Over Marine Resources and the Re-implementation of the Ra'ui

On the island of Rarotonga the Ra'ui was re-instated by the traditional leaders in 1998 in five different community lagoon areas surrounding the island:

> The Ra'ui has been declared to assist in the protection of the marine environment, to contribute towards an increase in the numbers of fish and shellfish available for present and future generations. It may provide the additional benefit of promoting the area as a tourist attraction, bringing opportunities for additional revenue to the people (Passfield and Tiraa 1998c: 3).

The Ra'ui is a complete ban on fishing or collecting of all marine life. However, the restricted area remains open to recreational users for non-motorized activities such as snorkeling and surfing. The demarcated areas extend from the high water mark to the reef slope to a depth of 30m. Community wardens of all ages are appointed to enforce the prohibition of killing and taking of marine life. The duration of the Ra'ui varies from community to community, but is not seasonal. Instead, communities are assessing the marine resource stocks to determine their rate of recovery.

Why was the Ra'ui reinstated in Rarotonga after so many years? The idea emerged in 1975s when Gare (1975) and later Dahl (1981) suggested creating marine reserves around the island (Dahl 1981; Gare 1975). Soon after, the traditional chiefs, *Koutu Nui*[31], in 1989 requested the Ministry of Marine Resources to survey the marine resources in the lagoon. The chiefs were once again thinking of creating marine reserves and wanted some biological data to support this proposal. By 1991, the Cook Island Tourism Master Plan suggested creating a marine reserve, as did the Asian Development Bank in 1995 (Barrett Consulting Group 1985; Darby 1991). The 1991 Tourism Master Plan suggested organizing and standardizing tourist cultural sites as well as coastal areas (Darby 1991). The plans also recommended ways to better manage limited water resources and disposal of waste on the tiny islands, and develop inland hiking trials for visitors. The creation of a marine reserve was thought to attract tourists and create revenue. In 1997, the idea was again brought to the attention of the Cook Island Tourism Master Plan Implementation Assistance Programme (TMPIAP). This NZ$2.8 million program funded by the New Zealand Overseas Development Agency (NZODA) and Cook Island government had the goal to develop, promote, and strengthen tourism. One report was carried out, by the request of the *Koutu Nui*, under the TMPIAP, which proposed the establishment of marine protected using the Ra'ui concept (Passfield and Tiraa 1998c). This crucial report, "Parks, Reserves, and Ra'ui on Rarotonga: A Proposal for Establishment of Protected Areas in Partnership Between Landowners, the Community and Government", instigated discussions with the communities on establishing the marine reserves, Ra'ui (King April 1997). After the completion of the report, the World Wildlife Fund for Nature (WWF) decided to support the concept, but only if it was community based. By September 1997, the feasibility study was presented at a stakeholders' meeting for commentary by the government, NGO, business, fishers, and chiefs to discuss. At this point the President of the *Koutu Nui,* Dorice Reed, said that the *Koutu Nui* should promote and support the Ra'ui and convey this agenda to the communities. Furthermore, to truly accomplish and implement the Ra'ui all the groups agreed that the *Koutu Nui* had to be the ones establishing the Ra'ui. The advantage of using the traditional system in the

[31] The *Koutu Nui* is a formal group of traditional leaders. They create the Lower House of Traditional Chiefs Passfield, K., and Tiraa, A. (1998c). "Management Plan for a Ra'ui in Rutaki." , Koutu Nui, Rarotonga, Cook Islands..

Picture 5.1: Women Collecting on the Reef Rarotonga, Cook Islands.

modern context is that it is community-based and managed. Furthermore, over the years the Cook Island government has been perceived as oppressive, as one local person stated the "government involvement in restricting fishing is seen as politically incorrect" and "the government is not trusted. In the past [the government] did not deliver promises and the communities have not always been consulted on various projects" (Interview #12, Rarotonga: Interview#14, Rarotonga). Native inhabitants trust and respect their community leaders. Furthermore, it would be expensive to enforce the regulation. Peer pressure and the *mana* of traditional leaders was often all that was required to prevent a violation in the past, and people thought it would work again today. In order for it to be established and successful, once implemented, the entire community support was and is essential for continual success.

Members of the community from many different groups came together to share the responsibility of accomplishing tasks and supporting financial aspects of the project. The *Koutu Nui* gathered support from WWF to help prepare the management plans for four of the five selected sites. The Ministry of Marine Resources agreed to survey the Ra'ui and advise on appropriate times to open the Ra'ui for harvesting or move the Ra'ui to another location.

Picture 5.2: Nikao Ra'ui sign Rarotonga, Cook Islands

NZODA through the Tourism Master Plan provided funds and created awareness campaigns and activities. They paid for the Ra'ui signs, boundary markers, leaflets, and flyers educating tourists and the community. Businesses, schools, and the church supported the initiative with money, educational programs, and material.

Community Establishment of the Ra'ui

Implementation of the Ra'ui has resulted in 14 percent of the lagoon being demarcated as a Ra'ui (Ponia 1998: 30). These temporary reserves allow fish stocks, corals and other marine resources to rejuvenate. Five sites were initiated in February 1, 1998 by the traditional chief, *Koutu Nui*. The first five Ra'ui were declared by the groups of traditional chiefs and the communities of Rarotonga. This was the first step to improve the inshore marine environment surrounding Rarotonga. The five Ra'ui are in the communities of Aroko/Nukupure Ra'ui, Nikao Ra'ui, Kavera Ra'ui, Tikioki Ra'ui, and Matavera/Pouara Ra'ui.

> Four of the Ra'ui declared in 1998, (Tikioki, Nikao, Aroko and Pouara) were in place for two years (WWF personal communication, 1/5/01).

After the *Koutu Nui* decided to support and implement the Ra'ui, they went to each of their respected villages for discussion.

> Each community is unique and the chiefs of each area called [a] meeting with their community. They told the communities that they wanted [the] Ra'ui. And, asked the community, and discussed the boundaries and how long it should be in place for, as well as what species to protect for certain Ra'ui like Avana/Nukopure/Aroko, which has restricted species (Interview #14, Rarotonga).

Each village held a meeting deciding whether or not to establish a Ra'ui. There was discussion until overall consensus was achieved. Other meetings were held at each village so that the community, could decide upon the location and period of time that the Ra'ui would be in place. It was determined that towards the end of the Ra'ui another community meeting would be held to discuss whether or not the Ra'ui should continue. Each village held a different number of meetings and made different decisions about whether to establish a Ra'ui, the size of the Ra'ui, the period of time the Ra'ui should be in place, and the restrictions. Once the communities decided on the establishment of the Ra'ui, they agreed to implement them all on the same day. The Ra'ui was declared in the traditional manner by the *Koutu Nui*, with a special church service blessing the formation of the Ra'ui.

Nikao

Nikao Beach, Black Rocks is one of the most popular beaches on the island. The Nikao Community decided to place a Ra'ui on the popular site to protect the reef and lagoon from harvesting and trampling. Most of the community supported the establishment of the Ra'ui.

> The community decides about the Ra'ui and I chair the village, but the people decide. I put a map up and people decide. Not a lot of debate … All communities have a similar process..in the village everyone is the same…we are all equal…(Interview #18, Rarotonga).

