

**Hawaii Coral Reef Initiative**  
**Coral Reef Assessment and Monitoring Program (CRAMP)**  
**Final Report 1999-2000**

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## EXECUTIVE SUMMARY

1. During the first two years of operation CRAMP met the challenge to develop and implement statistically valid survey techniques for detecting change in benthic and fish communities in Hawaiian waters. This involved installation and quantification of transects at over 30 monitoring sites in the State of Hawaii. CRAMP completed the first cycle of monitoring and data analysis and began the second cycle.
2. In addition to the monitoring effort, during year 2, CRAMP undertook and completed a major study of the impact of trampling on Hawaiian reef corals that will stand as the definitive work on the topic. Detailed studies of the mechanical strength of corals developed in this work will also be invaluable in defining the role of wave impact on structuring of coral reef communities.
3. CRAMP has designed and implemented a well-designed database that will allow rapid access to a very large amount of data being taken as part of the project. In addition, the database includes bibliographic and historical data for Hawaiian waters.
4. CRAMP has met monitoring objectives set by managers and scientists in 1998. Initial baseline data have undergone preliminary analysis for spatial trends. Resurvey data are being processed rapidly and initial analysis of temporal change is underway.
5. CRAMP is now in position to evaluate short-term impacts of episodic events.
6. CRAMP is positioned to evaluate long-term effects of global warming (bleaching), CO<sub>2</sub> impact on calcification, nutrification, sedimentation, etc.
7. CRAMP will continue to monitor the completed network with increasing emphasis on integration of monitoring activity with state-wide assessment, habitat mapping, information synthesis and information dissemination through partnerships and co-operating agreements.

Analysis of the initial spatial data taken at the monitoring sites has already led to significant findings on the natural and anthropogenic factors responsible for spatial and temporal variation observed on Hawaiian coral reefs. Observations on temporal changes await the completion of the second survey. Some highlights of the findings to date are as follows:

- Exposure (wave energy) was shown to be a significant factor in determining the structure of Hawaiian benthic and fish communities.

- Bottom relief (rugosity) is a significant factor in determining fish habitat quality, with a significant relationship between rugosity and fish biomass.
- Average coverage for all CRAMP sites is approximately 23%. All transects are positioned on hard substratum. The sites were selected over a representative cross section of Hawaiian coastal environments, so this is probably a reasonable estimate for coral cover on hard substratum over the entire main Hawaiian Islands in the depth range sampled. Published literature values generally show coverage estimates higher (mean of the previously published values is approximately 35-40% cover). Previous studies often targeted high coral coverage areas rather than selecting a good cross section of reefs throughout the state.
- The reefs of Hawaii are best described as "*Porites* reefs", being overwhelmingly dominated by massive and encrusting *Porites lobata* and branched *Porites compressa*. *Montipora capitata* (= *Montipora verrucosa*) and *Montipora patula* (= *Montipora verrilli*) also account for a significant amount of the coverage. *Pocillopora meandrina* is common in shallow turbulent environments.
- A latitudinal gradient in the coral community composition is not evident in these data. Coral cover appears to be controlled primarily by local variation in dominant environmental factors such as wave energy, bathymetry, watershed influences, substrate type, etc.
- Coastal sites with high wave exposure (e.g. Pupukea, Hoai Bay) have the lowest cover while bays and wave-protected coastal areas (e.g. south Molokai) have the highest coral cover.
- The most significant anomaly in coral coverage and reef conditions occurs off south Molokai. Coral cover along this coast is extremely high. The two sites with highest coral cover in the state (Palaau and Kamalo) are located here. A large zone of damaged reef occurs in the middle portion of the south Molokai coastline, between these two high-cover survey sites. Within this damaged zone is another survey site (Kamiloloa), which has the lowest coral coverage in the state.
- Areas protected from fishing have distinct assemblages and had higher biomass compared to areas where all fishing was permitted.
- The marine protected areas that were fully protected from fishing showed a much higher fish biomass than partially protected or open access sites. However, degree of protection did not show a relationship with coral reef community structure, probably because corals are protected and not being harvested anywhere in the state.
- Surgeonfishes were the dominant fish family observed on transects, and herbivores accounted for over 70% of the total reef fish biomass over all locations.
- Fish assemblages in Kaneohe Bay, Oahu were very distinct and differed greatly from all other fish assemblages around the state.
- The approach taken in this study is developing a functional relationship between habitats and fishes, and will provide criteria for selection and management of marine protected areas and reserves.

- Results of the trampling investigation clearly demonstrate the impact of direct contact (reef walking and snorkeling) on shallow coral reefs in Hawaii. Reef corals in shallow areas with high visitor use (over 300,000 visitors annually) are quickly pulverized by the contact and fail to survive continued exposure to trampling.
- Experiments suggest that coral colonies can recover from an intense period of trampling if the stress is not continued. The original colonies and most of the larger fragment broken off these colonies will recover. Not all coral communities are equal in their ability to withstand direct human trampling contact. Species typical of high wave energy environments have much stronger skeletons and resist breakage from human contact.
- In Hawaii, the area of reef being subjected to trampling is quite small compared to the total reef resource. However, the areas being impacted are those areas with high recreation value and high value to the visitor industry. Sites in Kaneohe Bay with moderate levels of visitor activity showed less impact of trampling largely because most of the visitors at that location are supplied with flotation devices that kept them from contacting the bottom.

## Section 1. Overview

This report covers progress made during the second year of the Hawaii Coral Reef Assessment and Monitoring Program (CRAMP). The first six months of year 1 were devoted to development of the standard monitoring methods and database. The last 6 months of year 1 and the first six months of year 2 were devoted to establishing permanent transects at 30 sites throughout the Hawaiian Islands. The remaining six months of year 2 were focused on data analysis. In addition, a major study on the effects of trampling on reef corals was undertaken at the request of the Division of Aquatic Resources (DAR) and completed by the end of the funding year.

Hawaii's valuable reefs are increasingly under environmental pressures. Management of our reefs is largely the responsibility of the State of Hawaii Department of Land and Natural Resources (DLNR), Division of Aquatic Resources (DAR), while research is largely the responsibility of the University of Hawaii (UH). In the past, one of the greatest frustrations to scientists and managers in Hawaii had been lack of information on mechanisms responsible for reef decline. Further, there was a need for an integrated coral reef research and monitoring program. Scientific studies and surveys had been conducted piecemeal throughout the State with little consistency in methodology or large-scale experimental design. A second major problem facing Hawaii had been its geography. The Hawaiian Islands form an archipelago that extends over a vast area of the Pacific Ocean. Our vast reef resources are spread over thousands of miles of coastline on numerous islands. Managers and scientists in Hawaii have been faced with increasing evidence and a growing consensus among leading scientists that coral reefs throughout the world will undergo massive changes within the next few decades. The cause is increasing levels of anthropogenic atmospheric gasses that are responsible for global warming and a reduction in carbonate saturation in tropical surface waters (e.g. Hough-Guldberg, 1999, Kleypas et al. 1999, Wilkerson et al. 1999). The first factor is leading to increasingly severe mass bleaching and mass mortality of reef corals on a global scale. The second factor will result in a reduction in the ability of reef corals and other reef organisms to calcify, with possible dire consequences to existing populations. These impacts have been added onto the already documented worldwide decline due to other anthropogenic factors such as over-fishing, eutrophication, sedimentation etc.

Growing awareness of the value and plight of coral reefs led to development of the Coral Reef Initiative (CRI) at the national, international and local level. At the federal level, the CRI led to legislation aimed at securing funds for reef monitoring, and thereby directly promoted development of a comprehensive monitoring program for Hawaii. The Hawaii Coral Reef

Assessment and Monitoring Program (CRAMP) was developed during 1997-98 by leading coral reef researchers and managers in Hawaii. The design was further refined during the international "Hawaii Coral Reef Monitoring Workshop" organized by the DAR in conjunction with the East-West Center and held in Honolulu during June 9-11, 1998 (Maragos and Grober-Dunsmore, 1999). The need for a coherent, integrated monitoring program for Hawaii using standard methods appropriate for our situation was clearly identified. In the first year of operation, CRAMP has resolved these issues.

CRAMP has overcome the geographic barriers facing our island state through collaborative effort and modern communication technology. UH has excellent coral reef research groups presently operating at UH Manoa (Oahu), Maui Community College, and at UH Hilo (Hawaii). The UH groups share a common computer network, administrative, and fiscal system. The scientists and managers of DAR are working collaboratively with the UH groups on all of the main Hawaiian Islands. The UH/DAR scientists receive excellent assistance in their work from a variety of non-government organizations, other State agencies such as the Coastal Zone Management Office and Department of Health, and Federal agencies such as the Fish and Wildlife Service and National Marine Fisheries Service.

At the research level CRAMP is designed to identify the controlling factors, both natural and anthropogenic, contributing to stability, decline or recovery of our reefs. CRAMP was designed as an integrated Statewide, UH/DAR system-wide coral reef research program, common database and rapid information dissemination system that will provide the means for managers and researchers to detect and respond appropriately to environmental threats to our reefs. CRAMP also includes scientists and managers from the, Bishop Museum, Waikiki Aquarium and other organizations in an ongoing collaborative statewide research and monitoring program. The design is such that CRAMP can address questions from a local to a global scale. At the local level, CRAMP is designed to determine statewide environmental trends. On the global scale, CRAMP has initiated the research needed to test the hypotheses that we are headed for a generalized long- term decline in coral cover. The CRAMP experimental design selected a wide range of research sites to provide answers to questions concerning acute and chronic localized impacts as well as regional trends. Historical surveying and monitoring techniques were evaluated for precision and statistical power to determine a standardized sampling protocol. The final CRAMP survey protocol employs digital video transects and fixed photoquadrats to address changes in overall cover of substrate types and growth, recruitment and mortality of benthic organisms. We also have developed and implemented a standard protocol for monitoring reef fish populations (see section IV).

## **General Experimental Design - “Problem Focused” Research**

CRAMP experimental design allows detection of changes that can be attributed to various factors such as overuse (overfishing, anchor damage, aquarium trade collection, etc.), sedimentation, nutrient loading, catastrophic natural events (storm wave impact), coastal construction, urbanization, global warming (bleaching), introduced species, algal invasions, and fish and invertebrate diseases. The experimental design provides vital information on all of the above issues, but the emphasis is on the major problems facing Hawaiian coral reefs as listed by managers and reef scientists during workshops and meetings held in Hawaii during 1997-1998. These are: overfishing, sedimentation, eutrophication and algal outbreaks. CRAMP experimental design gives priority to areas where baseline data relevant to these issues were previously collected. This program will continue to synthesize existing data into the experimental design, and conduct further work in order to test hypotheses concerning the role of various environmental factors in the ecology of coral reefs. CRAMP researchers are quantifying changes that have occurred on coral reefs subjected to varying degrees of fishing pressure, sedimentation, and eutrophication. In addition, we are studying reefs that have experienced algal outbreaks. We are in the process of resurveying, updating and integrating existing ecological information on an array of coral reefs that have been designated as areas of concern by managers and scientists.

### **Study Sites**

Designated research sites were chosen from throughout the State of Hawaii with input from managers and scientists. These sites give us a good cross section of reef types found throughout the main Hawaiian Islands and allow testing of hypotheses involving the impact of factors noted above. Research sites include areas of primary concern originally designated by the DAR. Data taken in a standard and precise manner in a wide range of habitats allows us to describe the biology and ecology of reefs throughout the high islands, allows us to develop and test basic scientific theories concerning factors controlling the structure and function of coral reefs, and can facilitate the selection of areas for future marine protected area (MPA) designation. Sites were selected on Kauai, Oahu, Maui and Hawaii with regard to factors such as type of environmental stress, presence of historical data, degree of environmental degradation and/or recovery, and degree of wave exposure.

