MAMALA BAY STUDY

SHALLOW MARINE COMMUNITY RESPONSE TO POINT AND NONPOINT SOURCES OF POLLUTION IN MAMALA BAY, OAHU

PART A: FISH AND CORAL COMMUNITIES

PROJECT MB-9

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1 EXECUTIVE SUMMARY

The objective of this study was to quantitatively determine the response of shallow benthic and fish communities in Mamala Bay to point (sewage) and non-point discharges. Twenty permanently marked stations were established at three locations (offshore of Waikiki, Sand Island and Barbers Point) and within each location at three depths (5m, 15m, 20m). Sampling was undertaken on three occasions (Summer 1994, Winter 1994 and Summer 1995) to discern seasonal differences. The sampling strategy focused on a quantitative delineation of macrobenthos and fish communities at these locations.

The results suggest that fish community development in Mamala Bay is related primarily to the availability of appropriately scaled shelter space. Where such shelter is available as on the armor rock overlying the two wastewater discharge pipes or at artificial reefs (as offshore of Waikiki), the fish communities are well-developed. Coral communities in Mamala Bay are poorly developed on hard substratum at depths of 20m or less. Coral communities are subjected to considerable sand scour caused by occasional wave impact. Because corals are slow-growing, these benthic assemblages are kept at an early successional stage by occasional wave impact through much of Mamala Bay. Where hard substratum is protected from wave-induced sand scour as on the elevated basalt armor rock of the wastewater discharge pipes, coral communities are better developed.

Sponges which are normally relatively cryptic on coral reefs and subject to the same wave stress as corals, show some development offshore of Sand Island and to a lesser extent off Barbers Point. Sponges are particulate (filter) feeders suggesting that food or other niche requirements are more appropriate at Sand Island than at other sample sites in Mamala Bay. Sources for particulate materials include those emanating from harbors (Pearl, Honolulu, Kewalo and Ala Wai) as well as from point source discharges (i.e., treated sewage moving shoreward). However, nowhere does the benthic cover by sponges exceed 2% and the other benthic particulate feeders usually associated with a sewage particle food

resources are absent, suggesting that the particulate source(s) is not large or from a sewage source.

The results of this study parallel those of other recent research on coral reef resources of Mamala Bay in that there is no quantitative evidence supporting the view that the discharge of sewage is impacting the shallow reef resources shoreward of the two sewage outfalls. The data for non-point source impacts is less conclusive, thus this study recommends further research addressing this question.

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2 INTRODUCTION

2.1 Background

There are numerous perturbations that have occurred and continue to occur which impact the shallow water marine communities of Mamala Bay. These impacts may be considered in three broad categories: impacts due to habitat alteration, changes due to declines in water quality and impacts due to heavy utilization of marine resources. Perhaps the most obvious impacts have been related to habitat alteration. Although much of the habitat alteration occurred years ago, the impact continues to be manifested in the marine communities. The draining and filling of lowlands and shoreline fishponds served to virtually eliminate the estuarine nursery grounds that are important to many inshore Hawaiian fish species. Indirectly, such habitat alteration has contributed to declines in water quality today by the loss of this important natural "biofilter".

The physical alteration of Oahu's south shore is a relatively permanent feature whose impacts have probably caused major shifts in community structure many years ago. The biological response to these changes has occurred and will continue into the future. Heavy fishing pressure has caused declines in target species leading to shifts in species dominance both in the fish and indirectly in benthic communities (i.e., loss of keystone species, see Brock 1979).

Impacts to nearshore marine communities in Mamala Bay due to changes in water quality are from point and non-point sources. Common elements with all water quality changes are (1) all of these are land derived and (2) pollutants are transported to the sea via freshwater. Major point sources include the two municipal sewer outfalls (Honouliuli and Sand Island). Non-point sources occur all along the Mamala Bay shoreline (i.e., stream flows and harbor inputs) as well as in the shallow subtidal via groundwater discharge. Differentially distinguishing impacts to benthic and fish communities due to point and nonpoint sources is often very difficult at best. In Mamala Bay point sources deliver

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primary treated domestic wastes which are high in particulate material. In other shallow Hawaiian marine communities, high particulate loading from primary treated sewage results in a benthic and fish community response favoring particulate feeding species (Brock and Smith 1982, Smith et al. 1982). Such benthic communities are best developed on hard substratum relative to soft substratum (Brock and Smith 1982).

The community structure of the sessile benthos at a given location represents the environmental history of that site. This fact may be used to determine the relative roles of point and non-point inputs. Thus the exposure to specific perturbation results in a community response favoring a suite of species that are either resistant to that perturbation or are capable of directly utilizing some aspect of that perturbation to their advantage (i.e., high particulate loading from domestic wastes may serve as a direct food resource for the guild of particulate feeding species). The obvious heterotrophic response of these tropical marine communities influenced by sewage (Odum 1960, Odum et al. 1963, McNulty 1970, Kinsey 1979, Brock and Smith 1982) assists in their recognition and differentiation from the usual autotrophic (coral dominated) communities.

The differential quantitative delineation of impacts due to point (here defined as primary treated domestic wastes from the Sand Island and Honouliuli outfalls) and non-point sources in Mamala Bay must be made if conservation, management and improvement of the bay's resources is to be undertaken in the future. Knowledge of the degree of impact to inshore marine communities attributable to diffuse non-point sources relative to those due to the deep ocean outfalls (releasing domestic wastes) is essential if (1) the limited resources for restoration and improvement of Mamala Bay water quality are to be wisely used and (2) the general public is to understand and appreciate the degree of impact. This study addresses these questions.

2.2 Association With Other Mamala Bay Teams

Studies focused on ecosystem response to pollutional stresses in MB-9 are all interrelated. Dr. C. Smith's work on recruitment patterns of benthic invertebrates relates to

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the findings of the present study which has focused on post-settlement community structure relative to point source perturbation. The results of Dr. R. Grigg's study of impact of pollutants on Mamala Bay's coral reefs also provides a direct comparison to the present study with both studies examining coral communities of the bay. The results of Dr. Laws' work on isotope ratios in benthic species relative to known inputs (both point and non-point) is another example demonstrating the interface among the projects.

2.3 Scope Of Work

This study entails a quantitative description of the structure of marine communities in Mamala Bay at selected permanent sites sampled through time. Sites were selected at varying distances from known sources of point and non-point pollution inputs. Important elements of community structure as measured by the diversity of species, numbers of individuals of each species, trophic relationships and standing crop were comparatively analyzed at each permanent station. The results of these analyses were used to determine the relative impact of extant pollution on the shallow marine communities of Mamala Bay.

2.4 Objectives

The objectives of this study were:

1. To identify a series of study sites for the sampling of benthic and fish communities presumably exposed to varying degrees of impact (i.e., gradients) from known point and non-point discharges in Mamala Bay;

2. To quantitatively sample benthic and fish communities at these permanently marked sample sites through an 18-month period allowing delineation of community and trophic structure;

3. To use information from above to quantitatively demonstrate the response of benthic and fish communities to point and non-point discharges in Mamala Bay.

2.5 Project Organization

Principal Investigator: Dr. E.A. Kay, University of Hawaii

Co-Principal Investigators: Dr. J.H. Bailey-Brock, University of Hawaii, Dr. R. Brock, University of Hawaii

Assistant: Mr. A.K.H. Kam, University of Hawaii

Graduate Assistants: Reuben Wolff, Dave Gulko, University of Hawaii

Dr. Kay's duties included the oversight of the entire project, determining micromollusk community structure, as well as directing the work of the two graduate assistants. Dr. Bailey-Brock worked on proposal development, the field and macroinvertebrate studies. Similarly, Dr. Brock worked on the development of the proposal and with Mr. Kam were responsible for the collection of macrobenthos and fish data, the analysis of these data and the preparation of this report.

3 METHODS

3.1 Task Summary

This study quantitatively examined marine communities at 20 permanent stations in Mamala Bay along presumed gradients of pollution impact. The field methods used include visual censuses of fishes, counts of macroinvertebrates, visual and photographic appraisals of quadrats to assess sessile and/or substratum types. Comparative analyses of the data generated included use of simple nonparametric statistical methods.

3.2 Task Methodology

This study made the following assumptions: (1) gradients of impact exist in Mamala Bay from both point and non-point sources, (2) that marine community response to these gradients of impact is quantifiable over spatial scales that may be appropriately sampled by use of techniques as given below and (3) that the structure of the marine community at a given site represents the integration of impacts that have occurred over the lifespans of organisms present at that particular location.