When the meeting was held to review the Ra'ui in 1999 all the people of the community wanted the Ra'ui because they saw higher density and diversity of marine species in the waters (Interview #18, Rarotonga). The community decided to establish another Ra'ui:

> There are two in the village. The second is by the parliament and it is in place for five years. It is their land, of the family. Little Clams in the sand were gone and [the family] want[s] to bring them back. This second Ra'ui is a reef owned by the family. There is no access to the beach except through this families yard and they look after the beach, which is not Crown Land …(Interview #19, Rarotonga).

The Nikao community has been continually advised by the Ministry of Marine Resources to determine the optimal times to harvest trochus in the area. The Ministry of Marine Resources suggested briefs periods of time when only the trochus could be harvested (Interview #16, Rarotonga). The community profited greatly from the Ra'ui. They decided after the two year Ra'ui from 1998-2000 open the area for one month and allow spearfishing and harvesting of trochus.

> On Aitutaki NZ$400,000 was made harvesting the trochus. Our village first harvest of trochus benefits our village and we gave it two years and then we took it out. We collected five tons last year and it was NZ$41,000 for village projects and we only opened the Ra'ui for one month and

> allowed spearfishing and trochus, no net fishing (Interview #18, Rarotonga).

People in the Nikao community believe that the Ra'ui system has respect from most of the community members. If a person does not abide by the Ra'ui he/she will be embarrassed in front of the community, and it is considered to be a bad omen.

> Nothing happens except warnings from the elders if you poach…. but you will get hurt accidentally if you fish in the Ra'ui and this is true. Two boys were caught fishing and were warned by the minister and the next day they were smashed against the sea wall (Interview #18, Rarotonga).

Tikioki

Tikioki reported an initial meeting of sixty people from the community to decide upon the creation of the Ra'ui. The creation of the Ra'ui was well received. The community decided to have a two year Ra'ui that restricted all taking and killing of marine life. The area remains open for recreation use, although no jet skiing or water skiing is permitted. Wardens were appointed from the Rangatira family. Towards the end of the Ra'ui period a review committee was appointed by the *Mataiapo* in 1999 (Passfield and Tiraa 1998d).

> The Tikioki Ra'ui was lifted on 1st February 2000 and moved west to Akapuao on the same day. This Ra'ui will be in place for five years. Again on the same day, a smaller area of the old Tikioki Ra'ui was declared a permanent marine sanctuary (WWF personal communication, 1/5/01).

The Tikioki private sector has been benefiting from the Ra'ui. In the past few years more eco-tourism tours and activities are available to tourists. The Ra'ui around Tikioki is becoming a tourist stop and popular snorkel and dive site.

> [The] commercial sector benefit[s] from the Ra'ui. Hotels, cruises for viewing coral have improved [business]. Small shops have popped up and more people are snorkeling. The bus stops now at [the] Ra'ui. Night dives [have been] organized and [there is] much opportunity (Interview #16, Rarotonga).

<u>Avana/Aroko/Nukupure</u>

The traditional leaders called a meeting and the location of the Ra'ui was determined. The community decided to place a ban on the harvesting of all marine plants and animals. Four species, however, are allowed to be harvested when in season: *patito*, (yellowtails), *matu rori*, (sea cucumber), and *ature,* (brown pencil sea urchin) (Passfield and Tiraa 1998a). Recreational activities are allowed in the Ra'ui, but no jet skiing or water skiing. Traditional landowners and the *Mataiapo* will appoint wardens, but all community members are encouraged to enforce the restrictions. A review process began in 1999 to decide on whether or not to keep the Ra'ui in place after February 2, 2000. The Aroko Ra'ui was lifted on 16th February and replaced on 2nd March (WWF personal communication, 1/5/01).

<u>Matavera/Pouara</u>

The initial discussion meeting was comprised of thirty people (Passfield and Tiraa 1998b). The community agreed to have a complete ban on the harvesting and killing of all marine life. The area remains open to recreational activities. The *Mataiapo* will select a review committee towards the end of the Ra'ui period, and the Rangatira will enforce the Ra'ui. One third of the Pouara Ra'ui was lifted [for harvesting] on 2nd February 2000 and replaced the next day on 3rd February (WWF personal communication, 1/5/01).

According to one community member it was not the community deciding upon the establishment of the first Ra'ui. It was the traditional families who owned the coastal land.

> [The] community decides and for Matavera there were four consultations and they could not agree and did not want the Ra'ui. [The] *Tapere* was owned by [his] family – reef to hills – and it is still seen as that today. Matavera could not decide and [his] family decided to post Ra'ui…. Matavera community was bullied into it and now they see the benefit (Interview #12, Rarotonga).

The traditional properties rights on still respected in the Matavera community. The families that own coastal property also are seen as the owners of the reefs.

Since access to the reef is through the families' property, most people respected the Ra'ui.

> Some poachers over the last three years ..overall the Ra'ui helped a lot, otherwise ten-fifteen people collecting everyday. No laws, if caught just embarrassed (Interview #12, Rarotonga).

The Ra'ui beginning in 2000 will be in place until 2005. The entire community supported and agreed to create a more permanent Ra'ui. Since the Ra'ui was strategically placed in the middle of two passages, there is "spillage" of marine life on both sides of the reef into over one km of village reef (Interview #12, Rarotonga). Furthermore, people are reporting that they are seeing clams, seaweed, and baby parrotfish that they had not seen for decades (Interview #12, Rarotonga).

> Matavera [will be in place for] five years…Tikioki [is] permanent and will be renamed Ra'ui Motukore (forever) and it is only a section of the patch reef (Interview #16, Rarotonga).

Rutaki

The seven traditional leaders, seven Mataiapo, decided to place a six month Ra'ui starting Febraury 2, 1998 and then lift the Ra'ui and then place another Ra'ui for six months in a different location. This was done four times. They decided to totally ban the killing and taking marine life and not allow any recreational activities or access inside the Ra'ui. People are allowed to access the ocean only through the reef passages. The community did not want to appoint wardens. They felt that the *mana* and *tapu* of the Ra'ui will be respected and, if otherwise, they will take other measures. The review process began at the end of 1999 (Passfield and Tiraa 1998c).

> Rutaki The fifth Ra'ui declared in 1998 (Rutaki) was in place for ten months. Fishing was intensive when it was lifted for Christmas in November 1998. Unfortunately, an assessment of marine resources was not done immediately before or after the lifting. Later, the Rutaki Ra'ui managers shifted the Ra'ui about two kilometres west to Kavera to be in place for ten months from 1st March 1999. This was lifted on December 31st 1999 and moved one kilometre east to Aroa on 1st March 2000. This Ra'ui, immediately adjacent to the Rarotongan Beach Resort will be in place for two years (WWF personal communication, 1/5/01).

The Rutaki Ra'ui, according to the Ministry of Marine Resources, was not very effective in protecting the marine resources because once the Ra'ui was lifted and the reef open for harvesting, the community over-exploited the resources.

> One Ra'ui lesson we learned was in Rutaki. For 6 months they placed a Ra'ui and when opened [the community] raped [the] reef and [there is] nothing now (Interview #16, Rarotonga).

The Ministry of Marine Resources recommends to the communities that they have the Ra'ui for a longer period of time with limited harvesting periods in between the Ra'ui. This prevents over-exploitation, and also allows communities to benefit from the Ra'ui.

The acceptance of the Ra'ui by the local people was a result of a number of factors. The emergence of the fish disease Ciguatera and the decline in the state of the lagoon health were the primary reasons for such overwhelming community support. In the early 1990s a fish toxin called ciguatera appeared in the lagoon fish. Studies have shown that Ciguatera is correlated with an increase in nutrients in the water column, which are a result of reef disturbance or destruction, construction, or agricultural pollutants (Lewis 1981).