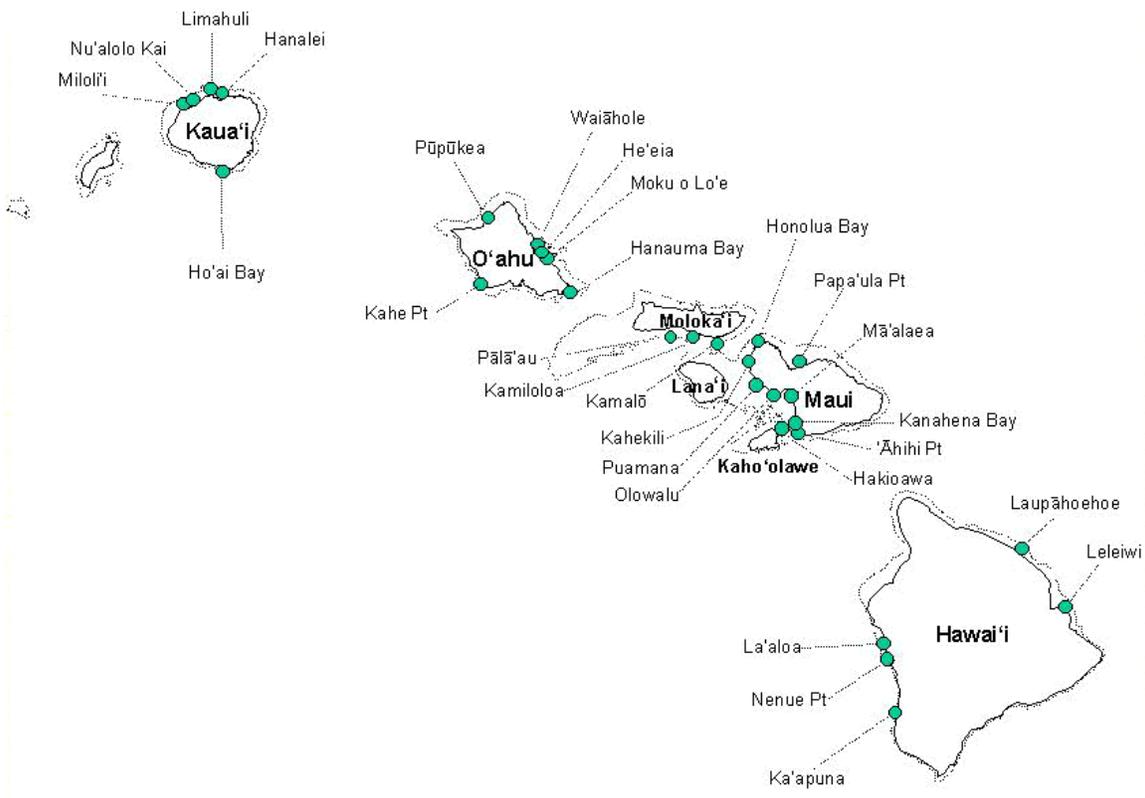


Figure 1-1. Completed CRAMP monitoring sites as of the end of year 2 (Oct 2000).

## Research Methodology

CRAMP has developed a “standardized” transect protocol in order to enable state-wide between-site comparisons. We also re-survey some previously existing monitoring sites that have long-term historical data sets. This requires using methods employed in the original surveys in order to detect long-term within-site changes in addition to installing and implementing standard CRAMP protocol.

## Data Management - Information Dissemination

The revolution in computer/communication technology now allows us to collect, process, and summarize data in a form that is readily available for use by the research and management community. Perpetuity of information and access is insured through redundant archiving of information in systems with expected longevity. The database system is designed for ease of access by all. A major advantage is that we are gradually accumulating all existing relevant information in a single location that is easily accessed by individual investigators and resource managers.

## **Section 2. Methodology**

During year 2 of CRAMP the final methodology was developed as CRAMP field teams became more proficient at installing and monitoring the sites. Inclusion of fish transecting techniques, rugosity measurements, and benthic video and quadrat techniques required a coordinated and integrated dive team approach for monitoring the sites.

### **Monitoring design and site installation**

The requirements of the CRAMP experimental design for observer-independent accuracy, reproducibility, quality control and archiving led to the abandonment of the classic method of using a 1 m square quadrat frame and an underwater writing slate to estimate benthic coverage. New methodology has been designed for both monitoring and assessment. This section describes the monitoring design in detail. The Assessment design is an abbreviated version of the monitoring design and is described under the Assessment section.

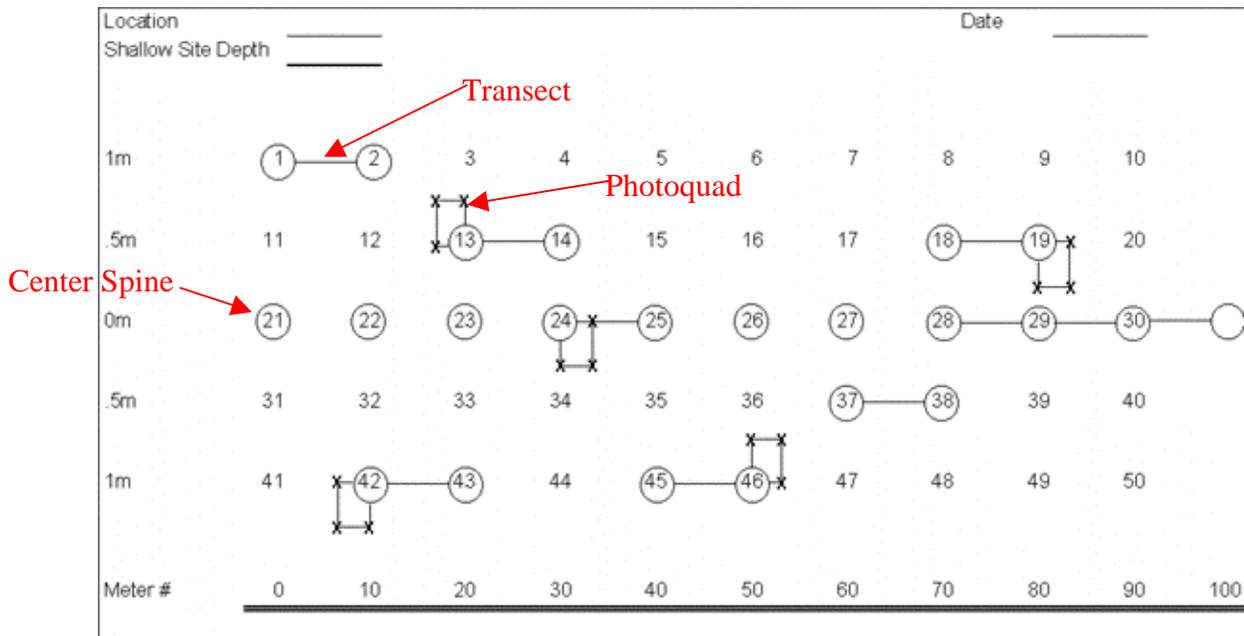
The classic monitoring method of collecting data underwater using a quadrat frame and writing slate had been used in Hawaii for over 30 years, but failed to yield reproducible results under the conditions set by the CRAMP experimental monitoring design. Once the researcher left the field, quality assurance and quality control was limited to data entry validation only. No new information could be extracted from the existing data if it was not already recorded on the slate. Things like collaboration on species identification was no longer possible, nor were training sets extractable from the original data. It was not possible to do inter-observer variation analysis from the same data (a requirement for statistical confidence with a reasonable sample size for this comparison). A permanent photographic record could not be created if it was not obtained in the field. The standard CRAMP surveying protocol of digital video overcame this methodological shortcoming, with an achievable, accessible, reproducible data set that could be used for existing analysis, and could also be used to address future questions that had not been addressed at the time of data collection.

The basic unit for long term CRAMP monitoring is a 100 m x 3 m transect corridor that follows a depth contour. The transect corridor is divided into a grid of 1 m intervals along its length by 0.5 m intervals along its width. Stainless steel pins are secured to the substrate along the length of the central transect line or "spine" (shown in yellow on diagram below) to serve as the reference point for installation of the 10 transects and five photoquadrats. The spine pins are marked by slipping a short length of plastic tubing over the pin to identify it as a "spine" pin. In addition, the first spine pin (0 m) is marked with a single cable tie, the sixth pin (50 m) is marked with two cable ties and the eleventh pin (100 m) is marked with three cable ties.

1.5 m											
1.0 m	1	2	3	4	5	6	7	8	9	10	
0.5 m	11	12	13	14	15	26	27	18	19	20	
0.0 m	21	21	23	24	25	26	27	28	29	30	
0.5 m	31	32	33	34	35	36	37	38	39	40	
1.0 m	41	42	43	44	45	46	47	48	49	50	
1.5 m											
distance along transect	0 m	10 m	20 m	30 m	40 m	50 m	60 m	70 m	80 m	90 m	100 m

Note: Vertical exaggeration approximately 30 times horizontal

As can be seen from the diagrams above and below, there are 50 possible pins to be used as starting locations for transects of 10 m length within this grid. Only ten of the 50 possible positions are randomly selected. Pins are installed only where needed to complete the array and mark the ends of the 10 transects. These are the 10 transects that will be monitored annually over time. In addition, five of the locations with pins are haphazardly selected for the installation of permanent photoquadrats. An example of a randomly designed grid layout is shown below. The spine pins also determine the location of the reef fish transects. Rugosity is measured along the same random 10 meter transects that are used for video monitoring.



### CRAMP site markers (pins).

The installation of markers on the reef is an essential part of the CRAMP monitoring protocol. We must be able to return to the exact location each and every time in order to detect changes to a degree that is pertinent to managers

and scientists alike. The CRAMP monitoring network is limited to 30 sites. With the exception of another site to be installed in the Waikiki area in year-three, and possible inclusion of current or proposed MPA sites, it is unlikely that additional sites will be needed. In future years these sites will be resurveyed annually. The marker pins are inert Type 360 stainless steel and do not corrode. Use of standard steel "reinforcing bar" was avoided due to possible stimulation of algae growth by the iron. Iron pins must also be replaced frequently due to corrosion, a process that can disturb the surrounding corals.

All CRAMP markers have been installed under permit from the agencies responsible for the resource. Appropriate oversight by management agencies has been in place since the initiation of the program.

### **Description and fabrication of the pins:**

The pins used to permanently mark the CRAMP survey sites are made from 'Grade 316' stainless steel all-thread, 3/8-inch diameter rod. The material is available in 6-foot lengths from most major hardware or steel suppliers. Cost per 6-foot length in Hawaii varies from about \$11.00 per unit to \$26.00 per unit, depending on the number of units ordered, if the vendor has them on hand or must special order them, and other vagaries of retail or wholesale purchase. The six-foot rods are cut into the smaller lengths that are appropriate to the substrate in which the installation will take place. The CRAMP installation team uses a range of rod lengths (of 9", 12", 18" and 24"). The hardness and depth of the substrate can vary over a range from loosely cemented carbonate fragments to basalt, necessitating the use of different length rods. Threaded rod is used because the rough threaded surface holds well when driven into rock crevices or other hard substrate. The two-part ceramic underwater epoxy used to hold the rod bonds well to a threaded rod. If epoxy putty is also needed to hold a pin in place, a Z-spar brand marine two-part epoxy putty is used. The epoxy materials are inert and soon are overgrown with the flora and fauna of the reef.

Cutting of the stainless rod is done in the machine shop at the Hawaii Institute of Marine Biology by one of the team members experienced in the use of the necessary equipment. The rods are cut with a metal cutting blade on a radial arm saw with a miter box. One end of each final rod is cut blunt/flat and the other end at a 45-degree angle (to expedite penetration of the reef substrate with minimum damage to the environment). Because the cutting process can cause the all-thread rods to develop sharp burrs, each cut rod is individually inspected at both ends and polished on a grinder as necessary. Safety considerations attendant to the cutting and polishing of the rods do not add materially to the cost of the operation. The most important safety measure is the undivided attention of the individual responsible for the cutting and preparation of the rods. The safety equipment involved is simple: gloves, safety glasses, covered-toe shoes, long-sleeved shirt with tight or taped cuffs so there is nothing hanging loose around the hands or arms.

### **Photoquadrats:**

Fixed photo-quadrats are used in order to examine trends of individual organisms with regards to growth, recruitment and mortality. Five haphazardly selected photo-quadrats at each depth contour are established with 4 pins at each corner to ensure accurate repositioning of the frame.

The frame is constructed of PVC plastic tubing and designed to hold a 35 mm Nikonos V camera system with two SB105 strobes (master/slave) in a rigid array. The frame is designed to photograph 0.25 square meters of the substrate at a height of 0.50 m from the bottom. Sampling is scheduled once a year at each site along with the digital video surveys. One roll of 35 mm film is used to capture 5 photo-quadrats at each depth with 2 exposures per photo-quadrat. Standard f-stop photo bracketing is used to assure a minimum of one photo with correct exposure for subsequent analysis. The resulting 35mm slides are scanned at high resolution (1200DPI) with a Nikon Scan to convert the positive slide images to digital format. Images are written to a CD-ROM for archiving and later analysis. The corals, different substrate types, and other sessile organisms within these digital images are traced and digitized into polygons for two-dimensional estimates of aerial coverage using SigmaScan or Scion Image programs. Aerial coverage of the polygons is computed for each object, organism, or substrate type, and compared with prior photos of the same site. Scion Image writes a text file that is readily available for a variety of programs. The resulting text file is imported into MS-Excel for proofreading. After proofreading, the data file is imported into MS-Access for incorporation into the CRAMP database. Output from Access is imported into Statistica for statistical analysis using an ANOVA repeated measures design with 2D aerial coverage of the substrate types as the dependent variable.