Because nonpoint sources enter at the shoreline (mouths of harbors, streams, etc.), it is expected that the greatest impact from this input would be evident in the shallow waters closest to these inputs. Likewise, deep sample sites (i.e., maximum 24m in depth) inshore of the Sand Island and Honouliuli sewer outfalls would have the greatest probability of impact from these point source discharges. Sample stations situated at varying distances from these inputs would be subjected to varying degrees of impact depending upon location.

As noted above, tropical hard bottom benthic communities show a strong response to moderate inputs of sewage whereas the response by soft bottom benthos is much less (Brock and Smith 1982). Consequently, much of the sampling effort has focused on benthic and fish communities associated with hard substratum. However, because

micromollusk assemblages which are part of the soft bottom benthos contain a number of species that are known indicators of specific perturbation and environmental conditions (Kay and Kawamoto 1980, 1983), these have been sampled in the vicinity of each station.

Sample sites were established in three areas: a control area offshore of the Natatorium War Memorial-Queen's Surf Beach which are located on the east side of Waikiki Beach (hereafter referred to as Waikiki), and two "experimental" sites at varying distances from point and non-point discharges (see Figure 3.1). The first experimental site is offshore of Sand Island adjacent to the Honolulu Wastewater Treatment Plant outfall pipe, Keehi Lagoon and Honolulu Harbor (the Sand Island site). The second experimental site is fronting Ewa Beach in the vicinity of the Honouliuli Wastewater Treatment Plant outfall pipe (the Barbers Point site). Pairs of permanently marked stations were established at each of three depths: at 5m depth, at approximately 15m depth and a pair of deep transects at 20-24m depth. Additionally at a depth of 15m, a station was established on the cap or armor rock of both the Sand Island and Honouliuli outfall pipes.

The rationale for station locations is as follows: the shallow station fronting Sand Island should be subjected to considerable nonpoint disturbance emanating from Honolulu Harbor and the industrial areas inland of Keehi Lagoon. The shallow site offshore of Ewa Beach may be occasionally impacted by non-point pollution from Pearl Harbor. The shallow site fronting Queen's Surf Beach at Waikiki serves as the control. Intermediate depth stations (15m) at the two experimental areas should be subjected to less disturbance from non-point sources by virtue of their greater distance from the shore. The sample stations on the caprock of the two sewage discharge pipes represent areas of high topographical relief (i.e., greater shelter and areas away from sand scour), relative to that encountered on adjacent less complex substratum. The two experimental deep sites by virtue of their proximity to the terminus of each sewage discharge pipe should receive some level of disturbance from point sources (the sewage outfalls) if this material is carried shoreward.
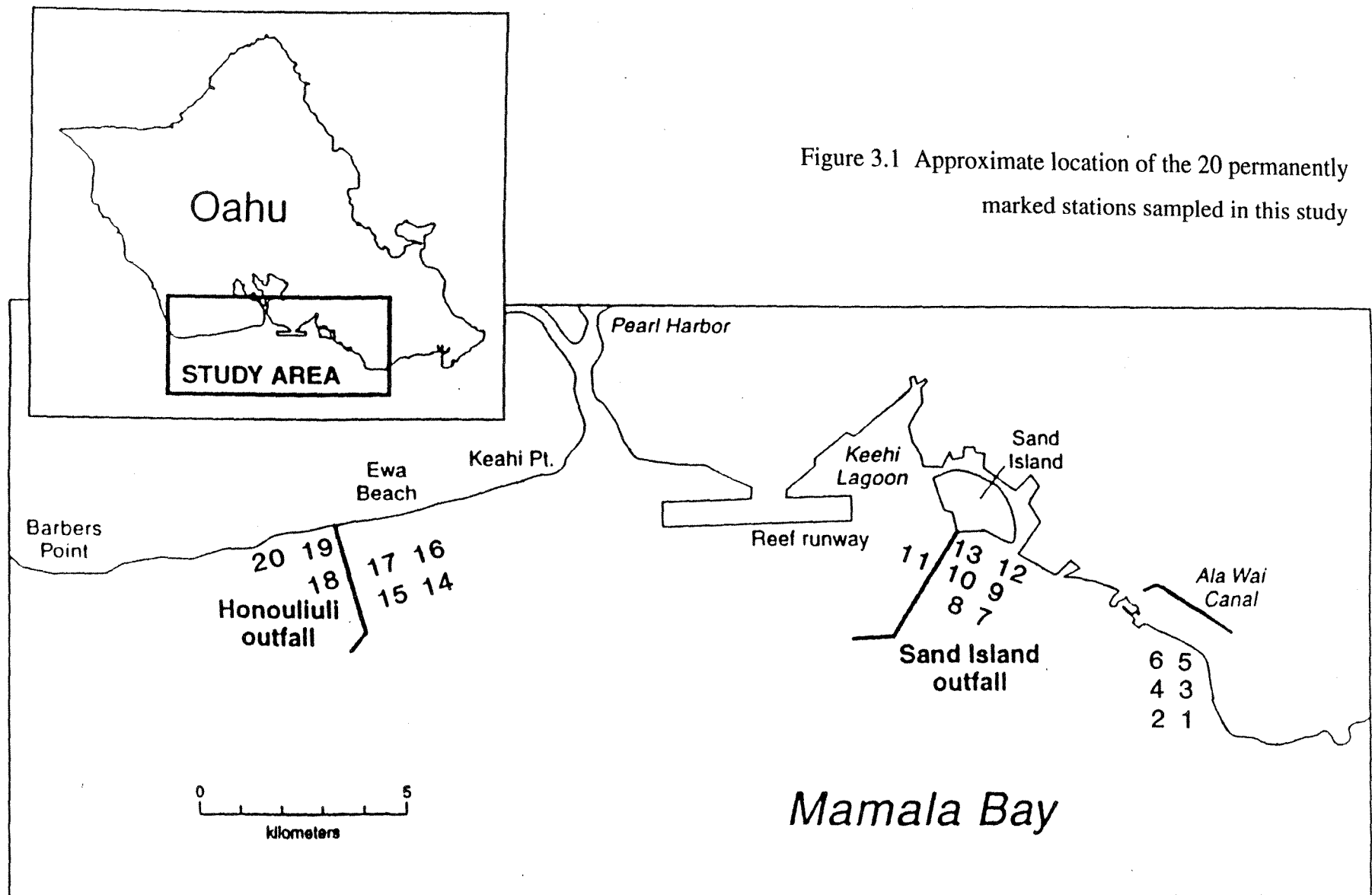
Figure 3.1 Approximate location of the 20 permanently marked stations sampled in this study

Each transect was permanently marked as were the quadrat sites on those transects so that the same areas could be sampled through time. Once selected, transect locations were determined using a combination of a ground positioning system and prominent features on the shore. Transects were established on hard sub-stratum and were 25m in length. Information collected from each transect included a visual fish census over a 4 x 25m corridor (to the water's surface), counts of large (greater than 2 cm) diurnally exposed macroinvertebrates over the same area, estimates of percent cover by colonial sessile invertebrates (corals, sponges and tunicates) and algae using a 1 x 1m quadrat at six established points along the transect line. A photographic method was also used where each photograph samples an area of 0.67 x 1m at six locations on the transect to also estimate coverage by sessile benthos and provide a permanent record.

Because substratum rugosity serves as a source of shelter for many fishes and invertebrates, an effort was made to quantify the local topographical complexity both on and adjacent to each transect site. Rugosity on the transect was measured using a 10 m length of chain (link length = 2 cm) draped over the bottom fitting into the contours of the substratum. The ratio of the actual linear distance traversed by the fitted chain to its true length (10 m) provides an index of rugosity on the transect line (Risk 1972); two such measurements were made on each transect line. Additionally, larger structural elements such as boulders, coral heads, and ledges within 15 m of each transect were mapped and roughly measured using a tape. These data were used in assigning a relative rugosity measurement to each transect site. The relative rugosity measurement ranges from 1 (flat, no topographical relief) to 5 (high topographical relief where 80% or more of the substratum has cover with heights of 50 cm or more) with a value of 3 providing approximately 15% of the substratum surrounding a transect having cover on the scale of up to 50 cm in height.