> *Ciguatera* came out five to six years ago and local[s] stopped eating [the] fish. This was an opportunity to impose conservation in the lagoon areas and improve lagoon areas with [the] Ra'ui system. Now [the] lagoon [is] re-stocked and the locals want to fish and eat again…Ra'ui is a traditional system – traditionally a stocking exercise for a feast and only lasts up to a year (Interview #3, Rarotonga).

Ciguatera derives from a toxin accumulated in some fish in the tropical seas. The production of the toxic agent, a dinoflagelette algae *Gambierdiscus toxicus,* occurs when there are too many nutrients in the water column. The outbreaks tend to occur following environmental disturbances caused by cyclones, dredging, the use of underwater explosives, or increased sedimentation. The dinoflagellate, *Gambierdiscus toxicus*, colonizes the disturbed area in large numbers a few months after the disturbance. They are consumed and concentrated in the food chain, and the toxin intensifies as it moves up the food chain. As a result, when humans consume species of fish containing by the toxin, the result can be fatal (Lewis 1981). Fish in Rarotonga that may be poisonous include: *Maito*, Black Surgeonfish; *A'a pata*, Moray Eel; *Anga mea*, Red Snapper; *Maratea*, Napalean Wrasse; *A'a manga*, Snake Mackerel; *Ku pa*, Bullseye; *Ume,* Unicorn Fish; *Ono*, Barracuda; *Tongua*, Large Snapper; *Titiara*, Jacks; *Iroa*, Emperors, and *Kokiri tua*, Triggerfish.

On Rarotonga the number of cases has varied over the years, but has been fairly considerable (see table below). The fishers in the communities were ready to accept a Ra'ui system to protect the people from eating toxic fish.

Table 5.1: Ciguatera Outbreaks in Rarotonga

Year	Number of Cases
1989	158
1990	109
1991	81
1992	148
1993	55
1994	216
1995	281
1996	304

Sources: (Losacker 1992; Munokoa 1997)

In addition, "the local people were complaining to the chiefs during the monthly meetings. People were dissatisfied with the state of the lagoon" (Interview #12, Rarotonga). According to a Technical Report prepared for the South Pacific Applied Geoscience Commission (SOPAC), fish populations around Rarotonga have declined over the past few decades and there has been a "continuing problem in the use of vegetable poisons, pesticides and explosives to kill fish" (Holden and South Pacific Applied Geoscience Commission 1992:27). Furthermore, Holden (1992) mentions that the water quality is essentially the same quality as the ocean surrounding Rarotonga, but is usually oversaturated with oxygen. The researchers claim that the real cause of fish decline is due to the use of nets, poisons such as *Ora*[32], explosives used for fishing, and loss of mangrove habitat and other breeding grounds as a result of coastal development

(Holden and South Pacific Applied Geoscience Commission 1992). Therefore, the idea of protecting an area from destructive fishing practices is crucial to increase the fish populations. The Ra'ui is one way for communities to increase fish populations for subsistence, for tourists, and also to prevent people from eating fish that may have Ciguatera.

The third reason why the communities accepted the Ra'ui is because the majority of people respect the traditional chiefs and this traditional marine institution.

> In general, chiefs have great support, and people trust their leaders in the community. The Cook Island government has control of marine resources, but the chiefs have customary right to manage it (Interview #14, Rarotonga).

People also trust their community leaders because they know that the community leaders are volunteering their time to make the community a better place for everyone.

> The community members tell chiefs what they want and the chiefs do not dictate. The *Koutu Nui* have a powerful mandate and respect started way back (Interview #16, Rarotonga).

WWF has supported the establishment of Ra'ui with the development of management plans. In addition, it has provided funding, coordination of all the stakeholders, and an education campaign. In a recent newspaper article in the *Cook Island News*, WWF employee Jacqui Evans discussed the importance of the communities "coming up with the ideas themselves and take ownership of the problem" and states that outside agencies like WWF can play an advisory role to help village communities "do what they feel needs to be done to manage their natural resources" (LW 1999). However,

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[32] *Ora* is a Maori word for *Derris* spp.

the Ministry of Marine Resources, WWF, and other conservation organizations would like to see the Ra'ui be permanent and also develop into a management plan that integrated land use practices and more restrictions on fish net sizes. Not everyone in the communities wants this:

> Locals want to stop [the Ra'ui] because [they are] ready to eat and Cook Islanders from New Zealand returning home tend to break the rules, not respecting the system (Interview #3, Rarotonga).

The Environment Department on the island asked locals to not leave nets in the water. However, many have been found in the Ra'ui. Furthermore, when Cook Islanders return to Rarotonga from New Zealand for the holidays there is an increase in illegal fishing. The increase in visitors is not good for the reef and the reef fish (Environment Department 1999).

The local people and government are interested in protecting the reef not only for health reasons. In the 1970s, Rarotonga primarily exported citrus fruits, but the growth and export of these products has ceased. Tourism is now the main industry on the island, with approximately 55,000 tourists visiting The Cook Islands each year. Tourists like to snorkel inside the reef and see a diverse reef with a large variety of tropical fish. Communities are benefiting from the Ra'ui tourism and also benefiting from harvesting the trochus.

A Model of Success

The Ra'ui is seen by all community groups as a success. New eco-tourism businesses have developed around the Ra'ui as they become a point of interest for tourists. Some of the communities are benefiting from a monitored trochus fishery. All groups have participated in the formation of the success and continue to support the Ra'ui. New Ra'ui have been created on the island of Rarotonga since this research was done in 1999. The *Koutu Nui* is trying to promote and establish Ra'ui not just on Rarotonga, but also on other islands. Aitutaki established three Ra'ui in 2000 and Mangaia has started the process to create Ra'ui. Furthermore, community members notice a change in the diversity and density of marine species, in particular mollusks and fish. The next portion of this paper examines whether or not the Ra'ui is really improving the ecological habitat. I examine two sites in the Nikao community.

Ecological Data: Trends and Patterns of Coral Reef Health and the Nikao Ra'ui

There have been no studies of coral growth on the reef flat or differences inside and outside the Ra'ui. I selected the Nikao Ra'ui site to survey and compare with a second study area within 500 meters. This study compares two sites, one inside and one outside a protected area using methods described in Chapter 1. In Nikao Reef, Site #1 and Site #2, all reefs were fringing reefs. Transect locations were non-adjacent, non-overlapping and dispersed at least 100m laterally along each reef. Therefore the reef areas sampled incorporate variation. Three transects of 25m were measured with counts being taken each meter with a 1m x 1m quadrat for a total of 75 quadrats at each site.

<u>Site #1 Descriptive Data of Nikao, Ra'ui: W159.49.376 S21.12.474, see Chapter 4</u>

The Ra'ui covers 25 ha, including 800 meters of beach. The beach is public and easily accessed by locals and tourists. The Ra'ui began in 1998 and was planned to be lifted by February 1, 2000, unless the community agrees to continue it (its current status is uncertain). According to the Ministry of Marine Resources, large increases in invertebrates have been recorded in the Nikao Ra'ui, but no data are available.