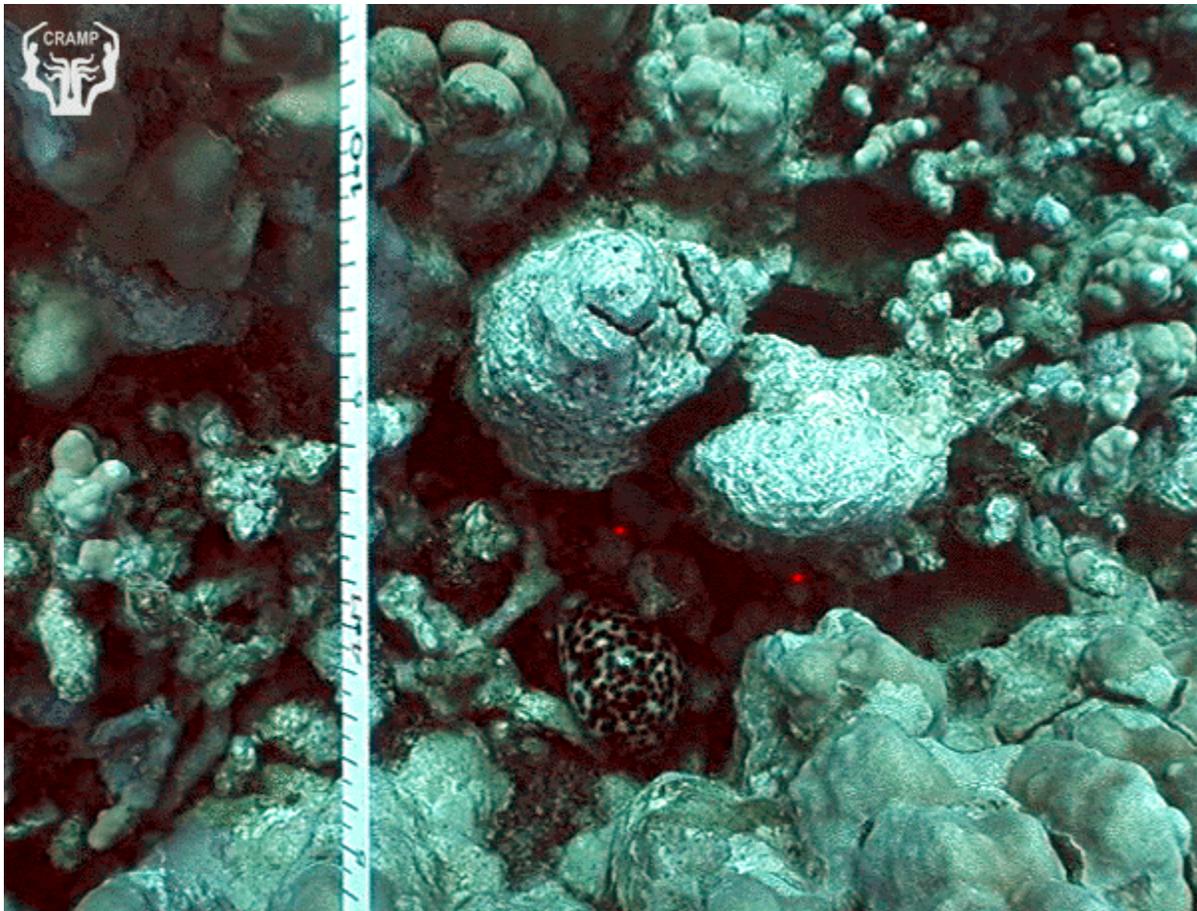
### **Video Transect Method:**

#### **Field Recording**

Video transect data are collected using a Sony DCR-TRV900 Mini DV camcorder enclosed in an Amphibico VHDB0900 Dive Buddy Housing. During early 2000, a Quest Aqua-Lite dual head U/W video lighting system with 35watt bulbs was added. The lighting system enhanced feature detection and allowed true-color data collection at depth.

The sequence of data collection in the field is as follows. While on the surface, the diver videotapes the landmark "line-ups" used to locate the site. These serve to identify the tape if there is any question of proper labeling. Also, the images can be frame-grabbed and subsequently printed and laminated for use when relocating the site. In many cases the use of landmarks is faster and more convenient than using the GPS position to relocate the transect site. The

diver then goes to the bottom and videotapes a full 360-degree panorama of the site as part of the permanent video record. The diver proceeds to the start of the first 10 m transect and records the transect number on the video through use of hand signals in front of the camera (number of fingers representing transect no.). The videographer then moves slowly (4 min per transect) along the 10 m transect while videotaping the bottom at a distance of 0.5 m. Initially a rod attached to the camera was used to insure proper distance from the bottom. This has been replaced with two small underwater lasers that converge at 0.5 m, allowing the videographer to hold the distance constant by keeping the two red laser dots overlapped at the point of convergence (see photo below). Each of the 10 transects within the 100 meter by three meter corridor is recorded in this manner. One digital videotape (1 hour tape) is used to capture 10 transects.



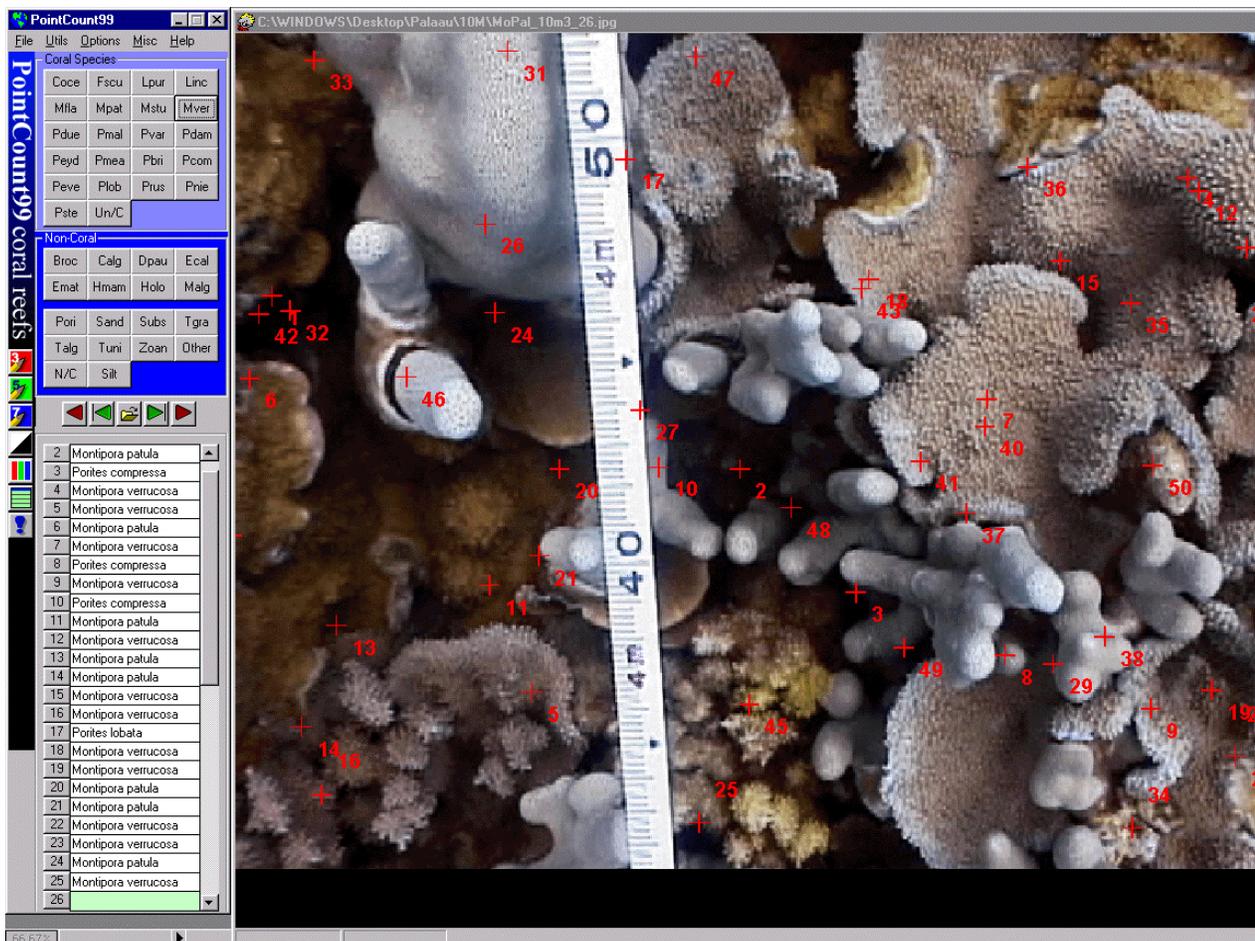
Note the two small laser dots in the center of the image above the tiger cowry. When these dots overlap (converge) the camera is 0.5 m above the substratum, allowing the videographer to maintain the proper distance above the substrate while videotaping along the transect line.

## Video Recordings - Laboratory Data Analysis

Each transect is 10 m in length. Twenty randomly selected, non-overlapping video frames are selected and processed using PointCount99 software to develop estimates for coral and substrate types. The statistical data analysis includes a repeated measures ANOVA design with nesting of transects in depth, where frames per transect are treated as sub-samples along a transect.

### Detailed Video Analysis Protocol:

The videotape is played back on a computer using PhotoShop with the plug-in Photo DV for frame grabbing. Each transect's video consists of approximately 7500 to 9000 frames. From these 7500 - 9000 sequential overlapping frames, a subset of 45 to 60 randomly selected frames are captured. These sequential frames have approximately 40 to 50% overlap, and when viewed edge-to-edge, form a complete photographic representation of the entire 10 m transect. From these 45 to 60 images, twenty randomly selected non-overlapping frames per transect are captured for analysis with PointCount99.



PointCount99 program displaying a frame with random points (right) and species ID list (left).

All frame-grabbed images are temporarily captured onto the hard disk in JPEG file format and subsequently written to CD-ROM for analysis and archiving. Each of these individual frames is projected on the screen within PointCount99, and 50 randomly located points are overlaid on this image on the screen (see photo above). The observer records the proper category under each of the 50 points. PointCount99 writes a Comma Separated Value (CSV) file that is generic text and readily available for a variety of programs. This CSV file is imported into MS-Excel for proofreading. After proofreading the CSV file is imported into MS-Access for incorporation and archiving in the CRAMP database.

## **Site Survey Protocol**

Two types of protocol have been developed: Monitoring Protocol and Assessment Protocol. The Assessment Protocol is simply an abbreviated version of the Monitoring Protocol. The Assessment Protocol is a rapid quantitative method that is most useful for describing spatial relationships. The Assessment Protocol lacks the statistical power of the Monitoring Protocol to detect change over time in the benthos. The Assessment Protocol is a more cost-effective method for answering certain questions on the status of coral reefs.

### **Monitoring Protocol - General Description**

Installing the fixed monitoring sites is a process that was generally completed by a team of six divers during a single dive. All primary sites were completed during year 2 of CRAMP. The initial monitoring of a given site was generally initiated within a few days after the permanent site was installed. Upon reaching an established monitoring site a number of tasks must be performed. CRAMP generally surveys two depths (3 m and 10 m) at one site per day with a team of 6 divers. The deeper site is surveyed in the morning, the shallow site in the afternoon after a proper surface interval. The beginning of the transect is located by visual lineups and/or GPS by skin divers and marked with a dive flag to alert boaters of our presence and enable quick site location by the divers. Subsequent SCUBA teams entering the water take materials needed for the survey (spooled transect tapes, rugosity chain, video camera, photo-quadrat apparatus, extra marker pins, etc) and deposit the material near the start of the transect for use by the teams during the dive.