The visual fish censuses included counts of individuals of each species seen and an estimate of length for each fish. The length data were later used in estimating the standing

crop for each species using linear regression techniques (Ricker 1975, Brock and Norris 1989). Because of their importance as indicator species, micromollusks that occur in sand were sampled in areas directly adjacent to each transect site. The micromollusk samples were analyzed using the methods as outlined by Kay (1980), Kay and Kawamoto (1983). Also adjacent to each transect site algal biomass samples were collected using a 50cm ring. In the laboratory, these dominant algae were sorted by species and oven dried to constant weight for an estimate of biomass.

Where known, species were assigned to feeding categories in an effort to understand local trophic structure as well as to identify communities influenced by high particulate loading which could originate from sewage. Nonparametric statistical methods were used to avoid assumptions of normality. Diversity (H') is calculated for the fish transect data as described by Pielou (1966) where:

$$H' = -P_i \ln P_i$$

where P_i is that proportion of the individuals census belonging to species i. This is the Shannon-Wiener Index.

4 RESULTS

4.1 Benthic Station Descriptions

As noted above, pairs of stations were established in three areas (Waikiki, Sand Island, and Barbers Point) at three depths. Stations are numbered consecutively from east to west and deep to shallow. The locations of these sample sites are given in Figure 3.1. All permanently marked transects have an orientation that is perpendicular to the shoreline. A description of each sampling station is given in Appendix A. In general, all stations were established on hard substratum affording little cover except for the two stations established directly on the caprock of the Sand Island and Honouliuli Wastewater discharge pipes.

4.2 Field Results

Biological parameters measured in this study include the number of coral, algal, sponge and other sessile species in quadrats at a station, percent coverage of each sessile species which includes corals, algae, sponges, soft corals, etc.), number of each diurnally exposed macroinvertebrate species, number of fish species, number of individual fish of each species and the estimated biomass of fish for each transect site during each sampling period.

All raw data collected in this study have been submitted to the Mamala Bay data base as part of the requirements of the Mamala Bay Study Commission. A summary of these data are presented as means for individual transects and sampling dates in Appendix B.

Inspection of Appendix B shows that the greatest development of the fish and macrobenthic communities occurs where the substratum rugosity or topographical complexity is best developed as on the caprock of the sewage discharge pipes for Sand Island and Honouliuli Wastewater Treatment Plants (transect nos. 11 and 18). No

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equivalent habitat could be found in the Waikiki area at similar depths to serve as control. Since the substratum at these stations was placed by humans, is topographically distinct from the natural substratum in Mamala Bay and no similar control could be found, the data from these two stations were not included the statistical analyses presented below. Thus the statistical analyses focus on the marine communities present on natural substratum in Mamala Bay.

In the analysis of the data given in Appendix B, the nonparametric Kruskal-Wallis ANOVA was used to determine if statistically significant differences occur among different classes for a given parameter. If significance was indicated, the Student-Newman-Keuls (SNK) Test was subsequently employed to determine which of the classes were statistically different and to what degree. The data analysis commenced with addressing broad questions (i.e., across all stations, sample dates and depths) to questions more focused on smaller scale issues in subsequent analyses.

Utilizing the data in Appendix B, the first question to be addressed is: "Are there significant differences among Waikiki, Sand Island and Barbers Point study sites for any of the parameters measured in this study?" This analysis combines data across the three sample dates and depths within each major study area. The results of the Kruskal-Wallis ANOVA and the SNK Test addressing this question are given in Appendix C. The Kruskal-Wallis ANOVA noted that there are significant differences for the mean number of coral species ($p > 0.002$), the mean percent of substratum covered by sponges ($p > 0.0007$), the mean percent of substratum covered by macrothalloid algae ($p > 0.003$), the mean number of diurnally exposed macroinvertebrate species ($p > 0.005$), and the mean number of diurnally exposed macroinvertebrate individuals counted among the three areas (Waikiki, Sand Island and Barbers Point). The SNK analysis noted that the mean number of coral species was significantly less at Barbers Point (3 species) than encountered at either Sand Island or Waikiki (4 species each). Mean sponge cover was significantly less at Waikiki (0.06%) than at Barbers Point (0.4%) or Sand Island (0.5%). The only other significant differences noted by the SNK test was the significantly greater mean number of diurnally

exposed macroinvertebrate species at Barbers Point (6 species) than found at either Waikiki or Sand Island (4 species each).

The second question to be addressed is "Are there statistically significant differences among the three sample dates (Summer 1994, Winter 1994 and Summer 1995) for the parameters measured in this study?" In this analysis data from the three locations and depths are combined and analyzed by date. The results of the Kruskal-Wallis ANOVA and the SNK Test are given in Appendix D. As shown in Appendix D, no statistically significant change occurred among the ten parameters over the three sample periods.

The next question to be addressed is "Are there statistically significant differences among the shallow depth Waikiki, the shallow depth Sand Island and the shallow depth Barbers Point study areas for the parameters measured in this study?" This analysis combines data from the different sample dates. Considering only the shallow stations, the Waikiki site has a significantly greater mean number of coral species ($p>0.004$; mean = 4 species per transect) than do either the Sand Island or Barbers Point shallow transects (means for both are 2 species per transect). Sponge cover is significantly greater at the Barbers Point shallow stations ($p>0.004$; mean cover = 0.8%) than at either the Sand Island shallow stations (mean = 0.04%) or the shallow Waikiki stations (mean = 0.01%). The mean number of diurnally exposed macroinvertebrate species is significantly greater at Barbers Point shallow stations ($p>0.02$; mean = 6 species) and Waikiki shallow stations (mean = 5 species) than found at Sand Island (mean = 3 species). With respect to the mean number of diurnally exposed macroinvertebrate individuals, shallow stations at Barbers Point had significantly greater numbers ($p>0.0006$; mean = 38 individuals) than found at either Waikiki shallow stations (mean = 11 individuals) or Sand Island shallow stations (mean = 4 species).

The same question was posed for mid-depth stations, i.e., "Are there statistically significant differences among the mid-depth stations at Waikiki, Sand Island and Barbers Point study areas for the parameters measured in this study?" The results of the Kruskal-Wallis

ANOVA and the SNK Test addressing this question are given in Appendix F. Four parameters showed statistically significant separation at mid-depth stations; these were for the mean number of coral species, the mean percent coral cover, the mean percent sponge cover and the mean percent algal cover. The Sand Island mid-depth stations had a statistically greater mean number of coral species per transect (p>0.0009; mean = 6 species) than did the Waikiki mid-depth stations (mean = 3 species) which was statistically greater than the mid-depth Barbers Point stations (mean 2 species). The Sand Island mid-depth stations had a statistically greater mean coral coverage (p>0.003; mean = 4.8%) than did either the Barbers Point or Waikiki mid-depth stations (both means = 1%). Similarly, the Sand Island mid-depth stations had a statistically greater mean cover by sponges (p>0.003; mean = 0.30%) than did the Barbers Point mid-depth stations (mean = 0.08%) or the Waikiki mid-depth stations (mean = 0.04%). The mean coverage by macrothalloid algae was significantly greater at Waikiki mid-depth stations (p>0.003; mean = 3.9%) than either at Barbers Point (mean = 0.1%) or Sand Island (mean = 0.03%).

The same parameters were comparatively examined at the deep water stations for the three locations (Waikiki, Sand Island, Barbers Point). The question addressed was "Are there differences among the deep Waikiki, deep Sand Island and deep Barbers Point study areas for the parameters measured in this study?" The results of the Kruskal-Wallis ANOVA and the SNK Test are given in Appendix G. Considering only deep water stations, the mean percent coral cover was greatest at Waikiki (p>0.001; mean = 3.7%) relative to Barbers Point deep stations (mean = 2.6%) or Sand Island deep stations (mean = 2.1%). Sponge cover differed significantly among all three deep water sites (p>0.003). At Sand Island the mean cover was 1.3%, which was significantly greater than the mean sponge cover at Barbers Point (0.7%) which was significantly greater than the mean cover at Waikiki deep water sites (0.1%). The number of diurnally exposed macroinvertebrate species was significantly greater at Barbers Point deep stations (p>0.01; mean = 6 species) than either at Sand Island deep stations (mean = 3 species) or Waikiki deep stations (mean = 3 species). The mean number of diurnally exposed macroinvertebrate individuals was

significantly greatest at Waikiki deep stations (p>0.01; mean = 10 individuals) as differentiated from the deep Sand Island stations (mean = 4 species). The mean number of diurnally exposed invertebrates at deep water Barbers Point stations (mean = 9 individuals) was statistically indistinguishable from the means for the other two locations. The mean number of fish species encountered on a deep water transect was significantly greater at Waikiki stations (p>0.008; mean = 22 species) as compared to deep stations at Sand Island (mean = 16 species) or Barbers Point (mean = 14 species). The relative rugosity at deep water stations was significantly better developed at Sand Island (p>0.03; mean = 2.0) than either at Barbers Point or Waikiki (means both = 1.0).