Site #2 Descriptive Data of Nikao, no Ra'ui: W159.49.388 S21.12.470, see Chapter 4

Map 5.1: Rarotonga Study Sites, Cook Islands

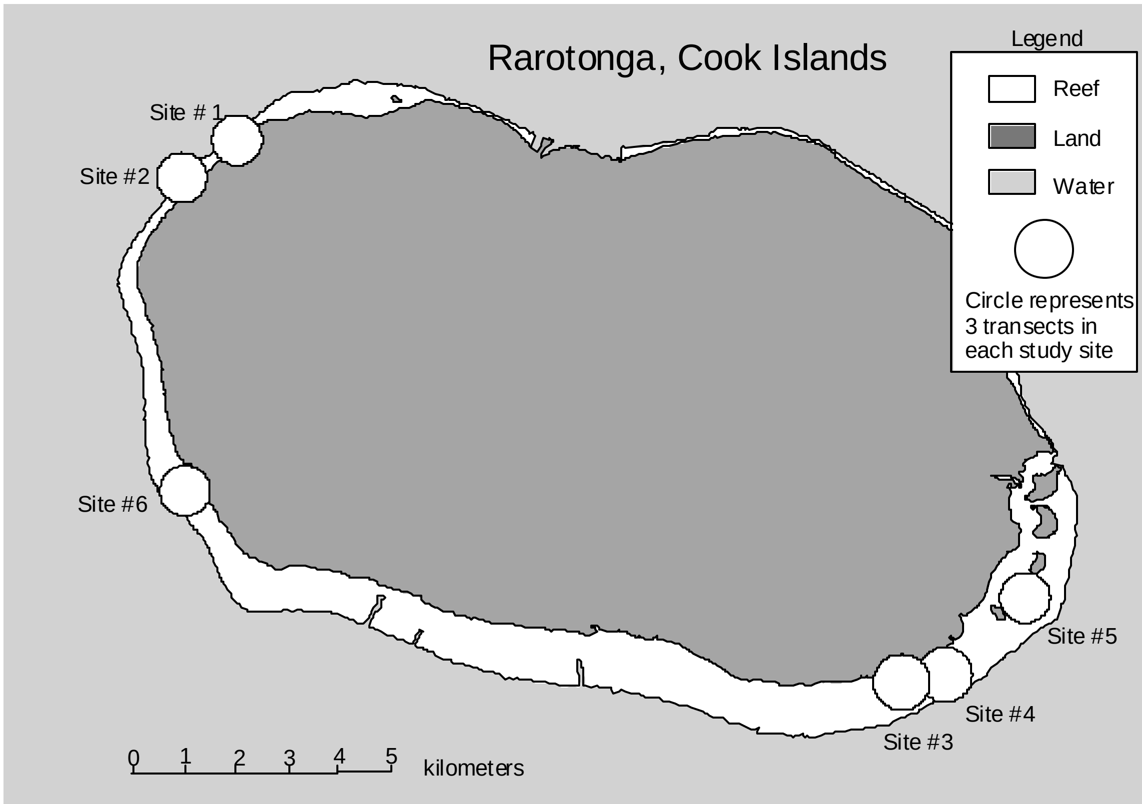


Table 5.3: 10 Minute Rapid Visual Fish Transect

Nikao Ra'ui – Site 1	Nikao, no Ra'ui – Site 2
Epinephelus Mulloides Paneneus Chaetodon Centropyge Chromis Chrysiptera Bothus Cheilinus Rhinecanthus Stethojulis Thallasoma Scarus Parapercis Naso Acanthurus Ctenochaetus Zanclus Siganus Canthigaster	Chaetodon Stethojulis Thallasoma Scarus Naso Acanthurus Aulostemis Chromis Parapeneus Naso Fistularia Mulloidichthys Siganus Canthigaster

Presenting the Quantitative Data and Discussion

The average mortality index is higher in the Ra'ui Site #1 0.871 than in Site #2 0.827. The difference is not significant using a Wicoxon test. The number of affected corals and the presence of algae are all higher in Site #1, but

Table 5.4: Ecological Data Means

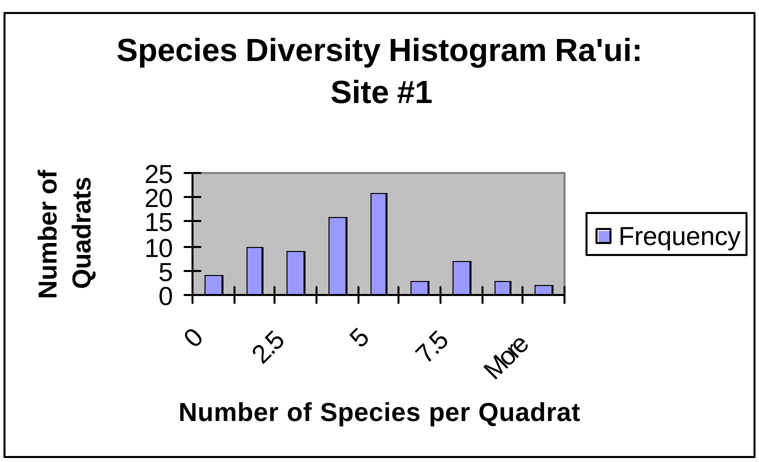
Means	MI	% Dead	% Live	#Affected	Clonal Condition	Fil. Algae	Cyanophyta	Spp. Diversity
Ra'ui Site 1	0.871	73.667	11.173	0.04	0.133	0.12	0.067	3.693
Site 2	0.827	70.2	14.307	0	0.133	0.067	0.133	3.253

again this result was not significant at the percent level. The presence of Cyanophyta were higher in Site #2. The difference in the number of coral species present in each quadrat was striking, though the means are similar: 3.69 at Site #1 and 3.25 at Site #2. Especially since as discussed in Chapter 4, when you have a higher MI, the species diversity is usually lower. Other indicators of the difference between these two species data sets are shown in the variance and the skewness. The variance at Site #1 is 5.270 and considerably higher than Site #2, which is 2.003. The skewness at Site #1 is 0.574 and the skewness at Site #2 is 0.711. This illustrates that the data in Site #1 has a longer tail and a higher number of species present in some of the quadrats.

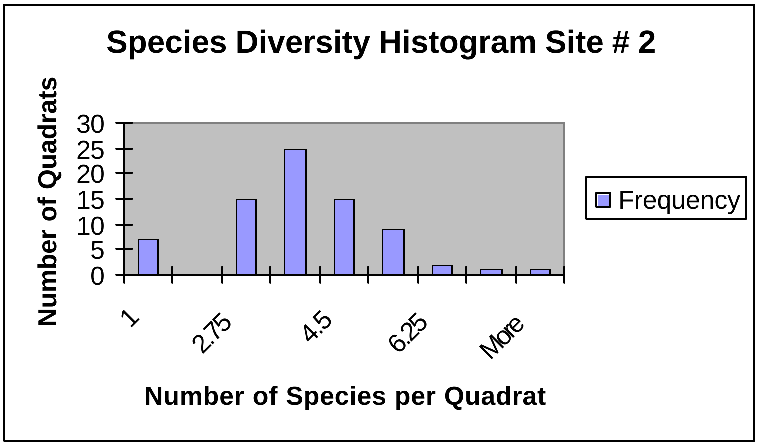
Table 5.5: Descriptive Statistics

Descriptive Statistics	Species Diversity Ra'ui Site #1	Species Diversity Site 2
Mean	3.693	3.253
Standard Error	0.265	0.163
Median	3	3
Mode	3	3
Standard Deviation	2.296	1.415
Sample Variance	**5.270**	**2.002**
Kurtosis	-0.119	0.984
Skewness	**0.574**	**0.711**
Confidence Level(95.0%)	0.528	0.326

Both data sets have normal distributions even though they have a difference in their skewness. The two histograms below show the frequency of the number of species present in the quadrat. The normal quantile plots really highlight the differences in the two data sets.