The first SCUBA team to enter the water consists of two divers: the person doing the fish survey and a back-up diver who stays within visual range and photographs the fixed photo-quadrats as the fish survey proceeds. Estimates of fish species richness, abundance, and biomass are taken before the benthic transect lines are laid out so as to sample a relatively undisturbed habitat. The standard CRAMP fish transect is taken along a depth contour within the CRAMP grid of benthic transects, and consists of four, 5x25m transects that

are separated by 5m. The scientist doing the fish survey counts fish while deploying a 25 m line behind them. As the survey proceeds, two more SCUBA divers enter the water. One of the pair starts videotaping the replicate benthic transects while the second deploys the transect tapes and records species information on the corals/algae located along each transect for later reference. The third team of two divers follows the video transect team and measure rugosity under the replicate transects. Upon completion of the fish transect, the first dive team completes the photo-quadrats. As other teams complete their work they return to the start of the transect and begin taking up the transect tapes.

During the survey, various divers complete additional functions. These include taking sediment samples, stabilizing or replacing loose transect pins, routine photography of organisms, description of habitats, making algae collections, and various other activities.

The same procedure is carried out at the shallow site during the afternoon. In addition, at various times of the day (depending on time availability) two members of the group will skin dive with a dive flag and water proof GPS unit while describing and recording habitat distribution throughout the study site for later mapping efforts.

### **Assessment Protocol - General Description**

This method does not involve placement of permanent markers, does not utilize photo-quadrats and involves fewer benthic transects.

The CRAMP Assessment Protocol is based on the CRAMP monitoring protocol and will be utilized to broaden coastal coverage during the coming years. The assessment protocol is designed to produce quantitative spatial data that is consistent and comparable to data taken at the permanent monitoring sites. The assessment program expands our ability to describe spatial distributions of Hawaiian reef organisms in relation to various environmental factors. However, the assessment protocol requires less than a tenth of the human effort and cost per site. Considerable time saving is achieved because no permanent transect markers are needed and no permanent photo-quadrats are installed. Assessment data can be used with monitoring data for spatial comparisons, but the benthic assessment data does not have the statistical power needed to establish temporal change with the degree of precision involved in the monitoring effort. The reef fish sampling method is identical to the monitoring method, but the benthic sampling effort is reduced to a level that only has sufficient power to detect habitat differences between and among sites, but not change over time. The method requires the use of two divers to conduct the full survey (fish, benthic video recording, rugosity measurement, sediment and observations) in a single dive. In contrast, establishing the monitoring sites took a team of 6 divers multiple dives to install and conduct the initial monitoring

of the site. Multiple two-diver teams can operate from the same boat simultaneously where assessment sites are close together. Data entry time for the assessment method is reduced to less than 4 person hours per site for the assessment method compared to more than 20 person hours for the monitoring sites. The monitoring site protocol must have sufficient statistical power to detect a less than 10% change in coral cover between samplings. The assessment protocol only requires sufficient statistical power to allow quantitative description of a given habitat.

1. Selection of location for assessments is an ongoing collaborative effort between all the agencies involved in CRAMP (DAR, UH, NMFS, NOAA, ect...) with particular attention placed on the needs of those managing the resource. Precise location of the assessment site is determined using habitat maps and other information to develop the experimental design. Latitude and longitude are determined for each site to be assessed and entered as waypoints into the GPS.

2. A field team consisting of 2 divers navigates to waypoint using GPS, marks the location with a lead weight and float. Divers descend together. Diver 1 carries two 50 m transect lines, a 10-m line and 1 rugosity chain. Diver 1 leaves this equipment at the beginning of the transect corridor and begins fish transect starting at the marked waypoint and movies along a depth contour recording compass heading. The fish count method is identical to that used for the monitoring method. Diver 2 carries digital video system, rugosity chain and one 10 m transect line. As diver 1 lays out transect line behind themselves while collection fishes data, diver 2 video records the general environment through the full 360-degree panorama at the transect corridor starting point. Diver 2 then begins to video 10 m transects running parallel to the fishes transect line, following a pre-established random pattern at various distances to the right and left of this line. Diver 2 also runs rugosity on the first of the 10-m transects. Diver 1 completes the fish transect and doubles back along the transect line to assists Diver 2 in completion of the rugosity, sediment sampling and general observations. This produces a data set similar to the monitoring sites but with only half the number of transects and no photoquads.

3. Manual entry for the fishes data takes less than one hour; the same amount of time as needed for fish data entry taken at monitoring sites. The major time saving for the assessment protocol is on the benthic sampling data. No permanent photo-quadrats are involved. Only five transects are videotaped, and only 10 frames per transect and 25 points per frame are sampled with Point Count. This procedure will require less than 4 hours of analysis time per site.

The Assessment Protocol has been tested and will be used increasingly to expand the spatial data in reference to the monitoring sites during year 3.

### Section 3. Benthic Monitoring Results

During the first year our primary objectives were to develop a standardized sampling protocol, establish and collect baseline data from across the state of Hawaii, and initiate a procedure for analyzing images that would allow spatial and temporal comparisons of substrate cover. This objective was met. The task of completing the baseline survey, digitizing the data and completing initial analysis was completed during year two. By the end of year two we were well into the second cycle of monitoring. This section will focus the results of the first cycle of monitoring.

#### Benthic data - General

#### Coral -3 m sites, spatial summary

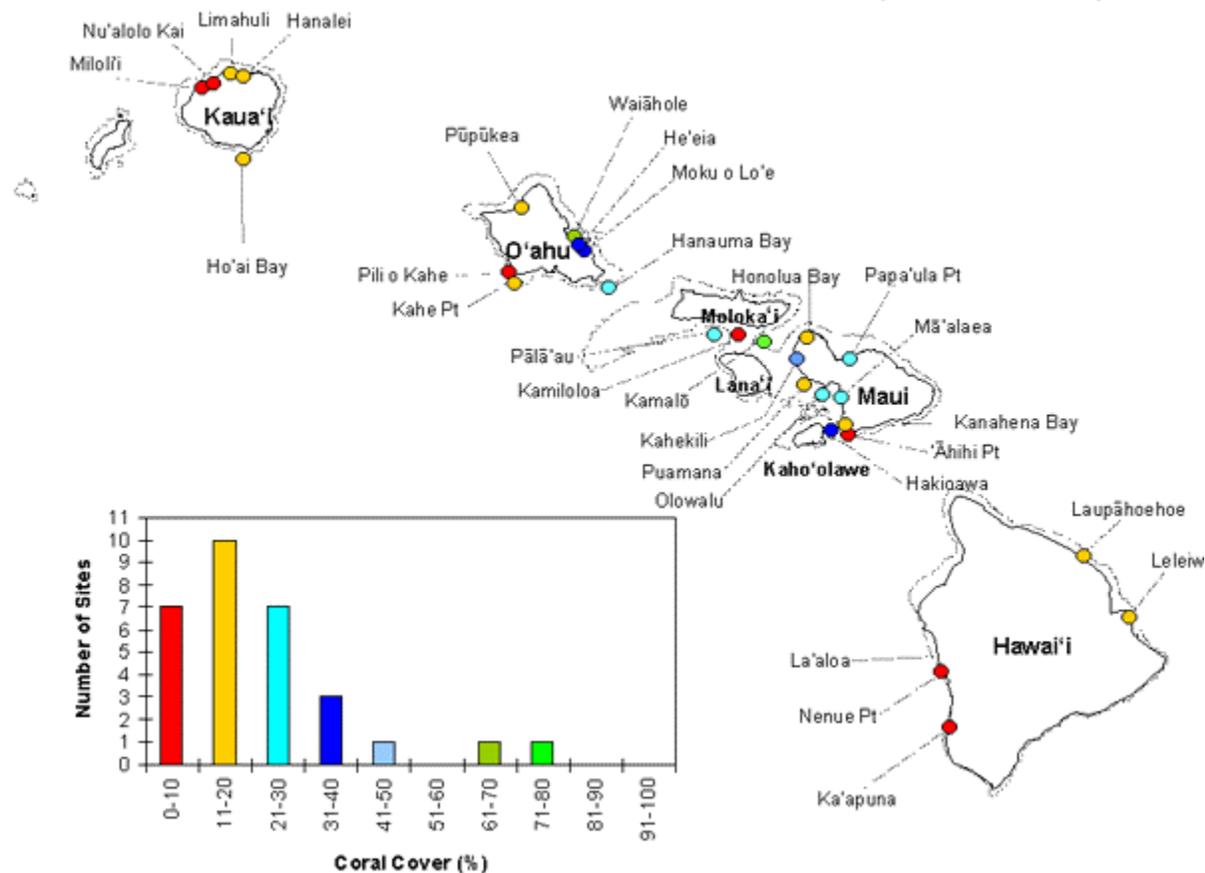


Figure 3-1. Data summary - shallow (3m) sites.

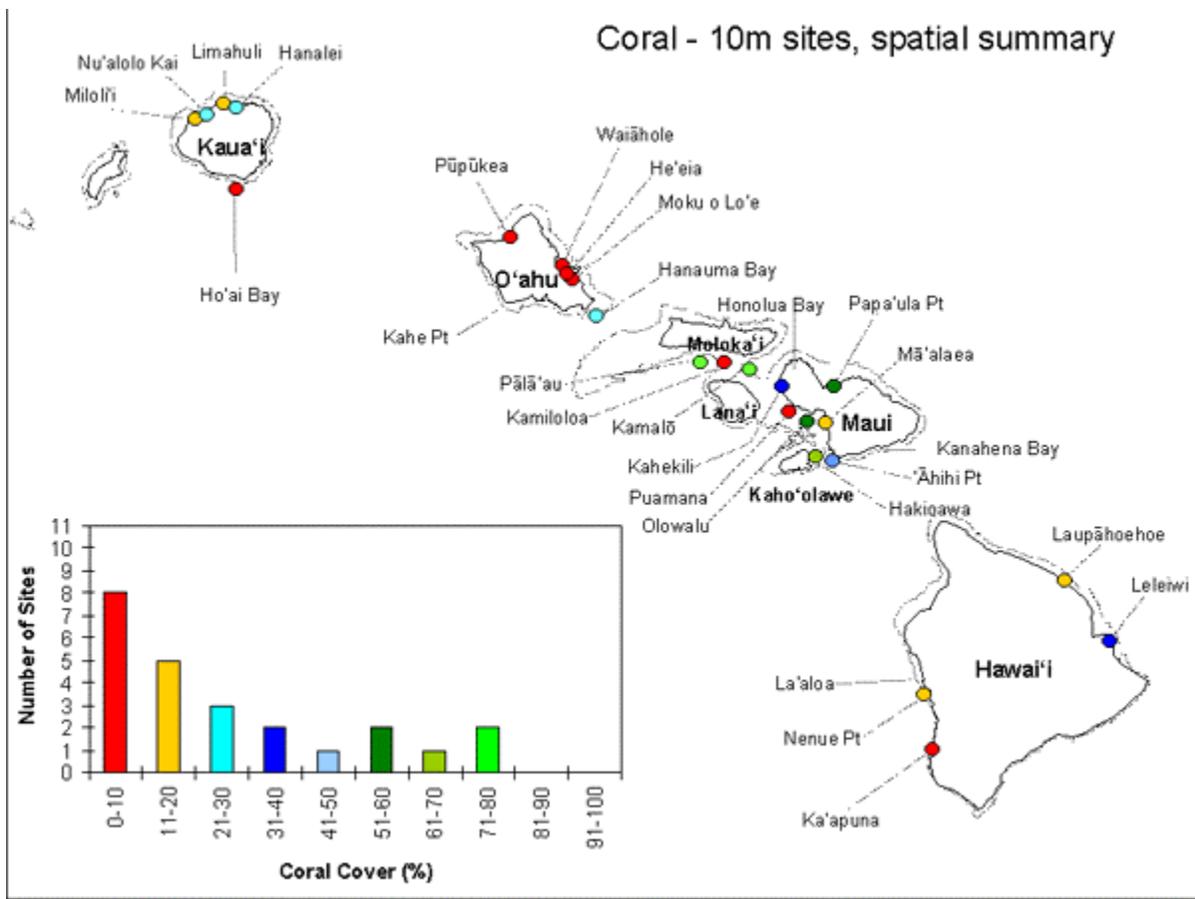


Figure 3-2. Data summary - deep (10m) sites.

Coral data from 28 CRAMP sites are summarized in Figures 3-1 (shallow sites) and 3-2 (deep sites). The data summarized in these two figures consist of 560 transects, with each transect being analyzed using Point Count with 20 frames per transect and 50 points per frame to yield over 500,000 data points. This survey is the most thorough, accurate and reproducible quantitative assessment of coral coverage in the main Hawaiian Islands to date. These data will provide a powerful baseline, which will be used in the future to quantitatively assess environmental trends on Hawaiian coral reefs, and will serve as an essential tool in site selection of future MPA's, ect....