In total 123 species of fishes were evaluated during this study in Mamala Bay. Seventeen species (or 13.8%) were classed as planktivorous meaning that they feed on (1) zooplankton, (2) small benthic crustaceans that emerge into the water column after dark, (3) large detrital particles or (4) a combination of these. Many of the planktivorous species are small as adults (e.g., damselfishes, etc.) but may occur in large aggregations. By numbers, 36% of the fish evaluated at Sand Island stations, 31% of the fishes counted at Waikiki stations and 22% of the fishes evaluated at Barbers Point stations were planktivores. By weight 10% of the biomass of fishes at Sand Island and Barbers Point stations were planktivores, while 6% of the biomass of fishes at Waikiki stations was comprised of planktivorous species.

Habitat complexity on coral reefs is very difficult to quantify. In this study, each sampling station and the surrounding bottom was subjectively rated with respect to topographical relief and cover. This scale of relative rugosity ranges from flat (a value of 1) to topographically complex (a value of 5). The relationship between relative rugosity and the diversity of fish (Shannon-Weiner index or H') encountered is given in Figure 4.1.

4.3 Discussion Of Results

Several of the methods employed in this study do not accurately assess the abundance and diversity of organisms on the reefs of Mamala Bay. Among the least

effective are the counts made of the diurnally exposed macroinvertebrates. Most motile invertebrates are cryptic by day and many emerge after darkness to feed. This, coupled with the fact that the majority of these cryptic invertebrates are small, necessitates the use of methodologies that are beyond the scope of this survey (see Brock and Brock 1977). The counts are made in the 25 x 4m transect area and focus on exposed invertebrates that are 2 cm or greater in some dimension without disturbing the substratum. Thus this sampling strategy is reasonably accurate for some echinoid and holothurian species and little else. For these reasons, little significance should be attached to the macroinvertebrate census data or the analyses of these data.
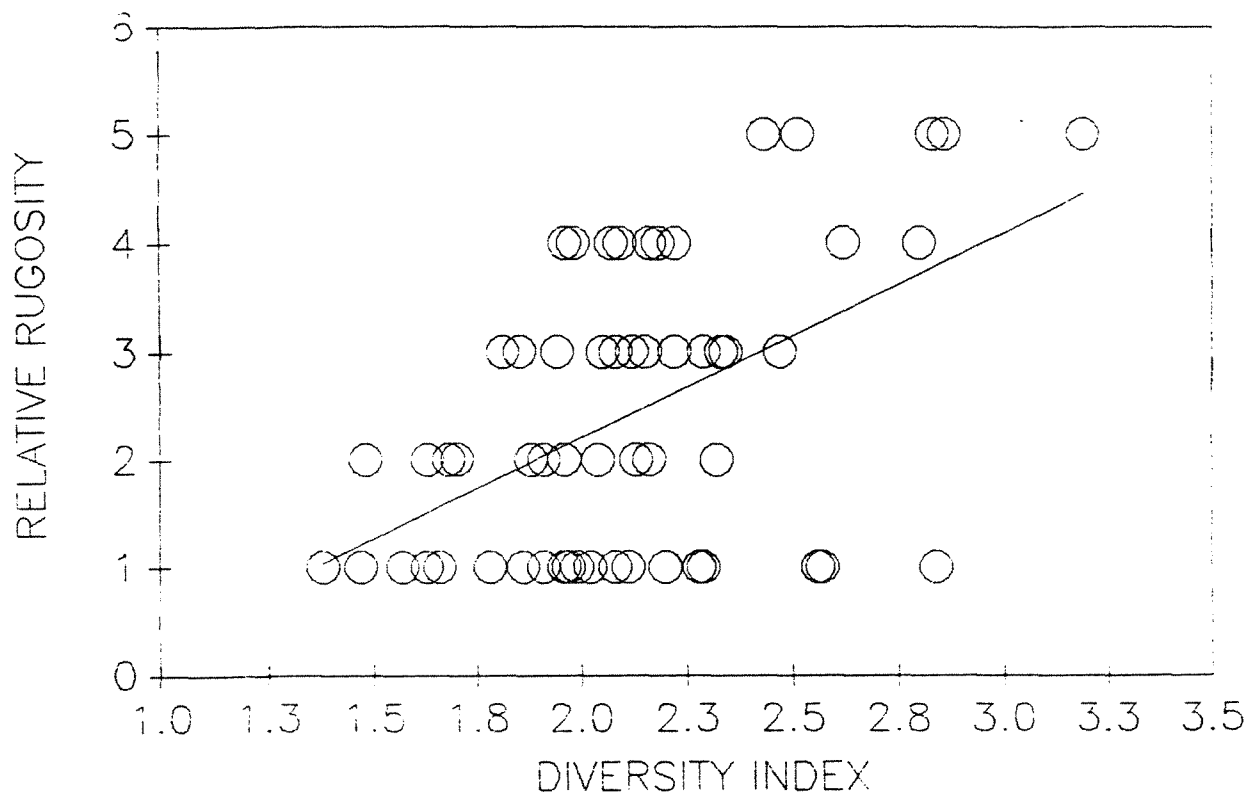
Figure 4.1 Plot of substratum complexity measured as relative rugosity against the diversity of fishes.

Also given is the fitted regression line (r=0.52, p>>0.0005). The relative rugosity of a given area is estimated on a scale from 1 to 5 where 1 = no topographical relief (flat) to 5 where rugosity is on the order of 0.5m or greater (vertically) covering 80% or more of the local area. The diversity of fishes is calculated using the Shannon-Weiner index (H').

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Similarly, the species counts for other groups that are poorly represented should not be given much consideration in the statistical analysis. In this category are the species counts for corals. In total, only eight species of corals were encountered in the twenty quantitative transects established for this study. The grand mean number of coral species per transect is 3 species. In some instances shown above, statistical significance was achieved with a difference of 1 coral species on a transect. Nowhere did coral cover exceed 7% other than on the basalt capstones of the two discharge pipes. Thus assigning much to the statistical differences in the mean number of coral species encountered at a given location or time is not justified.

Coral cover is often used as a measure of the degree of "health" in many studies of impacts to coral reefs. Coral cover is dependent upon the availability of appropriate substratum, water quality as well as the degree to which the area is subjected to occasional storm surf. Physical disturbance from occasional storm surf is one of the most important parameters in determining the structure of Hawaiian coral communities (Dollar 1982). Numerous studies have shown that occasional storm generated surf may keep coral reefs in a non-equilibrium or sub-climax state (Grigg and Maragos 1974, Connell 1978, Woodley et al. 1981, Grigg 1983). Indeed, the large expanses of near-featureless lava or limestone substratum present around much of the Hawaiian Islands at depths less than 30m attest to the force and frequency of these events (Brock and Norris 1989). These same wave forces also impinge on and impact fish communities (Walsh 1983).

Previous studies of coral development inshore of the Sand Island and Honouliuli Wastewater Treatment Plant diffusers have shown that the coral communities are poorly developed at depths less than 20m due to occasional wave impact and sand scour (Brock 1994, 1995a). Excluding the two stations established on the elevated discharge pipe capstones in the present study, mean coral coverage (all stations and all dates combined) was 2.4%. These low coverage values are probably the result of occasional sand scour due to wave activity over the relatively flat limestone substratum that is present at all three

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locations (Waikiki, Sand Island and Barbers Point). Much of the shallow limestone substratum throughout Mamala Bay has a similar scoured appearance with low coral coverage. Locally on scales of a few square meters, coral coverage may be much greater in areas where the substratum is protected from scour; the basalt capstones on the Sand Island and Honouliuli Wastewater discharge pipes are elevated as much as 2.5 m above the surrounding substratum and are above most sand scour. As a result, mean coral coverage at these stations is 14.3% or almost six times greater than on the surrounding flat limestone substratum.