Graph 5.1



Graph 5.2

The higher and greater slope in the data for Site #1 indicates a higher mean and higher variance than Site #2. Furthermore, Site # 1 90 percent of the 75 data points have below 7 species and in Site #2 90 percent of the 75 data points are below five. This again highlights the long tail of the data in Site #1, which has eight, nine, or even ten different species of coral accounted for in the quadrats. By contrast, in Site #2 the maximum number of different species found in a quadrat was eight.

To further highlight the differences between the two sites I normalized the data by taking the number of different species present in each quadrat and divided it by the mortality index. I then took these data sets and used an F-test to measure the difference in the variance between the two sites. In an F-test the bigger the value is for F the more significant the result. There is a significant difference in the two sites.

Table 5.6: F-Test Two-Sample for Variances Ra'ui Site #1 and Site #2

F-Test Two-Sample for Variances Species Diversity

	Ra'ui Site #1	*Site # 2*
Mean	3.693	3.253
Variance	5.270	2.003
Observations	75	75
df	74	74
F	2.631	
P(F<=f) one-tail	2.342	
F Critical one-tail	1.469	

Conclusion

The recovery of the coral reef Ra'ui at Nikao is illustrated by the number of different species in each quadrat. The Ministry of Marine Resources has been monitoring invertebrates and fish density inside the Ra'ui. Their data shows that marine invertebrates have increased in species diversity and evenness in all of the Ra'ui that they are monitoring (Ponia April 1999; Ponia March 1998; Raumea January 2000). Furthermore, their study in Tikioki found that there were more fish species inside the Ra'ui than outside (Ponia April 1999; Ponia March 1998; Raumea and al. January 2000). Fewer people are collecting and fishing in this area and this is what is most likely contributing to the difference between these two study sites species abundance. This allows for the coral to settle and grow instead of having people walking all over the reef. The sites are similar in all other environmental factors due to their close proximity. The only difference between the two sites is the fact that Site #1 is in a protected Ra'ui and Site # 2 is not. Further research should be done on coral growth, and recruitment.

Customary Marine Tenure and traditional systems of resource management for the ocean are found in numerous fishing communities throughout the world. Researchers have only recently begun to realize the biological, economic, and social significance of these practices. A number of researchers have also seen how they may play a vital role in future marine management (Cordell 1989; Hviding and Baines 1992). Traditional systems like the Ra'ui can provide a successful model for conservation. This type of system can control access to resources and it can also provide culturally sanctioned rules for managing resources that can reduce administrative costs by not incorporating government officials in the management process. Finally, traditional systems of management are thought to be more flexible to changes in both biological and socioeconomic conditions affecting marine resources. At the same time, researchers often report the friction associated with access and control of resources. For example, certain fisher groups abide by local rules and traditions, and outsiders exploit resources with additional capital and expertise (Johannes 1981; Ruddle et al. 1985). But, the case of Rarotonga is unique because the Ra'ui were established by the local communities and supported by the government and commercial sector. Both government and some local people fear that the Ra'ui will only be temporarily in place.

As I have shown throughout this dissertation research, due to the various histories of development on the islands even in the same country, the individual islands have different present day systems of property rights and social norms based upon the embedded historical context, which in turns influences reef health. The re-introduction of the Ra'ui is a unique model of a traditional marine social institution improving coral reef health. In Chapters 3 and 4 I showed that commodification of the reef is one of the primary factors causing the decline of coral reef health. In addition, I argue that the loss of traditional marine social institutions has affected coral reef health. Specifically, the decline in live coral coverage and species diversity on the reefs in the recent past has been primarily influenced by the transformation of common property resources from communally owned property to state owned with open access status.

Chapter 6: Coral Reef Conservation and Future Research

Malthus Challenged

Based on this research, and contrary to the *Reefs at Risk* report, population pressure is not what is causing the decline of coral reefs in the South Pacific (Bryant 1998). Islands such as Aitutaki that have had constant human population levels for the past forty years have had other factors such as development of marine resource markets and changes in marine property institutions that have changed the reef. Changes in technology that improve marine harvesting and the development of agro-industry have affected the reef more than population pressure. Ovalau is an island that exemplifies how the changes in marine resource institutions may negatively affect the reef. The government controls the harbor and immediate surrounding reef area and this marine space also has the highest Mortality Index and lowest species diversity. Based on the four island case studies one can see that commodification and marine property institutions, play a greater role in the decline of reef health than does population growth. If one looked solely at population as a factor influencing reef health one would assume that the Rarotongan reefs would have the highest MI: the two sites in Rarotonga do have MI's of .93 and .94, whereas Ovalau has three sites of .92, .93, and .94. Furthermore, Rarotonga has an overall higher hard coral species diversity than Ovalau. This is even more significant because scientists know that Fijian reefs have higher species diversity than those in the Cooks. As discussed in Chapter 4, site by site comparisons between the study sites show how the property regime and level of market development affects the reef.   The overall hard coral species diversity is lower in Aitutaki than in Rarotonga.

Table 6 .1: Island Population per Square Kilometer

Island	Island Land Area	**Population per Square Kilometer**
Aitutaki, Cook Islands	16.8 square kilometers	142
Rarotonga, Cook Islands	67 square kilometers	168
Ovalau, Fiji	103 square kilometers	84
Vatulele, Fiji	31.6 square kilometers	29

Based upon this research one can see that population is not the main factor causing the decline in reef health. I suggest that these four islands exemplify a pattern that is typical of other South Pacific islands.

An Island Tragedy and the Commodification of the Reef

These data from this research show that in order to understand the "tragedy of the commons" one must examine historical, cultural, social and economic factors. The coral reefs of the island case studies described in this research are not a "tragedy of the commons" according to Hardin's model, exploited and degraded as a result of population pressure in open access areas. Rather, coral reefs and reef resources are deteriorating due to the economic development of the reef and the externalities associated with each market sector (Hardin 1968).

Challenges and additions to Hardin's original model indicate that in marine systems there are many different patterns of use, property rights, resource degradation, and overuse, all of which are highly variable in a marine environment (McCay 1995). Marine property systems can be extremely complex because they are variable and can create conflict over resources within the area. There is not one model that accurately describes all marine property regimes, the types of degradation, and exploitation of resources within the area. I did see relationships between intensive market development and the externalities associated with the market, as well as a relationship with intensive market development and the transformation of traditional systems of marine property to a state-driven, open access regime.

As described in the island case studies, each island has a unique environmental history, set of social processes, and political economy that influences the demise of the marine environment. For example, as I have shown from the Ovalau case, because an area of the reef is communally owned by the local community does not mean that the reef is immune to pollutants and problems that have been created in open access regime marine areas operated by the state. This is a result of the physical and environmental factors inherent in marine environments. Effluent released in the Levuka reefs, for example, is dispersed downstream by currents. In this case, the state owned and operated marine areas have degraded reefs and also change the small community property systems on the island of Ovalau. The small community property systems as described in Vatuele, Fiji, and with the re-introduction of a traditional system such as the Ra'ui in Rarotonga, Cook Islands, can ensure sustainable use of communally owned marine areas for generations to come. In addition they may improve the health of the coral reef environment as described in Chapter 4 and Chapter 5.