**Overall coral coverage.**

Average coverage for all CRAMP sites with both depths combined (Figure 3-3) is approximately 23%. All transects are positioned on hard substratum. The sites were selected over a representative cross section of Hawaiian coastal environments, so this is probably a reasonable estimate for coral cover on hard substratum over the entire main Hawaiian Islands in the depth range sampled. Published literature values generally show coverage estimates higher (mean of the previously published values is approximately 35-40% cover). Previous studies often targeted high coral coverage

areas rather than selecting a good cross section of reefs throughout the state. Further Point Count yields lower coverage values than most other methods because it forces the observer to count only living tissue. An area that visually appears to be 100% live coral (no room for more colonies) can yield less than 90% cover when analyzed by the Point Count method).

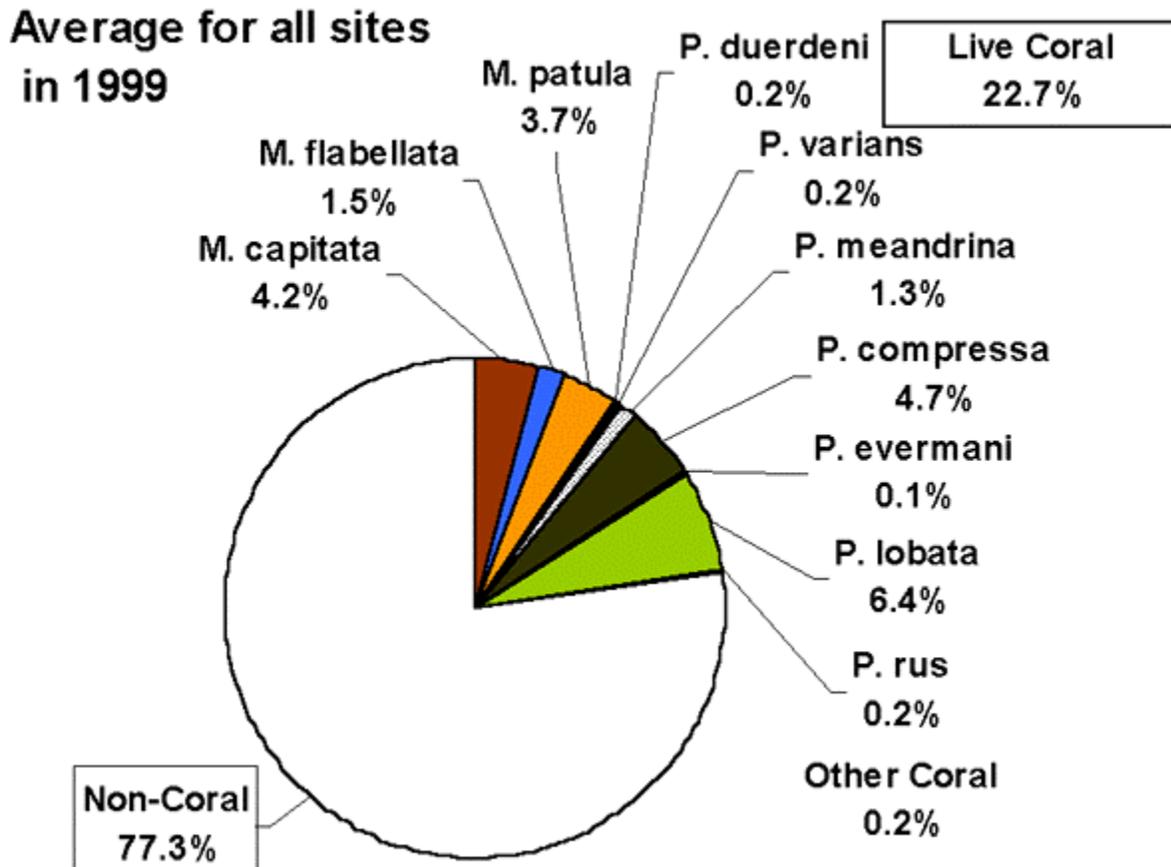


Figure 3-3. Summary of all data from all sites and depths for mean coral coverage.

### Species composition.

The reefs of Hawaii are best described as "*Porites* reefs", being overwhelmingly dominated by massive and encrusting *Porites lobata* and branched *Porites compressa*. *Montipora capitata* (= *Montipora verrucosa*) and *Montipora patula* (= *Montipora verrilli*) also account for a significant amount of the coverage. *Pocillopora meandrina* is common in shallow turbulent environments.

### Other observations:

1. A latitudinal gradient is not evident in these data. Differences in coral cover are controlled primarily by local variation in dominant environmental factors such as wave energy, bathymetry, watershed influences, substrate type, etc.
2. In general, coastal sites with high wave exposure (e.g. Pupukea, Hoai Bay) have the

lowest cover while bays and wave-protected coastal areas (e.g. south Molokai) have the highest coral cover.

3. The most significant anomaly occurs off south Molokai. Coral cover along this coast is extremely high. There are three CRAMP sites along this section of coast. Two of these three sites (Palaau and Kamalo) have the highest coral cover in the statewide monitoring network. A large zone of damaged reef occurs between these two sites, in the middle portion of the south Molokai coastline. Within this damaged zone is the third CRAMP site (Kamiloloa), which has the lowest coral coverage within the statewide network.

### Other Analyses

Detrended correspondence analysis (as described in section 4) of the initial CRAMP data is yielding some valuable spatial insights. If we examine the relationship between marine protected area status (degree of protection) and coral community structure we find no strong relationship between these two parameters (Figure 3-4).

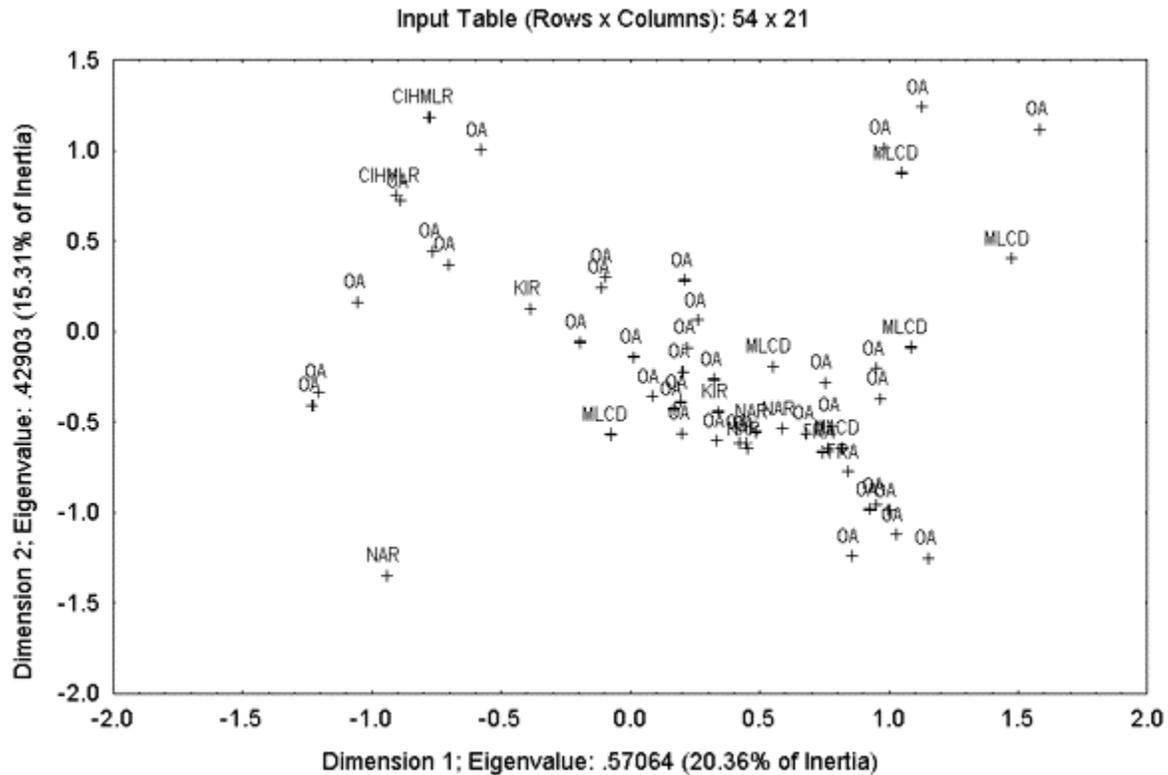


Figure 3-4. Relationship between benthic community and degree of legal protection. OA = Open Access, MLCD = Marine Life Conservation District, NAR = natural Area Reserve, KIR = Kahoolawe Island Reserve, FRA = Fisheries Replenishment Area, CIHML = Coconut Island Hawaii Marine Laboratory Reserve.

The result of the above analysis provides several important insights. Unlike above, the same analysis for fish communities data (see Section 4) yielded strong patterns. The benthic communities show no such relationship with degree of protection

(Figure 3-4). Corals are protected from harvest throughout the state by law. Therefore MPA legal status may not be related to benthic coral community structure unless there is a very strong interaction between the fish and benthos. Further, these results confirm that we have chosen a fairly good cross section of reef environments because we are not getting any strong clustering of a particular MPA group or OA group. Essentially the benthic community composition represents habitat type.

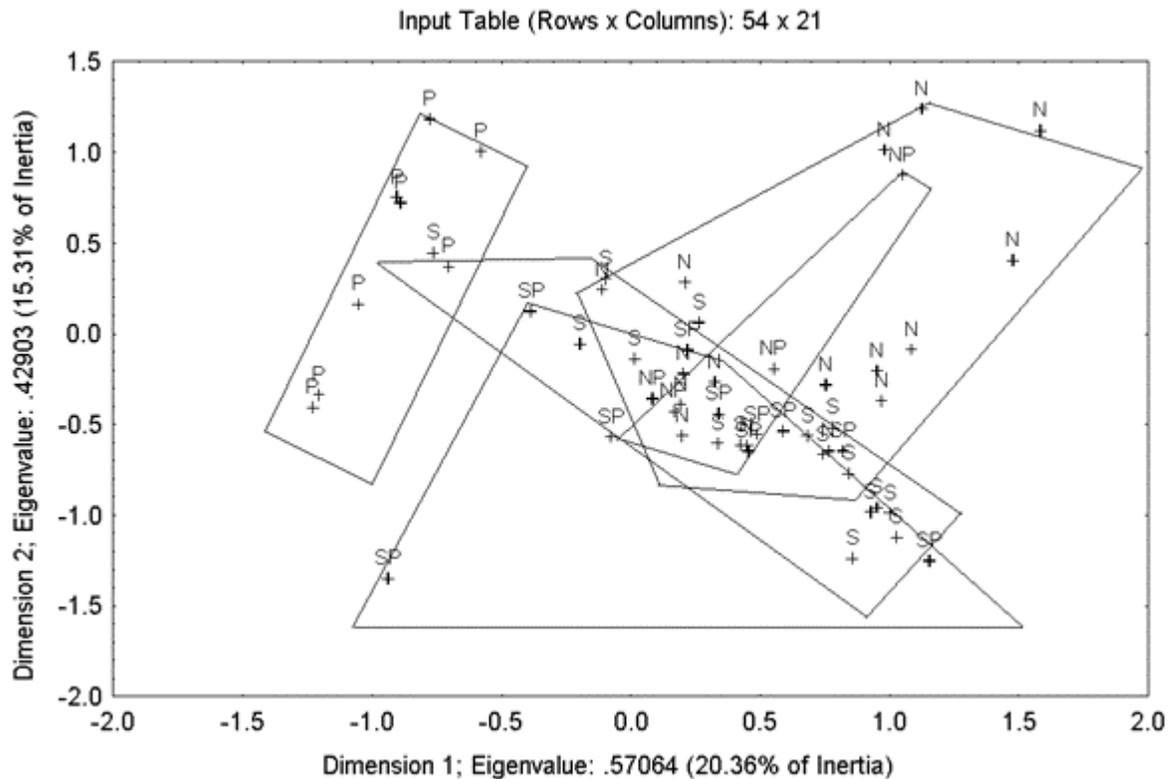


Figure 3-5. Correspondence analysis of the relationship between benthic community composition and wave exposure. N = North open coastline, S = South open coastline, NP = north exposure, semi protected, SP = south exposure, semi protected, P = highly sheltered (protected from waves).

The pattern in figure 3-5 demonstrates a strong relationship between benthic community type and wave exposure. Wave energy is a dominant forcing function that shapes our Hawaiian benthic communities. This pattern emerged even though we were using a very crude index of wave energy for the analysis. We presently are developing a quantitative database on the wave energy at each site using daily reported wave height and direction generated by the WAM model of the U. S. Naval Oceanographic Office. Future work based on this new quantitative wave data will refine our first order analysis.