Because wave energy impinging on the substratum is attenuated with depth, coral coverage would be expected to be greater at deeper stations. In general this is the case with deep stations having a mean coverage of 2.8%, mid-depth stations with a mean coverage of 2.3% and shallow stations having a mean coverage of 2.0%. As noted above, coral coverage at mid-depth stations is significantly greater at Sand Island than either at Barbers Point or Waikiki mid-depth stations and at the deeper stations Waikiki had significantly greater coral coverage than Barbers Point or Sand Island. These differences are attributed the local degree of exposure to wave stress rather than to any nonpoint source input from land or sewage effluent from the Sand Island or Honouliuli diffusers. If treated sewage effluent was creating an impact on coral coverage, then stations in closest proximity to these point source discharges (the deep Sand Island and Barbers Point stations) should have the lowest coverage and coverage should increase moving away (shoreward) from the source. The data do not support this hypothesis.

Sponges on most coral reefs are usually quite cryptic and rarely occur in most benthic quadrat studies. As a group, sponges feed on particulate material and thus may be indicative of particulate inputs. Brock (1995c, 1995d) using a remotely controlled video camera to assess macrobiota of the diffusers of both the Sand Island and the Honouliuli Wastewater Treatment facilities, has reported numerous sponges on the diffuser pipes suggesting that (1) the diffuser provides appropriate habitat for sponges, (2) the sewage may be providing a source of particulate food for sponges and (3) the sponges tolerate the

proximity of the low-salinity wastewater stream. Sponges were encountered in the present study; the most common species include Spriastrella coccinea, Chondrosia chucalla and Plakortis simplex.

In this study the mean benthic cover by sponges differed significantly among the three study areas; examination of this coverage by depth strata (i.e., shallow, mid-depth, and deep) resulted in Barbers Point shallow stations having significantly greater sponge coverage than at either Sand Island or Waikiki. At mid-depth and deep stations significantly greater coverage occurs at Sand Island relative to other sites. The occurrence of sponges in the quadrat data is noteworthy and the greater coverage by these animals at Sand Island suggests that appropriate substrate and/or food resources may be in greater supply in the Sand Island region. However, nowhere did the benthic coverage by sponges exceed 2% and the grand mean coverage across all stations and sample dates was 0.3%. Potential sources of particulate materials include discharged treated sewage effluent being carried shoreward from the diffusers and nonpoint source inputs such as from the Ala Wai Canal and Harbor, Kewalo Harbor, Honolulu Harbor, Keehi Lagoon and Pearl Harbor. Besides treated effluent, particulate materials such as phytoplankton, zooplankton and detritus from land or reef sources all may serve as food for sponges. In areas where particulate loading is high on coral reefs and from treated sewage effluent as occurred in Kaneohe Bay, benthic community development favors a complex of particulate-feeding species including bryozoans, tunicates, sponges, polychaetes and barnacles. Under the favorable food supply, benthic communities are dominated by these species (Smith et al. 1982, Brock and Smith 1982). The lack of these other benthic species in the Mamala Bay transects suggests that the food resources are other than sewage.

Sewage and land-derived particulate materials may serve as a food resources for fishes that feed either directly on the particulate material (as in sewage effluent) or indirectly on zooplankton that may be stimulated by the enhanced particulate loading. Thus the abundance and biomass of planktivorous fish may be greater in areas where these resources are greater. Brock et al. (1979) found that planktivores made up 59% of the

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biomass of fishes in a community subjected to advanced primary treated sewage effluent. As noted above, the biomass of planktivorous fishes at both Barbers Point and Sand Island stations did not exceed 10% suggesting that particulate food resources for planktivorous fishes is not elevated at the sample sites.

Studies conducted on coral reefs in Hawaii and elsewhere have estimated fish standing crops to range from 20 to 200g/m^2 (Brock 1954, Brock et al. 1979). Discounting the direct impact of humans due to fishing pressure and/or pollution, the variation in standing crop appears to be related to the variation in the local topographical complexity of the substratum. Thus habitats with high structural complexity affording considerable shelter space usually harbor a greater standing crop of coral reef fish (Risk 1972); conversely, studies carried out in structurally simple habitats (e.g., sand flats) usually result in a lower estimated standing crop of fish (0.2 to 20g/m^2). Goldman and Talbot (1975) noted that the upper limit to fish biomass on coral reefs is about 200g/m^2. Other studies (Brock and Norris 1989) suggest that with the manipulation (increasing) of habitat space or food resources (Brock 1987), local fish standing crops may approach 2000g/m^2.

In this study the abundance of fishes is related to the availability of appropriately scaled shelter. The high counts and biomass estimates of fishes occur primarily on the transects established on the basalt armor rock of the discharge pipe. In several instances fish counts were elevated on transects carried out adjacent to the discharge pipe because of its proximity and many fishes will form mixed schools and forage over the surrounding terrain. Inclusion of these fishes in a given transect adjacent to the discharge pipe is by chance; this occurred in the Summer 1994 censuses of stations 7 and 8 (Barbers Point deep stations).

5 CONCLUSIONS

The results of this study parallel those of other recent research on coral reef resources of Mamala Bay (Brock 1994, 1995a) in that there is no quantitative evidence supporting the view that the discharge of sewage is impacting the shallow reef resources shoreward of the two sewage outfalls.

This study has focused on the impact that may occur to the shallow macrobiota of the bay. The results suggest that fish community development in Mamala Bay is related primarily to the availability of appropriately scaled shelter space. Where such shelter is available as on the armor rock overlying the two wastewater discharge pipes or at the Atlantis Artificial Reef offshore of Waikiki (Brock 1995b), the fish communities are well-developed. Coral communities in Mamala Bay are poorly developed on hard substratum at depths of 20m or less. Coral communities are subjected to considerable sand scour caused by occasional wave impact. Because corals are slow-growing, these benthic assemblages are kept at an early successional stage by occasional wave impact through much of Mamala Bay. Where hard substratum is protected from wave-induced sand scour as on the elevated basalt armor rock of the wastewater discharge pipes, coral communities are better developed.

Sponges which are normally relatively cryptic on coral reefs and subject to the same wave stress as corals, show some development offshore of Sand Island and to a lesser extent off Barbers Point. Sponges are particulate (filter) feeders suggesting that food or other niche requirements are more appropriate at Sand Island than at other sample sites in Mamala Bay. Sources for particulate materials include those emanating from harbors (Pearl, Honolulu, Kewalo and Ala Wai) as well as from point source discharges (i.e., treated sewage moving shoreward). However, nowhere does the benthic cover by sponges exceed 2% and the other benthic particulate feeders usually associated with a sewage particle food resource are absent, suggesting that the particulate source(s) is not sewage.

6 RECOMMENDATIONS

The results of this study suggest that point source discharges (specifically the Sand Island and the Honouliuli Wastewater discharges) do not have a quantifiable impact on the shallow coral reef resources in Mamala Bay. Thus, we do not recommend any specific action be taken with respect to point source discharges in the bay other than the continuation of ongoing monitoring programs by the City and County of Honolulu.

The impact to shallow coral reef resources from non-point, diffuse inputs such as the discharge from harbors into Mamala Bay (Pearl, Honolulu, Kewalo and Ala Wai) as well as from Keehi Lagoon was not addressed with sufficient sampling by this study to provide an answer to this question. The obvious gradients in benthic community structure in proximity to Pearl Harbor and Keehi Lagoon qualitatively suggest localized impacts which are probably related more to the occasional input of stormwater runoff following heavy rainfall rather than other pollution sources. Because the impact of non-point source pollution is difficult to quantify in shallow marine communities, we recommend that this aspect receive further attention in the future.

As noted above, we suggest that future studies on the shallow marine resources of Mamala Bay address the question of impact of diffuse non-point source pollution to these resources. If funding becomes available for this, we recommend that the focus should be directed to marine communities and gradients in the vicinity of Pearl Harbor and Keehi Lagoon. These are probably the two largest non-point sources carrying materials into Mamala Bay.

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APPENDIX A

Summary of physical characteristics of 20 permanently marked stations sampled on three occasions in this study. Locations of these stations are shown in Figure 3.1

Station 1 - Deep Depth East Waikiki Station

This station is located approximately 1.8 km offshore of the Natatorium War Memorial in Waikiki at a depth of 21.5 m and is situated on a relatively smooth limestone flat. This station is approximately 35 m east of station 2. Often relatively strong tidal currents prevail at this and at stations 2, 3 and 4. These currents usually move either in a easterly or westerly direction, depending on the tide state and may exceed 10 cm/sec. Relative rugosity index for this site is 1.