Privatizing marine areas and creating areas of communally owned and managed reefs may be a solution. In Fiji and the Cook Islands, local people are paying closer attention to monitoring and enforcing rules concerning fishing rights. Social pressure in small communities may limit illegal and destructive fishing within the communally owned reef area. Furthermore, communities want to manage their resources and sustain stocks of fish and other organisms they harvest from the sea. Case studies in Kandavu, Fiji show that communities have successfully managed their fisheries (WWF 2000). It seems that these Fijian communities place a higher value on resources and their protection when they are able to see and directly benefit from them. For example, in Vatulele, Vatuelele Island Resort and other dive operators pay the local villages to use and access the reef for tourism purposes. This transaction has made the community aware of the value of the reef and they recognize that the communities must sustain this ecosystem to maintain the social and economic benefits it provides to them.

A Whole Reef Perspective: A Geographic View of Coral Reef Health

Health is the present state of an organism with respect to optimal functioning, reproduction, stability, disease, and abnormality. Like many organisms and natural systems, a coral reef has a natural equilibrium position that will fluctuate above and below this healthy state. When trying to define coral reef health one must try to measure it or compare it to a baseline of optimal coral reef health. This notion of reef health is almost hypothetical because one is creating an ideal reef system of optimal health. The question remains at what time and at what scale did this reef exist? These two geographic factors, space and time, make defining and determining the health of the reef unclear. Did this "healthy" system exist prior to the 1960s when the scientific literature began to document degradation of the reef and outbreaks of Crown of Thorn Starfish for example, or rather was it before industrialization in the 1800s, or did it exist prior to 15,000 years ago when there was changes in sea level due to deglaciation? The second reason why coral reef health may be difficult to define is because of scale. When discussing coral reef health is one talking about coral health at the organism level, or the entire reef? Does the reef also include the other ecosystems surrounding it such as the seagrass beds? Furthermore, each region and each reef is a unique habitat that does not have a set standard of what is healthy and what is not. For example, low live coral coverage in the Pacific is not a sign of bad health, but this may not be the case for Southeast Asian reefs. Few reefs in the South Pacific have more than 50 percent coral coverage due to high wave energy, tropical storms, and dominance of coralline algae (Wilkinson 1998). In addition, leeward sides of islands generally have 15-20 percent more species diversity than windward side of island because of wave energy and reef formations and structure (Edinger et al. 1998).

How can one quantify coral reef health based upon the geographical factors discussed above? I suggest that in order to accurately examine coral reef health and adaptability to short-term natural or human environmental change one must take an entire reef perspective. As already outlined in Chapter 1, a whole reef perspective is essential for assessing reef health. Results from this study as discussed in Chapter 4 confirm that if assessing reef health solely on, for example, coral affected by biotic factors, Vatulele would have had the highest prevalence of biotic factors affecting the reef. Scientists do realize that a small percentage of disease, predation, and bleaching are natural phenomena in a coral reef system. Data on coral diseases suggest that regional scale patterns of disease may indicate coral reef disturbance, but more research needs to be done on the correlations with human disturbance and coral disease as well as the relationship with the mortality of coral and certain coral diseases (Green and Bruckner 2000). Since reefs are such complex ecosystems it is difficult to do large-scale studies on the reef health and causes of degradation. Small scale studies examining all aspects of the history and development of the coastal zone as well as thorough examination of live hard and soft coral coverage, number of species of hard and soft coral, indicator species, such as certain types of algae, fish, and predators, corals affected by parasites and diseases, and clonal condition will provide a whole reef perspective on the health of the reef. Furthermore, by examining all these factors one can understand how to manage the reef better by gaining insight into management, conservation, and causes and consequences of different types of disturbances.

Local Interpretation of Reef Health

> Astrolabe lagoon has a small amount of Black Band Disease (Interview, #3 Suva, Viti Levu).
>
> Coral Coast [has] much eutrophication [and] lots of sargassum. [It was] never like that according to the older people (Interview #1, Suva, Viti Levu).
>
> [The] Lau group [has] many COTS and [recently had] an outbreak of Orange Coralline Algae Disease (Interview #4, Suva, Fiji).
>
> Ten years [ago, I use to use a] speargun around Naurabuta Point at night [and I would collect] two big bundles of parrotfish. At the moment [I] cannot find fish there. [There are] not near as many, very little (Interview #9, Vatulele).
>
> Twenty years ago [there were] clams everywhere. [The] reef [was] gorgeous. Now it is dead (Interview #3, Aitutaki, Cook Islands).

These are just a few of the statements from local divers, researchers, and government employees knowledgeable about the local reef health in Fiji and the Cook Islands. Although these people have not published their knowledge in magazines, journals, or government reports, they have firsthand knowledge of the reef health and have all been observing the transformation of their islands.

In the "gray", non-published, literature locals are aware that their marine resources are at risk. A few regional studies and local reports have been written. In a booklet about environmental concerns in the Cook Islands, the Director of Research for the Ministry of Marine Resources states that there is a major problem killing the reef that supports their economy through tourism and harvesting of marine resources. At the same time, he is not sure how to address and resolve the situation.

> Most often we have a limited understanding of the marine environment. For example, is the present Taramea (COTS) outbreak on Rarotonga induced by local coastal development, by a natural cyclical outbreak that is occurring Pacific wide, or by a combination of both? What action do we take? (Ponia 1998: 30)

As one can see, local people are aware of the value, fragility, and complexity of the coral reef system, but do not always have the money and knowledge to take the necessary steps to protect, manage, and sustain their reef resources. For example, the SPREP and SPC wrote in their *Report of the Third National Parks and Reserves Conference* in 1985 that Fiji's reefs were becoming severely threatened.

> Because of Fiji's increasing population and continuing trend towards urbanization, especially on Viti Levu, exploitation of inshore marine life is now taking place in localized areas near the larger population centers and will increase. Pollution will further deplete the marine life in these areas unless the increasing volumes of domestic and industrial wastes are adequately treated and controlled (South Pacific Regional Environment Programme 1985: 86)

They predicted that this degradation will continue in the future to the less populated areas of the country.

> Over-exploitation in the future may take place at other localized area such as at sites where aquarium organisms are repeatedly collected, and on fringing reefs near large resort hotels where there are nearby villages. At these locations, shellfish and coral are taken by tourists and locals collect these species, or fish, for either subsistence or commercial gain. Certain

> shellfish are more in demand than others and thus in greater danger of depletion (South Pacific Regional Environment Programme 1985: 86)

They concluded that the establishment of marine parks is the best solution to protect and sustain the productivity of marine resources in Fiji. But to this date there are no nationally recognized marine parks in Fiji.

In summary local people state that their reefs are in a state of decline and recognize that the coral reef ecosystem is changing into systems often dominated by algae and soft coral instead of diverse hard corals (Hughes and Connell 1999). In the case of the Ra'ui they also notice improvements in the reef. Yet although, the local conservationists, fisherpeople, divers, government employees, and other people who are knowledgeable about their local reef systems may not have published this information formally, they have first hand knowledge of reef transformation. Often they earn their livelihood from these marine resources and realize the value of their reefs, and thus want to do something to prevent the state of decline. This knowledge is not often accessible to governing bodies and other decision makers creating policy and managing coral reefs. Thus, many organizations are not aware of coral reef health in the South Pacific.