## Section 4. Reef Fish Monitoring Results.

Coral reefs have always been an important component of human existence in Hawaii, as they provide habitat and other resources for fish and invertebrates that are popular for human consumption and the aquarium trade. These reefs once provided the majority of the protein for the Hawaiian people, and today consumptive uses of reef resources include subsistence, commercial, and recreational activities. Coastal fisheries are facing severe depletion and overexploitation on a global scale (NRC 1999) and Hawaii is no exception. This decline in abundance, particularly around the more populated areas of the state, is likely the cumulative result of years of chronic overfishing (Shomura 1986). A growing population who no longer recognize traditional conservation practices has greatly contributed to the decline in inshore fisheries (Lowe 1996).

Fisheries catch statistics are unreliable owing to under-reporting by commercial fishers and a large resident recreational and subsistence fishing population whose catch goes unreported. Hawai'i is one of the few coastal states that does not require a saltwater recreational fishing license. The nearshore recreational catch is likely equal to or greater than the nearshore commercial fisheries catch, and these recreational fishers take more species using a wider range of fishing gear (Everson 1994, Friedlander et al. 1995, Friedlander and Parrish 1997). Hawai'i provides most of the ornamental fish and invertebrates caught in the USA, because quality is high and the rare endemic species are highly prized (Friedlander in press). There are no regulations limiting the size, number and collecting season for most species and the full impacts may not be felt yet.

Current management strategies are directed at restrictions or control of fishing, and are often focused on particular species or small groups of species. These strategies do not address the habitat associated with these species and therefore may not be appropriate for the long-term sustainability of these resources. Diversity, quality, and extent of habitat are among the most important environmental determinants of distribution, abundance, and diversity for coral reef fishes. Identification and conservation of fisheries habitat is an important consideration for sustaining fisheries production. Defining essential fish habitat has theoretical value in helping to explain the organization of fish assemblages and practical applications in designing reserve areas (Friedlander and Parrish 1998a). Reef fish assemblages can be influenced by the physical structure of the associated reef. Habitat complexity provides refuges and barriers that fragment the area, resulting in more heterogeneous assemblages (Sebens 1991). The variety of microhabitats available on the coral reef provides shelter from predation. Habitats with low spatial relief and limited shelter are often associated with low standing stocks for many fish species while highly complex habitats harbor high fish biomass (Friedlander and Parrish 1998a, Friedlander in press). A relationship between fish size and reef complexity may suggest the importance of shelter as a refuge for

certain fishes in avoiding predation. Many coral reef fishes show considerable site fidelity and associate with particular habitats of rather limited size.

The reauthorization of the Magnuson-Stevens Fisheries Conservation and Management Act requires incorporating the concept of "essential fish habitat" in Fishery Management Plans (Schmitten 1996). This means that all fisheries management plans must describe and identify essential fish habitat, identify and attempt to minimize adverse impacts to essential fish habitat, and develop measures to conserve and enhance essential fish habitat. Protecting essential fish habitat is a central element of the coral reef fishery management plan currently under development by the Western Regional Fishery Management Council (WPRFMC).

Standing stock of reef fishes can also vary as a result of anthropogenic effects (e.g., fishing pressure, pollution, loss of nursery habitat). High levels of fishing pressure are expected to affect the abundance and distribution of reef fishes. Mean standing stock of biomass of fishes on shallow unfished reefs at remote uninhabited locations in the Northwestern Hawaiian Islands was about twice as high as means reported from shallow fished reefs in the Main Hawaiian Islands (DeMartini et al. 1996). Fish biomass estimates throughout Hawaii varied greatly depending on location and habitat with the lowest biomass estimates recorded around the island of Oahu (Friedlander 1996). Marine Life Conservation Districts (MLCD) tended to have higher standing stock of reef fish compared to adjacent areas. The difference in biomass among these locations may reflect the heavy fishing pressure on reef fishes in the MHI compared to the NWHI (Grigg 1994; DeMartini et al. 1994). Growth overfishing of a number of valued species has been identified throughout the Main Hawaiian Islands, particularly in more populated areas (Friedlander et al. 1995, Friedlander and Parrish 1997, Friedlander and Ziemann in press).

Recent scientific and policy activities indicate a new interest in marine reserves, a traditional management technique of closing an area to fishing and protecting it from other major human impacts (Sladek Nowlis and Friedlander in press). Primarily due to the failure of conventional management practices to promote sustainable fisheries, marine protected areas (MPAs) have become an increasingly important tool for managing marine fisheries in both temperate and tropical seas. Closing areas to fishing is far from a new idea in the management of marine resources. The traditional system in Hawaii emphasized social and cultural controls on fishing with a code of conduct that was strictly enforced. Marine resource management was based on identification of the specific times and places where fishing could occur so it would not disrupt basic processes and habitats of important food resources, rather than on quotas (Friedlander *et al.*, submitted).

Marine protected areas can protect habitats and biological communities from fishing and other extractive uses that can lead to loss of biodiversity and changes in species interaction (Dayton et al., 1995; Boehlert, 1996; Hixon and Carr, 1997). The success of establishing closed areas and marine reserves has been well documented (Pauly, 1979; Pitcher and Hart, 1982; Gulland, 1988; Russ, 1991; Roberts and Polunin,

1991, 1993; Roberts, 1995; Bohnsack, 1996). Marine reserves or harvest refugia are also an effective management strategy that can help protect and maintain the complexity and quality of fish habitat as well as mitigate the direct effects of fishing (Bohnsack, 1996; Bohnsack and Ault, 1996; Auster and Shackell, 1997; Yoklavich, 1998). By protecting habitat and their associated fish populations, reserves can provide a precautionary approach to management that reduces the risks against overexploitation of fish stocks (Murray et al. 1999).

There are a variety of marine areas in Hawaii that have some type of protected status. These include Marine Life Conservation Districts (MLCDs), Fisheries Management Areas (FMAs), a Marine Laboratory Refuge, Natural Area Reserves (NARs), National Wildlife Refuges, and the Hawaiian Islands Humpback Whale Sanctuary (Clark and Gulko, 1999). For various reasons, some of these areas provide little to no protection from consumptive practices. In addition, certain MLCDs are very popular tourist destinations and experience intensive non-consumptive impacts. Results from a select group of MLCDs in Hawaii point to the fact that no-take marine protected areas with good habitat diversity and complexity can have a positive effect on fish standing stock (Friedlander in press). Despite their proven effectiveness, less than 1/3 of one percent (0.3%) of all coral reef habitats around the main Hawaiian Islands has complete no-take marine protected area status (Gulko et al. 2000). If existing as well as future protective areas are to be effective, they must include the diversity of habitats necessary to accommodate a wide range of fish species and life histories.

It is not entirely clear what specific characteristics of reefs are most attractive and how these habitat characteristics are quantitatively related to the abundance, distribution, and community composition of the fish inhabitants. Therefore, it is difficult for managers to predict the quantity and character of the fish assemblage that will be associated with particular reef habitats. This difficulty limits managers' ability to prioritize habitats for protection or enhancement, to develop effective artificial habitats, and to select appropriate areas as marine reserves. Limited information exists on the distributional differences of fishes at large scales around Hawaii. A landscape perspective is critical to enhance our knowledge of marine communities. Most studies of the association between fish assemblages and their supporting coral reef habitat have been conducted on individual reefs or small reef tracts or embayments. Management units are typically on the scale of an island or the entire state and resource evaluation should therefore be conducted on a similar scale. Resource evaluations that are stratified by habitat will lead to more accurate, efficient, and statistically sound results. This study evaluates the relationship between fish assemblages and their associated habitat on a scale consistent with the patterns of both the resources and their users. The purpose is to determine the relative importance of particular reef characteristics and to permit prediction of fish populations from practical measurements of reef characteristics.

## METHODS

### Study Sites

Designated research sites were chosen from throughout the State of Hawaii with input from managers and scientists (also see Section 1). Research sites include areas of primary concern originally designated by the Hawaii Department of Land and Natural Resources, Division of Aquatic Resources. Sites were selected on Kauai, Oahu, Maui, Kaho`olawe, and Hawaii with regard to factors such as type of environmental stress, presence of historical data, degree of environmental degradation and/or recovery, level of protection from fishing, and degree of wave exposure.

### Sampling Methodology

Abundance of fishes on hard substrate was assessed using standard underwater visual belt transect survey methods (Brock, 1954; Brock, 1982). A SCUBA diver swam each transect at a constant speed (~ 15 min/transect), identified to the lowest possible taxon all fishes visible within 2.5 m to either side of the centerline (125 m<sup>2</sup> transect area). Transects were located along the center line of previously established CRAMP survey grids. Four 25 x 5 m transects, separated by 5 m gaps, were conducted at each location (also see Section 2 Methodology). Total length (TL) of fish was estimated to the nearest centimeter. Length estimates of fishes from visual censuses were converted to weight using the following length-weight conversion:  $W = aSL^b$  - the parameters a and b are constants for the allometric growth equation where SL is standard length in mm and W in grams. Total length was converted to standard length (SL) by multiplying by 0.80. Length-weight parameters were available for 150 species commonly observed on visual fish transects in Hawaii (Friedlander et al. 1997). This was supplemented by using information from other published and web-based sources. In the case where length-weight information did not exist for a given species, the parameters from a congener species were used.

### Observer Variability

To compare observer variability, two divers swam parallel 25 x 5 m transects in similar habitat separated by 10 m on the forereef at Ho'ai Bay, Kaua'i. The areas consisted of basalt boulder habitat in ca. 25' of water. Visibility on average was greater than 50'. There were no significant differences in number of species ( $t = 0.206$ ,  $P = 0.839$ ), number of individuals ( $t = 1.800$ ,  $P = 0.086$ ), or biomass ( $t = 0.133$ ,  $P = 0.895$ ) observed between the two divers.

### Length Estimate Comparison

Biomass analysis is an important consideration both ecologically and from a fisheries management perspective. In Hawaii, where fishers target a wide variety of reef fishes, most of the biomass of fishes observed on the reef is exploitable. To examine the accuracy of these biomass estimates, we compared observer length

estimates to those of fish models. This study was also conducted on the forereef at Ho'ai Bay, Kaua'i.

Fish models were created from scanned photographs of a variety of reef fishes that exhibiting a wide range of body shaped and color patterns. These included members of the following families: parrotfishes (Scaridae), wrasses (Labridae), surgeonfishes (Acanthuridae), damselfishes (Pomacentridae), and goatfishes (Mullidae). The scanned images were imported into an image-processing program to create left and right-sided mirror images of each fish. Several different sizes of each fish were created and printed on a color ink-jet printer. Left and right-sided mirror images of each fish were cut out and thermal laminated with a thin layer of foam placed between the two sides to create positive buoyancy. Snap swivels and monofilament line were attached to the ventral surface of each fish to allow for easy deployment and manipulation of fish position along the transect line.

Typical fish census transects were 25 x 5 m with the diver swimming down the center of the transect and estimating width 2.5 m to either side of the transect centerline. To estimate fish lengths, each diver swam along a transect line that was ca. 2.5 meters from a parallel transect line with attached fish models. On the first run, 17 fishes were haphazardly positioned along the fish model transect and the diver swam at a constant speed while estimating the standard length of each fish model. The diver then returned along the fish model transects and measured the actual standard length of each model. On the second run, six additional models were added and the location of all the existing models was haphazardly changed. The diver again estimated fish lengths and measured the actual lengths on the return swim. One additional run was conducted with all 23 fish models again being haphazardly changed along the transect.

The difference in the observed vs. the actual standard fish lengths was significantly different between observers and among trials (Table 1). Overall, mean length estimate differences for observer 1 (Mean = 0.702 cm, SEM = 0.185) were significantly lower ( $t = 4.420$ ,  $P < 0.001$ ) than for observer 2 (Mean = 1.853, SEM = 0.184; Table 2).

Table 1. Two-way ANOVA with observers and trials as fixed factors. The dependent variable in the model is the absolute difference in the observed vs. the actual standard length of each fish model.

Source of Variation	DF	SS	MS	F	P
Observer	1	40.642	40.642	19.534	<0.001
Trial run	2	51.767	25.884	12.440	<0.001
Observer x Trial	2	39.182	19.591	9.416	<0.001
Residual	119	247.592	2.081		
Total	124	369.392	2.979		

Table 2. Least square means for observers and samples.