Station 2 - Deep Depth West Waikiki Station

As with the preceding station, this site is situated on a limestone flat with little topographical relief (relative rugosity index = 1). The depth at this station is 21.5m. The limestone flat abruptly ends on sand about 35 m west of the transect and approximately 250 m to the west of the line is the Atlantis Artificial Reef (a commercial dive tour operation). Coral cover at these deep stations is only about 3%.

Station 3 - Mid Depth East Waikiki Station

This station is located approximately 500 m shoreward of stations 1 and 2 and is situated on a limestone flat at a depth of 13.8 m. There is very little topographical relief on the transect itself but within 5m of the line is a large Porites lobata coral colony and a series of low ledges that parallel the transect line; these features result in a relative rugosity index of 4.

Station 4 - Mid Depth West Waikiki Station

The substratum at this station is limestone with little topographical relief present (relative rugosity index = 1). The water depth at this station is 13.8 m and this transect is located approximately 35m west of station 3. Overall coral cover at the mid-depth stations is only about 1%.

Station 5 - Shallow Depth East Waikiki Station

This station is located about 500 m shoreward of the mid-depth sites (or about 800m offshore of the beach) in 4.6 m of water. The substratum at this station is primarily limestone in the form of old spur and groove formations. The scale of the spurs is from 2 to 8m in width, 4 to 25m in length and these are spaced from 1 to 6m apart with a general orientation that is perpendicular to shore. Between these spurs are areas of sand and rubble. These formations are better developed on the west station. The relative rugosity index for this station is 2.

Station 6 - Shallow Depth West Waikiki Station

Station 6 is located approximately 30 m west of station 5. Water depth at this station is 4.6m (to the tops of the spurs or limestone ridges). The limestone ridges are better developed at this station than to the east; the relative rugosity index at this station is 3. Coral cover at the shallow Waikiki stations is less than 3%.

Station 7 - Deep Depth East Sand Island Station

Station 7 is situated on a limestone flat with a relative rugosity of 1. Just east and seaward of this station the limestone abruptly ends on sand. Water depth at this station is 25 m. Station 7 is located approximately 1.7 km from shore and is about 80 m east of the Sand Island Wastewater discharge pipe. Tidal driven currents are sometimes apparent at

these deep stations offshore of Sand Island. These currents usually parallel the shore at maximum estimated speeds of 5 cm/sec. These currents are not usually evident at the shallower stations.

Station 8 - Deep Depth West Sand Island Station

This station is similarly located on limestone but with some scattered basalt boulders in the vicinity of the transect line. These boulders range in size from 0.5 to about 0.8 m and the majority of them are in a loose pile covering about 25 m^2 of substratum. The relative rugosity index is 3. This station is located approximately 40 m west of station 7 and 40 m east of the discharge pipe. Coral coverage at these deep stations is less than 3%.

Station 9 - Mid Depth East Sand Island Station

Station 9 is located about 1.3 km from the shoreline at a depth of 14.1 m about 60 m east of the Sand Island Wastewater discharge pipe. The substratum at this station is limestone with some rugosity (chain ratio = 0.86) and a few scattered loose basalt rocks present that all afford some cover. The relative rugosity index for this station is 2.

Station 10 - Mid Depth West Sand Island Station

This station is located approximately 25m west of station 9 on the same limestone flat. The wastewater discharge pipe lies approximately 35 m to the west of this transect line. Water depth is 14.1 m; the limestone has some small-scale rugosity and 5 m west of the transect line is a large depression with ledges as well as several large (2 x 3m) loose boulders affording cover for fishes and invertebrates. Coral coverage at these mid depth stations ranges from 2 to 7%.

Station 11 - Mid Depth Sand Island Station on the Discharge Pipe

A single station was established on the basalt caprock overlying the discharge pipe. The caprock rises between 0.5 to 2.5 m above the surrounding substratum. These basalt

boulders range from 0.5 to about 1.2m in dimensions and thus provide considerable shelter for fishes and invertebrates. The chain rugosity ratio is 0.43 on this transect and the relative rugosity index is 5 (maximal cover). The transect sampling this rocky habitat was established down the center of the pipeline. Coral coverage ranges from 11 to 16%.

Station 12 - Shallow Depth East Sand Island Station

This station lies just east of the Sand Island Wastewater discharge pipeline alignment in 4.6m of water approximately 870 m from the shoreline. Both shallow stations were established on old limestone spur and groove formations that provide some rugosity and shelter. The relative rugosity index for station 12 is 2. The scale of the limestone ridges or spurs is from 2 to 8 m in width, 3 to 12 m in length with an orientation perpendicular to shore. The spurs or ridges are spaced from 1 to 6 m apart with sand and coral rubble in the intervening channels; the ridges rise above the channel floors from 0.2 to 1 m.

Station 13 - Shallow Depth West Sand Island Station

Station 13 is situated about 30 west of station 12. The spur and groove system is better developed at this station than at the previous transect site thus the relative rugosity is greater (here 3). Water depth at station 13 is 4.6 m. Coral coverage at these shallow stations is 2% or less.

Station 14 - Deep Depth East Barbers Point Station

This station is located about 1.8 km offshore of Oneula Beach at Barbers Point at a depth of 20 m. This station is situated about 55 m east of the Honouliuli Wastewater discharge pipe on a smooth limestone substratum. Seaward of both of these deep transects the limestone grades into an expanse of sand. Cover is near absent in the vicinity of this station and the relative rugosity index is 1. Currents in the vicinity of the deep stations at

Barbers Point appear to be tidally driven, approximately parallel the shore, and are less than an estimated 5 cm/sec.

Station 15 - Deep Depth West Barbers Point Station

Station 15 is situated about 25m east of the Honouliuli Wastewater discharge pipe on smooth limestone (relative rugosity index = 1). There are some small basalt rock at the interface of the limestone and sand about 10 m seaward of this transect, but these afford little local cover relative to the nearby discharge pipe. Coral cover ranges between 2 to 3% on these deep transects.

Station 16 - Mid Depth East Barbers Point Station

This pair of stations is situated approximately 1.6 km from shore (or 200 m inshore of the deep pair) adjacent to the discharge pipe at a depth of 13.2 m. Station 16 is located about 60m east of the discharge pipe on a relatively smooth limestone substratum (relative rugosity index for this station is 1).

Station 17 - Mid Depth West Barbers Point Station

Station 17 is located about 30 m from the Honouliuli Wastewater discharge pipe at a depth of 13.2 m. The substratum is relatively smooth limestone but along the west side of the transect are approximately 60 basalt rocks ranging in size from 0.4 to 0.8 m in dimensions that cover an area of approximately 30 m^2. These rocks create cover for fishes and invertebrates and the relative rugosity at this station is 4. Coral cover at these stations is less than 2%.

Station 18 - Mid Depth Barbers Point Station on Discharge Pipe

This station was established on top of the basalt caprock covering the Honouliuli Wastewater discharge pipe 1.6 km from shore and 30 m west of station 17. The caprock is comprised of basalt boulders ranging in size from about 0.4 to 1.2 m in dimensions; these

rocks create topographical relief from 0.5 to 1.6m in height. The relative rugosity at this station is 5 and the chain ratio is 0.62. Coral coverage ranges from 12 to 15% at this station.

Station 19 - Shallow Depth East Barbers Point Station

This station is located approximately 180 m west of the Honouliuli Wastewater discharge pipeline alignment approximately 750 m from the shoreline at a depth of 4.6 m. The substratum in the vicinity of both shallow stations is comprised of limestone with numerous complex depressions; these depressions are best developed at the westernmost station. The scale of these features are from 3 to 30 m across and up to 1.2 m in depth. The depressions are spaced from 8 to 100 m apart. In some areas, undercuts along the edges of these depressions create local cover for fishes and invertebrates. The relative rugosity at station 19 is 2 and the chain ratio = 0.88.

Station 20 - Shallow Depth West Barbers Point Station

Station 20 is located approximately 35 m west of station 17. Cover in the form of undercuts and ledges is better developed at this station than the previous one; the relative rugosity index is 4 (chain ratio = 0.77). Both stations 19 and 20 are subject to surf action; a small south two-foot swell will result in breaking waves across these stations. Coral cover at these stations is between 2 to 3%.