Mapping Coral Conservation Money

As discussed in Chapter 1, the findings on the status of coral reefs stated in the *Reefs at Risk* and GBRMN reports may be misleading, and they also have implications in the Western conservation community. First, the *Reefs at Risk* report was written by organizations seeking funding for future work on their agendas and goals by the original funders in additional to other donors. Second, the organizations that did fund the report are going to look at this report in terms of their priorities for funding other conservation projects. For example, the funders of the *Reefs at Risk* such as the World Bank, Hewlett

Packard Foundation, and others are all focusing their research and granting programs to regions at higher risk according to *Reefs at Risk*. In the table below the grantees for the year 2000 for the Conservation program in the Western Pacific funded by the David and Lucille Packard Foundation are listed. $511,479 grants were awarded to programs in the Pacific, and a total of $1,186,023 for the reminder of grantees whose work focuses primarily in South East Asia.

Table 6.2: The David and Lucile Packard Foundation Grants for 2000

Coral Reef Alliance $20,000 for the Dive Into Earth Day Project
Counterpart International $154,470 for the Coral Garden Initiative to empower coastal and island communities to conserve their coral reefs
Telapak Indonesia $49,363 for the Investigation of Destructive Fishing Practices as Part of an Effort to Develop an Independent Marine Resource Monitoring System in Indonesia Project
University of Rhode Island $20,000 to enable three Pacific Islanders to attend the Summer Institute in Coastal Management
University of South Florida Research Foundation $217,000 for the Ninth International Coral Reef Symposium
University of the South Pacific $292,000 for the Community-Based Marine Biodiversity Management and Monitoring in Fiji Project
World Resources Institute $375,000 for a regional assessment of coral reef health and threats in Southeast Asia and a review of aquaculture
World Wide Fund for Nature $45,000 to work with the Community Conservation Network to develop a resource management, enforcement, and marine protected area plan for Helen Reef Atoll, Palau
World Wide Fund for Nature Indonesia $524,660 for the Creating Tools and Incentives for Well-Managed Coral Reef Fisheries in the Wallacea Ecoregion of Indonesia Project

(The David and Lucile Packard Foundation 2000)

One of the main authors of the *Reefs at Risk* report, World Resources Institute (WRI), received a grant for $375,00 to assess reef health in Southeast Asia (see table above). The World Bank and Global Environment Facility have also been funding projects related to coral reef health. The portfolio update concentrates primarily on projects from 1988-1999 financed through the International Bank for Reconstruction and Development (IBRD), the International Development Association (IDA), the Pilot Program to Conserve the Brazilian Rainforest (RFTF), and the Global Environment Facility (GEF). There have been 226 World Bank Biodiversity Projects, one of which was in the Pacific. Samoa received $1.1 million for a Marine Biodiversity Protection and Management project. But, there have been many other projects focusing on marine issues in Indonesia, Philippines, Red Sea, and the Caribbean. In fact, the World Bank gave $118.8 million to Indonesia for funding on Coral Reef Management and Rehabilitation Project and an Integrated Swamp Project and $36.6 million for a Strategic Action Plan for the Red Sea. There have been a dozen other coastal marine projects in the Caribbean, South Asia, Southeast Asia, Red Sea, and Africa (The World Bank 2000).

I do not claim that projects are not being financed and supported by the international community in the South Pacific. However, not as many projects are funded in proportion to the area of reef in the region. The Indo-Pacific region is the center of coral diversity, where there are more than 450 coral species compared to only some 200 across the entire Indian Ocean to the Red Sea (Veron 1995). Although, the Indo-Pacific region is the center of marine biodiversity, the majority of coral reef research, coral disease research, and long-term monitoring has been in the Caribbean, not in the Indo-Pacific (Connell et al. 1997; Santavy and Peters 1997). Yet, the Indo-Pacific region encompasses 85 percent of the reefs in the world and extends over an area six times as large as the west Atlantic (Connell et al. 1997). Furthermore, in a recently published study from data compiled by the World Conservation Monitoring Centre, diseases are more prevalent in the Caribbean than in the Indo-Pacific. There has been a scarcity of observations in the Indo-Pacific (Green 2000). The researchers from this study conclude that this scarcity is telling about the health of the reef and also that coral disease is extremely prevalent in the Caribbean (Green 2000). I think that more research needs to be done on this topic because the regional differences may be due to the greater volume of research done in the Caribbean. Research in the Indo-Pacific is essential for the study of regional and global trends of coral reef health because of the rapid decline of these unique ecosystems.

The ICRI Pacific Regional Workshop is a good example of local and western knowledge collaborating together on issues and priorities (South Pacific Regional Environment Programme and International Coral Reef Initiative. Pacific Regional Workshop 1996). A few of these collaborative environmental non-governmental organizations (ENGOs) are working with communities. For example, the World Wildlife Fund (WWF) is working with communities to help them establish their own Marine Protected Areas (MPA). Currently, the Fijian government supports the concept of creating MPAs, but has not established any. In addition, WWF is also working in the Cook Islands to support communities' conservation efforts such as turtle conservation and the Ra'ui and has a project in the Solomon Islands. These are the only projects presently supported by WWF in the South Pacific (WWF 2000). Not much international funding is going to Pacific Islands for coral reef conservation and management. In addition, these countries have the little infrastructure to create and maintain MPAs. Presently, sixty MPAs exist in the Melanesia and Polynesia, twenty-five of which are in the United States and territories of the United States and the other thirty-five MPAs for the entire region (Wilkinson 1998: 103). There are 106 in Southeast Asia (Wilkinson 1998: 86).

Recommendations: Management, Conservation, and Coral Health for South Pacific Reefs

The South Pacific is a region of high coral species diversity and large reef area. Conservation and resource management programs are essential to protecting the reef, improving coral health, and preventing future degradation if people want to maintain and improve the ecosystem services that coral reefs provide for humans. Perceptions of coral reefs in the South Pacific by the global community as being healthy has influenced and shaped policy, research, and conservation agendas. Research and conservation programs, as well as the establishment of MPAs, should be a high priority in this region. Below I suggest seven key recommendations:

- <u>International and Regional Conservation Initiatives:</u> Slowly the global environmental community, such as UNEP and WRI is realizing the need for coral reef conservation and management in the South Pacific. For example, in March 2001, The International Coral Reef Action Network (ICRAN) announced funding of up to $10 million from the UN Foundation. This is the largest to date in the Foundation's environment portfolio. The money will support coral reef management in four of the United Nations Regional Seas Programmes, one of which is the South Pacific. These four regional sites will become models for managing coral reefs. ICRAN includes UNEP, the UNEP World Conservation Monitoring Centre; Regional Seas Programmes for the Caribbean, Eastern Africa, and East Asia; World Fish Centre; World Resources Institute; International Coral Reef Initiative Secretariat; Global Coral Reef Monitoring Network; Coral Reef Alliance and South Pacific Regional Environment Programme. Progress is being made in the South Pacific, as the South Pacific Regional Environment Programme is a member of ICRAN, but much research and applied work still needs to be done in this region.

- Research and Monitoring: Little research has been done on monitoring or even describing South Pacific coral reefs. In order to protect and manage these environments, baseline monitoring must be established and monitoring systems set up to document changes over time. This will give managers essential information needed to make decisions about the best places and ways to protect the reefs.

- Pollution Prevention: If corals are suffering degradation from anthropogenic factors, these factors will need to be identified and controlled and their effects alleviated. In the case of effluent from PAFCO in Ovalau, the treatment of the effluent must be more rigorous or the outflow pipes must more distant from the reef. Chronic impacts, such as sewage, sedimentation, and industrial effluents, are more harmful to the reef long-term than less frequent acute natural disturbances such as cyclones, which actually can increase long-term coral diversity and growth (Connell 1997).