Group	Mean	SEM
Observer 1	0.702	0.185
Observer 2	1.853	0.184
Trial 1	2.235	0.247
Trial 2	0.891	0.213
Trial 3	0.707	0.215

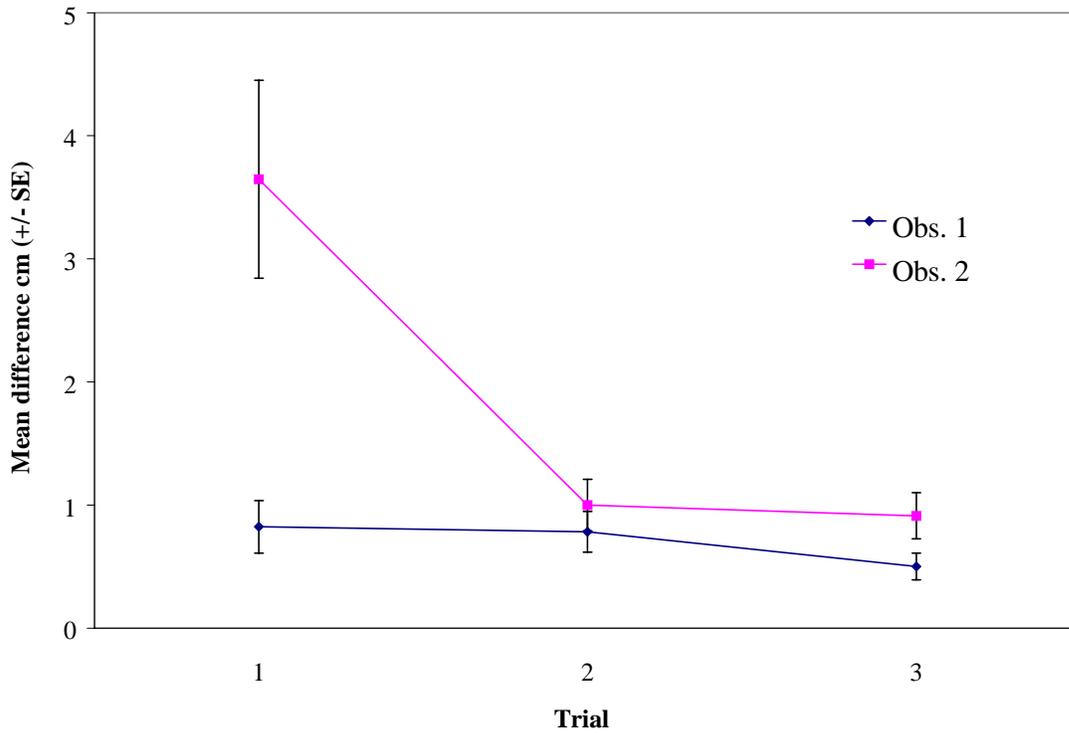
For both observers pooled, the mean difference in estimated vs. actual length was greatest for the first trial (2.235 cm) and became progressively lower with each subsequent run (trial 2 = 0.891 cm; trial 3 = 0.707 cm). The mean difference in estimated vs. actual length was not significantly different between trial 2 and 3 (Table 3). Observer 1 showed no significant difference in mean estimated length differences among the 3 trials (Table 3). The mean estimated vs. actual length difference for observer 2 after the first trial was 3.647 cm (SEM = 0.350). After the first trial, observer 2's estimated vs. actual length difference declined to 1.00 cm (SEM = 0.301) and showed no significant difference in mean estimated length difference between trial 2 and 3 (Table 3). After 3 trials, observer 1's mean estimate vs. actual fish lengths was 0.500 cm (SEM = 0.308) and observer 2's mean estimates vs. actual fish length was 0.913 cm (SEM = 0.301). Observer 1 and 2 differed significantly in their estimates vs. actual difference for trial 1 but these differences were not significant for the subsequent trials (Table 3).

Table 3. Comparison of fish length estimates for two observers All Pairwise Multiple Comparisons Procedures (Bonferroni t-test).

Comparison	Difference of Means	t	P	Results
Obs. 1 vs. Obs. 2	1.151	4.420	<0.001	Obs. 1 < Obs. 2
<b>Trials</b>				
Trial 1 vs. Trial 3	1.529	4.664	<0.001	
Trial 1 vs. Trial 2	1.344	4.120	<0.001	
Trial 2 vs. Trial 3	0.185	0.611	1.000	Trial 1 < Trial 2 = Trial 3
<b>Observer 1</b>				
Trial 1 vs. Trial 3	0.324	0.695	1.000	Trial 1 = Trial 2 = Trial 3
Trial 1 vs. Trial 2	0.041	0.089	1.000	
Trial 2 vs. Trial 3	0.283	0.657	1.000	
<b>Observer 2</b>				
Trial 1 vs. Trial 3	2.734	5.926	<0.001	Trial 3 = Trial 2 < Trial 1
Trial 1 vs. Trial 2	2.647	5.738	<0.001	
Trial 2 vs. Trial 3	0.087	0.204	1.000	
Observers within Trial 1	2.824	5.707	<0.001	Obs. 1 < Obs. 2
Observers within Trial 2	0.217	0.511	0.610	Obs. 2 = Obs. 2
Observers within Trial 3	0.413	0.960	0.339	Obs. 2 = Obs. 2

Observer 1 had extensive previous experience in estimating fish length and his estimates did not change significantly during the training period nor did his estimates differ much from the actual lengths (Figure 4-1). Observer 2 was relatively inexperienced at estimating fish lengths underwater, but after one trial his estimates were comparable to observer 1 and did not differ significantly from the actual lengths. This small experiment shows that with minimal training, divers can learn to estimate fish lengths underwater. Both observers obtained less than one cm accuracy in estimating actual fish length after only 2 trials. Re-calibration should be done on a periodic basis to insure that length estimates do not differ significantly from actual lengths.

Figure 4-1. Mean difference in length estimates for fish models at Ho'ai Bay, Kauai for two observers and three trials. Error bars are standard error of the mean.



## Statistical Analysis

Detrended correspondence analysis (DCA) was used to identify clusters of similar locations in ordination space. A matrix of sample units (44 locations) by fish species (mean number per location) was created for use in this analysis. This type of ordination results in an arrangement of samples of species in a low-dimensional space such that similar samples are in close proximity to one another (Gauch, 1982). In this DCA, habitat variables do not influence the ordination; rather, stations with similar assemblage structure cluster together (Greenfield and Johnson, 1990). Degree of wave exposure and level of protection from fishing were defined a priori and then overlaid on the station clusters created by DCA.

Species diversity was calculated from the Shannon-Weaver Diversity Index (Ludwig and Reynolds 1988):  $H' = \sum (p_i \ln p_i)$ , where  $p_i$  is the proportion of all individuals counted that were of species  $i$ . The evenness component of diversity was expressed as:  $J = H'/\ln(S)$ , where  $S$  is the total number of species present (Pielou, 1977).

Student t-tests were used to compare fish assemblage characteristics between depth strata and between areas protected from fishing and fished areas within Kaneohe Bay. One-Way ANOVA and Bonferroni Multiple Comparison Procedures were used to compare fish assemblage characteristics among sites with varying degrees of wave exposure. Kruskal-Wallis Rank Sum Test and Dunn's Multiple Comparison Procedures were used to compare fish assemblage characteristics among sites with different levels of protection from fishing.

## RESULTS

### Species Composition

The brown surgeonfish, (*Acanthurus nigrofuscus*), was the most dominant species over all study sites based on Index of Relative Dominance (Table 4). It occurred in 75% of all transects and accounted for more than 7% of the total fish biomass. This species was followed by the black surgeon (*Melichthys niger*), which accounted for over 11% of the total reef fish biomass but only occurred in 36% of the samples. Surgeonfishes accounted for five of the top ten species and herbivores overall comprised over 70% of the total reef fish biomass. This was followed by mobile invertebrate feeders (13%) and planktivores (9.7%). Piscivores were rare and accounted for only 3.8% of the total reef fish biomass.

Table 4. Top ten fish species overall at all 44 locations surveyed. Total number of transects = 175. Species are ordered by Index of Relative Dominance (IRD) = (frequency of occurrence x percent biomass) x 100.

Taxon Name	Common Name	Frequency of occurrence	Percent number	Percent biomass	IRD
<i>Acanthurus nigrofuscus</i>	Brown Surgeonfish	74.86%	10.68%	7.44%	5.57
<i>Melichthys niger</i>	Black Durgon	36.57%	2.65%	11.63%	4.25
<i>Ctenochaetus strigosus</i>	Goldring Surgeonfish	55.43%	6.98%	7.40%	4.10
<i>Thalassoma duperrey</i>	Saddle Wrasse	95.43%	13.45%	4.03%	3.84
<i>Naso lituratus</i>	Orangespine Surgeonfish	41.14%	1.27%	4.13%	1.70
<i>Acanthurus leucopareius</i>	Whitebar Surgeonfish	26.86%	1.38%	4.41%	1.19
<i>Abudefduf abdominalis</i>	Sargent Major	21.71%	5.57%	5.15%	1.12
<i>Acanthurus triostegus</i>	Convict Tang	27.43%	2.93%	3.23%	0.89
<i>Scarus rubroviolaceus</i>	Redlip Parrotfish	21.71%	0.24%	3.35%	0.73
<i>Stegastes fasciolatus</i>	Pacific Gregory	69.71%	3.40%	0.93%	0.65

### Depth Comparisons

There were no significant differences ( $P > 0.05$ ) in fish assemblage characteristics (e.g., number of species, number of individuals, biomass, diversity, and evenness) between shallow water locations (range 1-5 m) and deeper locations (range 6-13 m) for 44 locations surveyed around Kauai, Oahu, Maui, Kaho`olawe, and Hawaii (Table 5).

Despite no differences in some major fish assemblage characteristics, the composition of dominant species differed slightly between shallow and deep locations (Table 6). The brown surgeonfish, (*Acanthurus nigrofuscus*), was the most dominant species in the shallow sites but the fifth most dominant species at the deep locations. It accounted for 9.4% of the total fish biomass at the shallow sites and slightly less than 4% of the total biomass at the deep sites. The goldring surgeonfish (*Ctenochaetus strigosus*) was the most dominant species at the deep locations accounting for 10.7% of the total biomass while it ranked fourth and accounted for 5.5% of the total fish biomass at the shallow locations.

Table 5. Comparison of fish assemblage variables by depth strata. Shallow locations range from 1 to 5 m, deep locations range from 6 to 13 m. Statistical values for t-tests and associated probabilities at  $\alpha = 0.05$ . Biomass (kg)  $\ln(x + 1)$  transformed for statistical analysis.

Assemblage Characteristic	Deep (N = 20)	Shallow (N =24)	t	P
Species	17.99 (5.93)	18.94 (5.96)	0.532	0.598
Number	102.31 (53.15)	149.32 (101.65)	1.864	0.069
Biomass (kg)	10.44 (8.59)	15.50 (12.89)	0.762	0.450
Diversity	2.18 (0.43)	2.13 (0.33)	0.478	0.635
Evenness	0.78 (0.08)	0.74 (0.07)	1.694	0.098

Table 6. Top five fish species for shallow (N = 24, n = 95) and deep (N = 20, n = 80) locations. Species are ordered by Index of Relative Dominance (IRD) = (frequency of occurrence x percent biomass) x 100.

Shallow Locations	Common Name	Frequency of occurrence	Percent number	Percent biomass	IRD
<i>Acanthurus nigrofuscus</i>	Brown Surgeonfish	75.79%	12.78%	9.42%	7.14
<i>Melichthys niger</i>	Black Durgon	40.00%	2.75%	12.31%	4.92
<i>Thalassoma duperrey</i>	Saddle Wrasse	100.00%	14.71%	4.43%	4.43
<i>Ctenochaetus strigosus</i>	Goldring Surgeonfish	48.42%	4.87%	5.51%	2.67
<i>Abudefduf abdominalis</i>	Sergeant Major	23.16%	7.88%	7.40%	1.71
Deep Locations	Common Name	Frequency of occurrence	Percent number	Percent biomass	IRD
<i>Ctenochaetus strigosus</i>	Goldring Surgeonfish	63.75%	10.62%	10.70%	6.82
<i>Melichthys niger</i>	Black Durgon	32.50%	2.48%	10.43%	3.39
<i>Acanthurus leucopareius</i>	Whitebar Surgeonfish	30.00%	2.83%	10.01%	3.00
<i>Thalassoma duperrey</i>	Saddle Wrasse	90.00%	11.26%	3.33%	2.99
<i>Acanthurus nigrofuscus</i>	Brown Surgeonfish	73.75%	7.06%	3.98%	2.93

### Comparison of Wave Exposure among Locations

The degree of wave exposure is an important abiotic factor effecting the growth and development of coral reef communities in Hawaii. These abiotic factors can also have a profound influence on the structure of coral reef fish assemblages. Surf height and degree of wave exposure were negatively related to several measures of fish

assemblage organization in Hanalei Bay, Kauai (Friedlander and Parrish, 1998b). The inverse relationship of wave exposure with most fish assemblage variables is consistent with the idea that habitats protected from highest wave energies maintain larger populations with greater richness and evenness of species.