APPENDIX B
Summary of biological and physical data from 20 permanently marked stations sampled on three occasions in this study

SAMPLE PERIOD	TRANSECT NO.	NO. CORAL SPP	CORAL COVER	SPONGE COVER	ALGAL COVER	NO. INVERT SPP	NO. INVERT INDIV	FISH SPP	FISH INDIV	BIO-MASS	RELATIVE RUGOSITY	DIVERSITY (H')
SUMMER94	1	3	3.2	0.30	1.6	2	5	20	142	145	1	2.02
SUMMER94	2	4	3.4	0.05	1.2	2	6	20	62	98	1	2.56
SUMMER94	3	3	0.8	0.10	0.2	4	16	30	176	59	4	2.62
SUMMER94	4	3	1.3	0.10	0.4	2	6	10	14	17	1	2.20
SUMMER94	5	4	1.3	0.02	0.1	5	13	14	67	25	2	2.13
SUMMER94	6	4	2.6	0.00	0.2	4	9	14	66	38	3	1.81
SUMMER94	7	5	1.7	0.70	12.8	2	4	23	307	741	1	1.99
SUMMER94	8	6	2.4	1.70	10.5	4	5	19	139	311	3	2.12
SUMMER94	9	4	2.5	0.40	0.0	5	9	18	141	56	2	2.16
SUMMER94	10	6	6.6	0.30	0.0	5	8	14	83	27	3	2.15
SUMMER94	11	2	11.4	0.00	0.0	3	49	51	1379	1983	5	2.43
SUMMER94	12	1	0.2	0.10	0.1	3	3	11	97	36	2	1.70
SUMMER94	13	4	2.3	0.02	0.0	3	5	16	148	54	3	1.94
SUMMER94	14	4	2.5	0.50	2.0	6	9	11	56	117	1	1.66
SUMMER94	15	4	2.6	0.80	0.8	5	9	15	62	142	1	2.29
SUMMER94	16	1	0.1	0.03	0.0	3	3	7	12	2	1	1.86
SUMMER94	17	2	1.6	0.20	0.5	5	11	17	100	35	4	2.07
SUMMER94	18	3	12.7	0.40	0.1	5	63	39	438	248	5	2.83
SUMMER94	19	2	2.0	0.10	0.0	3	22	14	141	58	2	1.88
SUMMER94	20	2	2.4	0.10	0.0	10	68	20	145	74	4	1.96
WINTER94	1	3	3.0	0.30	2.6	3	6	19	86	33	1	2.11
WINTER94	2	4	4.5	0.00	1.9	4	11	23	57	32	1	2.84
WINTER94	3	4	1.0	0.03	2.8	6	12	22	148	54	4	1.98
WINTER94	4	3	0.6	0.00	3.7	3	6	10	27	12	1	1.91
WINTER94	5	4	1.7	0.02	0.3	6	6	15	54	20	2	2.13
WINTER94	6	4	2.6	0.00	0.5	6	12	26	171	40	3	2.34
WINTER94	7	3	1.9	0.70	0.2	3	4	13	100	55	1	1.63
WINTER94	8	4	2.4	1.90	0.7	4	4	16	165	165	3	1.85
WINTER94	9	6	2.9	0.30	0.2	3	5	11	40	8	2	1.63
WINTER94	10	7	6.9	0.30	0.0	3	5	20	207	73	3	2.29

SAMPLE PERIOD	TRANSECT NO.	NO. CORAL SPP	CORAL COVER	SPONGE COVER	ALGAL COVER	NO. INVERT SPP	NO. INVERT INDIV	FISH SPP	FISH INDIV	BIO-MASS	RELATIVE RUGOSITY	DIVERSITY (H')
WINTER94	11	3	16.6	1.80	0.0	7	121	48	1043	474	5	2.51
WINTER94	12	2	0.7	0.02	0.2	1	1	12	85	21	2	1.68
WINTER94	13	2	2.4	0.02	0.1	1	1	14	165	64	3	2.05
WINTER94	14	4	3.2	0.40	0.5	3	3	10	32	12	1	1.78
WINTER94	15	5	2.8	0.70	0.2	6	12	14	64	28	1	2.28
WINTER94	16	1	0.2	0.00	0.1	5	7	6	18	5	1	1.38
WINTER94	17	2	1.7	0.10	0.0	4	12	19	72	38	4	2.22
WINTER94	18	2	15.1	1.90	0.0	10	88	35	744	300	5	2.86
WINTER94	19	2	2.5	0.10	0.7	5	34	14	64	27	2	2.04
WINTER94	20	2	2.7	0.10	0.0	8	55	16	104	52	4	2.09
SUMMER95	1	4	4.0	0.08	0.0	3	21	22	90	34	1	2.08
SUMMER95	2	3	4.2	0.00	0.0	3	11	29	157	27	1	2.57
SUMMER95	3	4	1.1	0.03	6.2	7	9	25	93	35	4	2.80
SUMMER95	4	3	1.0	0.00	10.3	2	3	9	32	9	1	1.47
SUMMER95	5	4	2.1	0.00	0.9	5	11	20	84	23	2	2.32
SUMMER95	6	4	3.3	0.00	0.6	5	17	26	134	55	3	2.47
SUMMER95	7	4	2.1	0.60	0.1	2	3	9	42	11	1	1.57
SUMMER95	8	5	2.3	2.00	0.1	2	2	18	78	92	3	2.33
SUMMER95	9	4	2.9	0.30	0.0	6	8	10	35	7	2	1.91
SUMMER95	10	7	6.9	0.20	0.0	2	2	20	171	114	3	2.22
SUMMER95	11	2	16.2	0.00	0.0	8	138	54	718	486	5	2.83
SUMMER95	12	1	0.3	0.05	0.1	8	4	6	25	5	2	1.48
SUMMER95	13	3	2.3	0.00	0.2	5	7	16	99	39	3	2.08
SUMMER95	14	3	2.1	1.00	0.9	6	6	15	96	29	1	2.25
SUMMER95	15	3	2.5	0.90	0.5	8	12	16	173	115	1	1.97
SUMMER95	16	1	0.4	0.03	0.1	4	7	10	27	11	1	1.96
SUMMER95	17	3	1.8	0.10	0.1	4	12	17	110	104	4	2.16
SUMMER95	18	2	13.5	0.70	0.0	7	100	45	576	254	5	3.09
SUMMER95	19	2	2.2	0.05	0.0	4	19	16	94	39	2	1.96
SUMMER95	20	2	3.1	0.03	0.0	5	28	23	179	113	4	2.18

APPENDIX C

Summary of the results using the Kruskal-Wallis ANOVA (shown as p-value) and the Student-Newman-Kuels Test to address the question, "Are there differences among the Waikiki, Sand Island and Barbers Point study areas for the parameters measured in this study?". In the body of the table are given the parameter under consideration, the Kruskal-Wallis ANOVA result, the means for that parameter at each of the three study areas and the degree of statistical separation as given by letters. Letters with the same designation show means and sample locations that are related; changes in letter designation show where significant differences exist. Overlaps in the letters indicate a lack of significant differences.

PARAMETER	KRUSKAL-WALLIS p-value	LOCATION	SNK TEST MEAN	LETTER
No. of Coral Species	p>0.002 significant	Sand Island	4	A
		Waikiki	4	A
		Barbers Pt	3	B
% Coral Cover	p>0.75 not significant	Sand Island	4.5	A
		Barbers Pt	3.7	A
		Waikiki	2.3	A
% Sponge Cover	p>0.0007 significant	Sand Island	0.5	A
		Barbers Pt	0.4	A
		Waikiki	0.06	B
% Algal Cover	p>0.003 significant	Waikiki	1.9	A
		Sand Island	1.2	A
		Barbers Pt	0.3	A
No. of Invert Species	p>0.005 significant	Barbers Pt	6	A
		Waikiki	4	B
		Sand Island	4	B
No. of Invert Individuals	p>0.001 significant	Barbers Pt	28	A
		Sand Island	19	A
		Barbers Pt	10	A

PARAMETER	KRUSKAL-WALLIS p-value	LOCATION	SNK TEST MEAN	LETTER
No. of Fish Species	p>0.31 not significant	Sand Island	20	A
		Waikiki	20	A
		Barbers Pt	18	A
No. of Fish Individuals	p>0.22 not significant	Sand Island	251	A
		Barbers Pt	157	A
		Waikiki	92	A
Fish Biomass	p>0.17 not significant	Sand Island	230	A
		Barbers Pt	86	A
		Waikiki	42	A
Relative Rugosity	p>0.21 not significant	Sand Island	2.7	A
		Barbers Pt	2.6	A
		Waikiki	2.0	A

APPENDIX D

Summary of the results using the Kruskal-Wallis ANOVA (shown as p-value) and the Student-Newman-Kuels Test to address the question, "Are there differences among the three sample dates (Summer 1994, Winter 1994 and Summer 1995) for the parameters measured in this study?". In the body of the table are given the parameter under consideration, the Kruskal-Wallis ANOVA result, the means for that parameter at each of the three dates and the degree of statistical separation as given by letters. Letters with the same designation show means and sample locations that are related; changes in letter designation show where significant differences exist. Overlaps in the letters indicate a lack of significant differences.