- Sustainable Fishing Practices: Fishing practices, especially destructive fishing methods, may devastate the reefs. Cyanide fishing and dynamite fishing are not as prevalent in the South Pacific as in Southeast Asia, but bleach and *duva* fishing are common practices. The reefs of Fiji especially have been affected by *duva*. According to the chief of the village in Vatulele *duva* was one of the main reasons for the degradation of the lagoon corals in the early 1970s. The use of *duva* stuns fish and simultaneously kills the coral polyps. The community realized the impact the plant had on coral and its usage stopped (Interview #9, Vatulele). When I was doing my research in 1999 many communities wanted advice concerning specific ways to improve the reef and its main fish stocks. My advice to these communities was to enforce minimum size-limits on harvested marine organisms, and to create alternative livelihoods for local people. In Vatulele this has been done by developing two new areas of economic activity: the production of *tapa* cloth for sale, and the hiring of people from the village by the resort. My final three recommendations are the establishment of marine reserves, community-based conservation, and the education of coastal developers about coastal zone management.

- <u>MPAs</u>: The establishment and management of MPAs and traditionally managed reefs would include the creation of widely dispersed, strategically located small and large reserves. Site selection must be based upon many criteria: the current patterns, landbase activities, and larvae retention. The goal is to protect at least 20 percent of the coral reefs in the region. Not only is it essential to create such reserves, but also to gain the support of local communities to enforce the rules of the reserve.

- <u>Customary Marine Tenure, Traditional Management, and Privatization of Resources:</u> Traditional forms of protection and conservation are often successful because the community will often more likely support and respect the endeavor. Furthermore, if local communities can benefit financially through tourism or continued availability of resources, as is the case in Rarotonga with the Ra'ui, there is a greater likelihood of success. Dividing the reef into privately owned areas of access may be one way to better manage reef resources. As I have shown in Fiji customary marine tenure, locally owned, reefs tend to have better health when they are not excessively impacted by effluents that are emitted in common property areas.

- Integrated Coastal Zone Management: Integrated coastal zone management systems need to be created that take into consideration land-based activities. These would include the impacts of tourism, deforestation, and agricultural practices. Local people and government agencies need to improve and manage coastal zone areas in sustainable ways to minimize impacts upon the reefs.

Future Research Directions

Many relationships and correlations have been discussed throughout this dissertation, but new questions arise from this research and more information needs to be gathered to understand coral reef health in the four island study sites. This interdisciplinary project captures and describes the health of the reef at a unique period of time in relation to commodification of the marine resources and marine property systems. Future research recommendations include assessing the reefs again at regular intervals (e.g. every five years). This would further our knowledge about how human interaction with the coastal zone affects reef health. Furthermore, since this field research was completed in 1999, field informants have reported further bleaching events. It would be informative to investigate in more detail 1) what areas bleached and if and how they have recovered, and 2) whether or not the bleaching events and their significance for the reef is linked with the areas of communal property or higher levels of economic activity. Further monitoring should utilize those water quality testing instruments that are more sensitive than those that were available for this study in order to evaluate differences in water chemistry between sites. This would further understanding of reef responses to changes in salinity, temperature, nitrate, nitrite, pH, and other water characteristics. Finally, more work needs to be done on the significance of the Ra'ui and similar traditional systems of reef management. This could be divided into two different aspects, one a human geographic perspective and one a more environmental geography perspective. The first project could be to investigate in more detail the dynamics and politics associated with the Ra'ui to answer the following questions: 1) how does the Ra'ui affect the local people? 2) who really wants to have this site demarcated? 3) who does not and why? and, 4) why are sites changed so quickly? From an ecological perspective, the Ra'ui sites should be monitored on a continual basis to determine how much the corals reefs are recovering and fish stocks are increasing, if they are.

I see three broad areas of importance to continue researching:

Marine Property Regimes: Throughout the South Pacific and Western Pacific, there are many different types of marine institutions in place. More research needs to be done on which types of marine institutions are successful in relation to coral reef health and why. Why do certain marine institutions, such as communally owned and managed reefs or traditional marine tenure systems, work in some regions and not in others? This could be studied in locations such as the northern Cook Islands, other islands in Fiji such as Kandavu, and Pacific states such as New Caledonia, Tonga, the Federated States of Micronesia and many more.

Corals reefs throughout the South Pacific and in many other parts of the world need to be assessed and inventoried. Scientists know so little about the reefs of the world. In order to protect them, researchers must first try to understand the present community structure. Only after this is done will scientists be able to investigate relationships with environmental change.

Coral Reef Health and Coral Diseases: More research needs to be done to determine the 1) the geographic distribution of coral diseases throughout the world and 2) the relationship between disease, reef health, and mortality.

Each area of research raises more and more questions to be answered. A lifetime could be dedicated to understanding this exquisite, delicate, and unique underwater world. Ultimately the future of coral reefs relies upon many actors collaborating together to create policy, educate, manage, research, utilize, and protect this ecosystem.

Appendix A.

Aitutaki Interviews:

1. 12/14/99: Local Dive Operator

2. 12/15/99: Fisheries Patrol Officer, Aitutaki Ministry of Marine Resources

3. 12/17/99: Local Tour Operator

Rarotonga Interviews:

1. 12/2/99: Staff, Ministry of Marine Resources

2. 12/3/99: Local Dive Operator

3. 12/3/99: Local Dive Operator

4. 12/3/99: Staff, Public Health Ministry

5. 12/6/99: Staff, Department of Conservation and the Environment

6. 12/10/99: Staff, Natural Heritage

7. 12/13/99: Newspaper quote, Staff, Department of Conservation and the Environment

8. 12/14/99: Researcher

9. 12/22/99: Local Dive Operator

10. 12/23/99: Staff, Ministry of Agriculture

11. 12/23/99: Researcher

12. 06/18/01: Matavera Community Leader

13. 6/18/01: Staff, Library

14. 6/18/01: Staff, Non-Governmental Organization

15. 6/19/01: Staff, Ministry of Marine Resources

16. 6/19/01: Staff, Ministry of Marine Resources

17. 6/10/01: Head Meteorological Services

18. 6/20/01: Nikao Community Leader

19. 6/20/01: Nikao Community Leader

20. 6/20/01: Nikao Community Leader

Ovalau Interviews:

1. 9/27/99: Local Dive Operator

2. 9/27/99: Ovalau Fishing Warden

3. 9/27/99: Environmental Heritage Officer

4. 9/28/99: Ovalau Diver and fishermen

5. 9/28/99: Staff, Port Authority

6. 9/28/99: Local, Ovalau Tour Operator

7. 10/4/99: Local Fisherperson

8. 10/6/99: Local Fisherperson

9. 10/7/99: Local Fisherperson

10. 10/8/99: Local Fisherperson

11. 10/12/99: Local Fisherperson and Tour Operator

12. 10/12/99: Local Fisherperson

13. 10/12/99: Local Fisherperson

14. 10/12/99: Local Fisherperson

15. 10/12/99: Local Fisherperson

Vatulele Interviews:

1. 11/7/99: Local Diver

2. 11/8/99: Local Diver

3. 11/9/99: Local Diver

4. 11/9/99: Staff, Vatulele Island Resort

5. 11/11/99: Local Fisherperson

6. 11/12/99: Staff, Vatulele Island Resort

7. 11/13/99: Local Fisherperson

8. 11/13/99: Staff, Vatulele Island Resort

9. 11/13/99: Local Fisherperson

10. 11/16/99: Local Fisherperson

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