PARAMETER	KRUSKAL-WALLIS p-value	DATE	SNK TEST MEAN	LETTER
No. of Coral Species	p>0.92 not significant	Summer 94	3	A
		Winter 94	3	A
		Summer 95	3	A
% Coral Cover	p>0.81 not significant	Winter 94	3.8	A
		Summer 95	3.7	A
		Summer 94	3.2	A
% Sponge Cover	p>0.60 not significant	Winter 94	0.4	A
		Summer 95	0.3	A
		Summer 94	0.3	A
% Algal Cover	p>0.50 not significant	Summer 94	1.5	A
		Summer 95	1.0	A
		Winter 94	0.7	A
No. of Invert Species	p>0.60 not significant	Summer 95	5	A
		Winter 94	5	A
		Summer 94	4	A
No. of Invert Individual	p>0.88 not significant	Summer 95	21	A
		Winter 94	20	A
		Summer 94	16	A

PARAMETER	KRUSKAL-WALLIS p-value	DATE	SNK TEST MEAN	LETTER
No. of Fish Species	p>0.76 not significant	Summer 95	20	A
		Summer 94	19	A
		Winter 94	18	A
No. of Fish Individuals	p>0.89 not significant	Summer 94	189	A
		Winter 94	172	A
		Summer 95	151	A
Fish Biomass	p>0.15 not significant	Summer 94	213	A
		Summer 95	80	A
		Winter 94	76	A
Relative Rugosity	p>0.99 not significant	Summer 94	2.5	A
		Winter 94	2.5	A
		Summer 95	2.5	A

APPENDIX E

Summary of the results using the Kruskal-Wallis ANOVA (shown as p-value) and the Student-Newman-Kuels Test to address the question, "Are there differences among the shallow Waikiki, shallow Sand Island and shallow Barbers Point study areas for the parameters measured in this study?". In the body of the table are given the parameter under consideration, the Kruskal-Wallis ANOVA result, the means for that parameter at each of the three study areas and the degree of statistical separation as given by letters. Letters with the same designation show means and sample locations that are related; changes in letter designation show where significant differences exist. Overlaps in the letters indicate a lack of significant differences.

PARAMETER	KRUSKAL-WALLIS p-value	LOCATION	SNK TEST MEAN	LETTER
No. of Coral Species	p>0.004 significant	Waikiki	4	A
		Sand Island	2	B
		Barbers Pt	2	B
% Coral Cover	p>0.14 not significant	Barbers Pt	2.5	A
		Waikiki	2.3	A
		Sand Island	1.4	A
% Sponge Cover	p>0.004 significant	Barbers Pt	0.08	A
		Sand Island	0.04	B
		Waikiki	0.01	B
% Algal Cover	p>0.02 significant	Waikiki	0.4	A
		Sand Island	0.1	A
		Barbers Pt	0.1	A
No. of Invert Species	p>0.02 significant	Barbers Pt	6	A
		Waikiki	5	A
		Sand Island	3	B
No. of Invert Individuals	p>0.0006 significant	Barbers Pt	38	A
		Waikiki	11	B
		Sand Island	4	B

PARAMETER	KRUSKAL-WALLIS p-value	LOCATION	SNK TEST MEAN	LETTER
No. of Fish Species	p>0.11 not significant	Waikiki	19	A
		Barbers Pt	17	A
		Sand Island	13	A
No. of Fish Individuals	p>0.52 significant	Barbers Pt	121	A
		Sand Island	103	A
		Waikiki	96	A
Fish Biomass	p>0.15 not significant	Barbers Pt	61	A
		Sand Island	37	A
		Waikiki	34	A
Relative Rugosity	p>0.65 not significant	Barbers Pt	3.0	A
		Sand Island	2.5	A
		Waikiki	2.5	A

APPENDIX F

Summary of the results using the Kruskal-Wallis ANOVA (shown as p-value) and the Student-Newman-Kuels Test to address the question, "Are there differences among the mid-depth Waikiki, mid-depth Sand Island and mid-depth Barbers Point study areas for the parameters measured in this study?". In the body of the table are given the parameter under consideration, the Kruskal-Wallis ANOVA result, the means for that parameter at each of the three study areas and the degree of statistical separation as given by letters. Letters with the same designation show means and sample locations that are related; changes in letter designation show where significant differences exist. Overlaps in the letters indicate a lack of significant differences.

PARAMETER	KRUSKAL-WALLIS p-value	LOCATION	SNK TEST MEAN	LETTER
No. of Coral Species	p>0.0009 significant	Sand Island	6	A
		Waikiki	3	B
		Barbers Pt	2	C
% Coral Cover	p>0.003 significant	Sand Island	4.8	A
		Barbers Pt	1.0	B
		Waikiki	1.0	B
% Sponge Cover	p>0.003 significant	Sand Island	0.30	A
		Barbers Pt	0.08	B
		Waikiki	0.04	B
% Algal Cover	p>0.003 significant	Waikiki	3.9	A
		Barbers Pt	0.1	B
		Sand Island	0.03	B
No. of Invert Species	p>0.92 not significant	Barbers Pt	4	A
		Sand Island	4	A
		Waikiki	4	A
No. of Invert Individuals	p>0.44 not significant	Barbers Pt	9	A
		Waikiki	9	A
		Sand Island	6	A

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PARAMETER	KRUSKAL-WALLIS p-value	LOCATION	SNK TEST MEAN	LETTER
No. of Fish Species	p>0.39 not significant	Waikiki Sand Island Barbers Pt	18 16 13	A A A
No. of Fish Individuals	p>0.25 not significant	Sand Island Waikiki Barbers Pt	113 82 57	A A A
Fish Biomass	p>0.70 not significant	Sand Island Barbers Pt Waikiki	48 33 31	A A A
Relative Rugosity	p>0.99 not significant	Barbers Pt Sand Island Waikiki	2.5 2.5 2.5	A A A

APPENDIX G

Summary of the results using the Kruskal-Wallis ANOVA (shown as p-value) and the Student-Newman-Kuels Test to address the question, "Are there differences among the deep Waikiki, deep Sand Island and deep Barbers Point study areas for the parameters measured in this study?". In the body of the table are given the parameter under consideration, the Kruskal-Wallis ANOVA result, the means for that parameter at each of the three study areas and the degree of statistical separation as given by letters. Letters with the same designation show means and sample locations that are related; changes in letter designation show where significant differences exist. Overlaps in the letters indicate a lack of significant differences.

PARAMETER	KRUSKAL-WALLIS p-value	LOCATION	SNK TEST MEAN	LETTER
No. of Coral Species	p>0.17 not significant	Sand Island	5	A
		Barbers Pt	4	A
		Waikiki	4	A
% Coral Cover	p>0.001 significant	Waikiki	3.7	A
		Barbers Pt	2.6	B
		Sand Island	2.1	B
% Sponge Cover	p>0.003 significant	Sand Island	1.3	A
		Barbers Pt	0.7	B
		Waikiki	0.1	C
% Algal Cover	p>0.99 not significant	Sand Island	4.1	A
		Waikiki	1.2	A
		Barbers Pt	0.8	A
No. of Invert Species	p>0.01 significant	Barbers Pt	6	A
		Sand Island	3	B
		Waikiki	3	B
No. of Invert Individuals	p>0.01 significant	Waikiki	10	A
		Barbers	9	A B
		Sand Island	4	B

PARAMETER	KRUSKAL-WALLIS p-value	LOCATION	SNK TEST MEAN	LETTER
No. of Fish Species	p>0.008 significant	Waikiki	22	A
		Sand Island	16	B
		Barbers Pt	14	B
No. of Fish Individuals	p>0.42 not significant	Sand Island	139	A
		Waikiki	99	A
		Barbers Pt	81	A
Fish Biomass	p>0.42 not significant	Sand Island	229	A
		Barbers Pt	74	A
		Waikiki	62	A
Relative Rugosity	p>0.03 significant	Sand Island	2.0	A
		Barbers Pt	1.0	B
		Waikiki	1.0	B