The 44 locations surveyed were categorized according to their degree of wave exposure. Categories included: locations exposed to north swells, north facing locations protected from swell, locations exposed to south swells, south facing locations protected from swell, and locations within Kaneohe Bay protected from all swells. Fish assemblages in Kaneohe Bay, protected from all swells, were extremely different from fish assemblages from all other types of exposures based on detrended correspondence analysis (Figure 4-2). By both number and weight, the fish assemblages in Kaneohe Bay appear to be quite distinct from those of all other locations. Although there was a good deal of overlap in assemblage structure among all other locations, south protected and north protected locations had higher concordance than north and south exposed locations. North exposed locations appeared to be more dissimilar to the Kaneohe Bay protected locations compared with south, south protected, and north protected locations.

Fish assemblage characteristics differed significantly among locations with different degrees of wave exposure (Figure 4-3). Species richness differed significantly and was highest in the north protected locations followed by south protected locations. South, north, and protected areas in Kaneohe Bay had the lowest species richness, respectively. Species diversity also was highest in the north protected and south protected locations but was not significantly different from the south and north exposure locations (Figure 4-3). Protected locations with Kaneohe Bay had significantly lower species diversity compared with all other locations sampled. Total fish biomass was also significantly different among locations based on wave exposure with the south protected and north protected locations have the highest standing stocks of fish present. In contrast to species richness and diversity, biomass was lowest in the north exposed and south exposed locations. Protected areas within Kaneohe Bay harbored intermediate levels of fish biomass.

### **Comparison of Marine Protected Areas**

Of the 42 locations surveyed, 16 had some level of protection from fishing associated with it. Hanauma Bay (N = 2), Pupukea (N = 2), Honolua Bay (N = 2), and Molokini Crater (N = 2) are all Marine Life Conservation Districts (MCLDs) that restrict various fishing activities from occurring within their boundaries. Despite its designation as an MLC, a wide variety of fishing methods are permitted within the Pupukea MLC. For this reason, this area was only considered to have partial protection from fishing. Moko O Lo'e (Coconut Island) is protected from fishing although limited take for scientific purposes is permitted. Locations within the Kaho'olawe Island Reserve (N = 2) were considered protected from fishing owing to the limited take permitted for cultural, spiritual, and subsistence purposes authorized by the Kaho'olawe Island Reserve Commission. Ahihi-Kinau Natural Area Reserve was also considered to be protected

from fishing owing to the extremely limited take for cultural purposes permitted at this site (N = 2).

For both number of individuals and biomass, fish assemblage structure in marine protected areas tended to be different from those assemblages observed in areas where fishing was unregulated (Figure 4-4). Concordance within MPAs was greater for fish biomass compared to number of individuals likely owing to the larger size of fishes in areas protected from fishing. The fish assemblage structure in the Pupukea MLCD with limited protected from fishing was more similar to those areas with no protection from fishing. The Hawaii Marine Laboratory Refuge (Moko O Lo`e -Coconut Island) possessed a fish assemblage structure similar to other unprotected areas within Kaneohe Bay where fishing was permitted.

Species richness, species diversity, and biomass were all significantly different among locations protected from fishing, partially protected and unprotected locations excluding locations within Kaneohe Bay (Figure 4-5). Values for all assemblage characteristics were significantly higher in the areas protected from fishing with the unprotected areas and the Pupukea MLCD (partially protected) having similar values for these assemblage characteristics. Fish standing stock was lowest in the Pupukea MLCD including all areas not protected from fishing.

Comparisons of fish assemblage characteristics between areas protected from fishing (Moko O Lo`e -Coconut Island) and unprotected areas in Kaneohe Bay were analyzed separately owing to the distinctive nature of these fish assemblages compared with other locations around the state. There were no significant differences in species richness (T = 8.0, P = 0.80), species diversity (T = 8.0, P = 8.0), or biomass (T = 7.0, P = 1.0) between locations protected from fishing and those where fishing was permitted within Kaneohe Bay.

Areas protected from fishing varied greatly in values for fish assemblage characteristics (Figure 4-6). Species richness was highest at the shallow Hanauma Bay site on Oahu (OAHANS), followed by South and North Honolulu Bay on Maui (MAHOSS and MAHONS). Species richness at the Moko O Lo`e (Coconut Island) site on Oahu (OAMOKD) was 3.8 times lower than the highest site, possibly reflecting the limited habitat provided by patch reef habitats in Kaneohe Bay. Species diversity followed a somewhat similar trend with Hanauma Bay, Oahu, Kanahena Bay, Maui, and Honolulu Bay, Maui having the highest diversity indices among all the protected areas surveyed. Both deep and shallow sites at Moko O Lo`e had low diversity along with Kanahena Point on Maui. The low diversity at Kanahena Point is owing to the large number of surgeonfishes (*Ctenochaetus strigosus* and *Zebriasoma flavescens*) and black durgons (*Melichthys niger*) at this site. This site harbored the highest overall fish biomass followed by Honolulu Bay South and Moko O Lo`e shallow. Honolulu Bay biomass was dominated by gray chubs (*Kyphosus bigibbus*), ringtail surgeonfish (*Acanthurus blochii*), brown surgeonfish (*A. nigrofuscus*), and spectacled parrotfish (*Chlorurus perspicillatus*). Biomass at Moko O Lo`e shallow was dominated by juvenile parrotfish, Hawaiian

sergeants (*Abudefduf abdominalis*), bullethead parrotfish (*Chlorurus sordidus*), and spectacled parrotfish (*C. perspicillatus*).

### **Habitat Complexity**

Biomass among sites with low rugosity varied greatly while those sites with high rugosity tended to have higher standing stock of fishes (Figure 4-7). There was a significant positive relationship between reef fish biomass and reef rugosity ( $y = 1.9524x + 6.2501$ ,  $R^2 = 0.2866$ ,  $P < 0.001$ ). The Ahihi-Kinau Natural Area Reserve location had relatively low rugosity (1.23) yet harbored the highest biomass of any site surveyed. Excluding this location  $\ln\text{biomass} = 2.1512x + 5.8885$   $R^2 = 0.3628$ .

Figure 4-2. Detrended correspondence analysis (DCA) of coral reef fish assemblages for 44 locations in the main Hawaiian Islands based on degree of wave exposure. A. DCA by number of individuals. B. DCA by biomass (kg). P = protected areas in Kaneohe Bay (N = 6), S = areas exposed to south swells (N = 8), N = areas exposed to north swells (N = 16), NP = north facing areas protected from swell (N = 8), and SP = south facing areas protected from swell (N = 10).

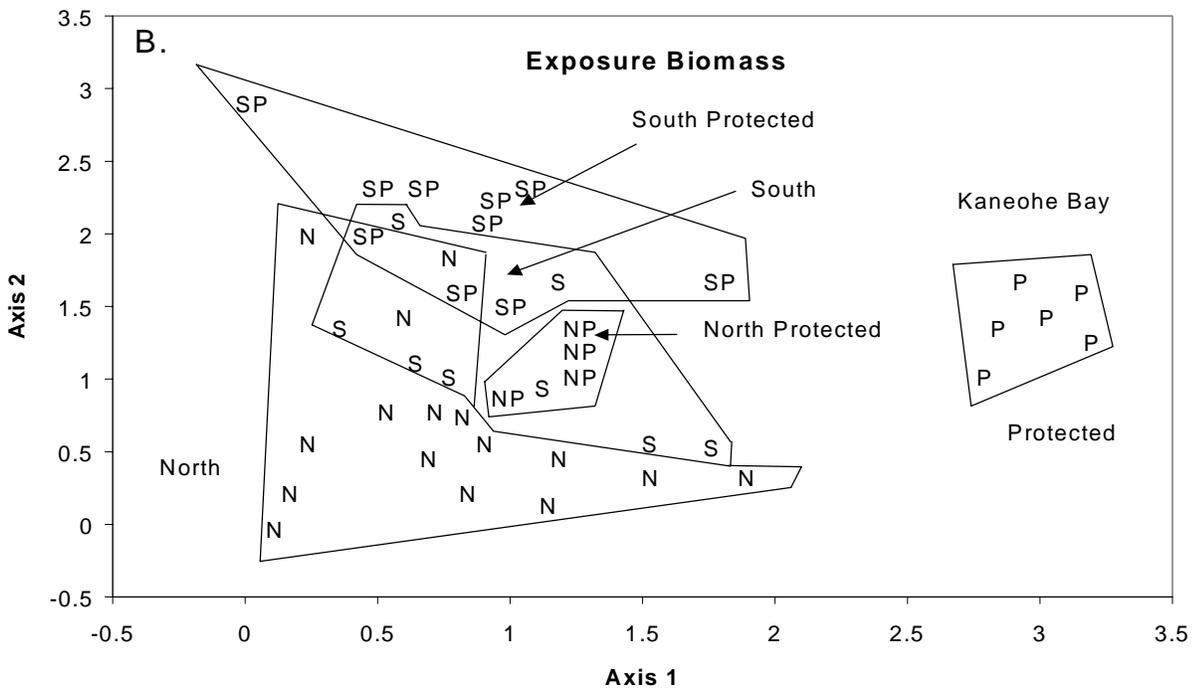
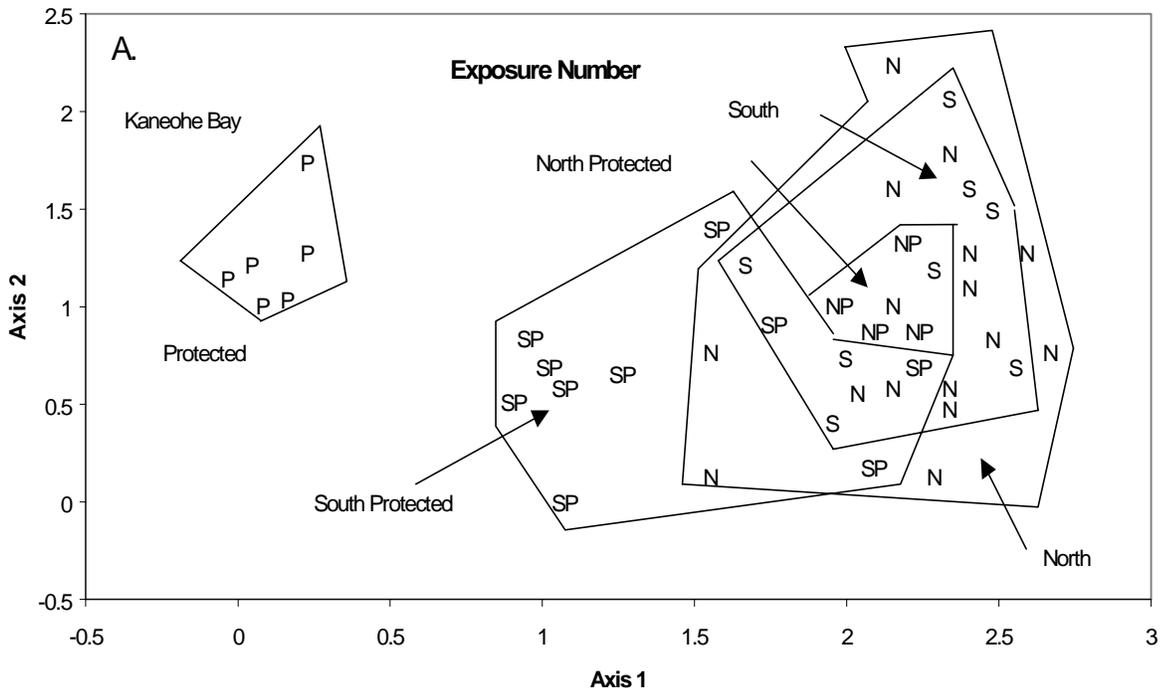


Figure 4-3. Comparison of fish assemblage characteristics among locations with varying degrees of wave exposure. Error bars are standard error of the mean. Results of one-way ANOVA and Bonferroni Multiple Comparison Procedures. Locations with the same letter are not significantly different at  $\alpha = 0.05$ .

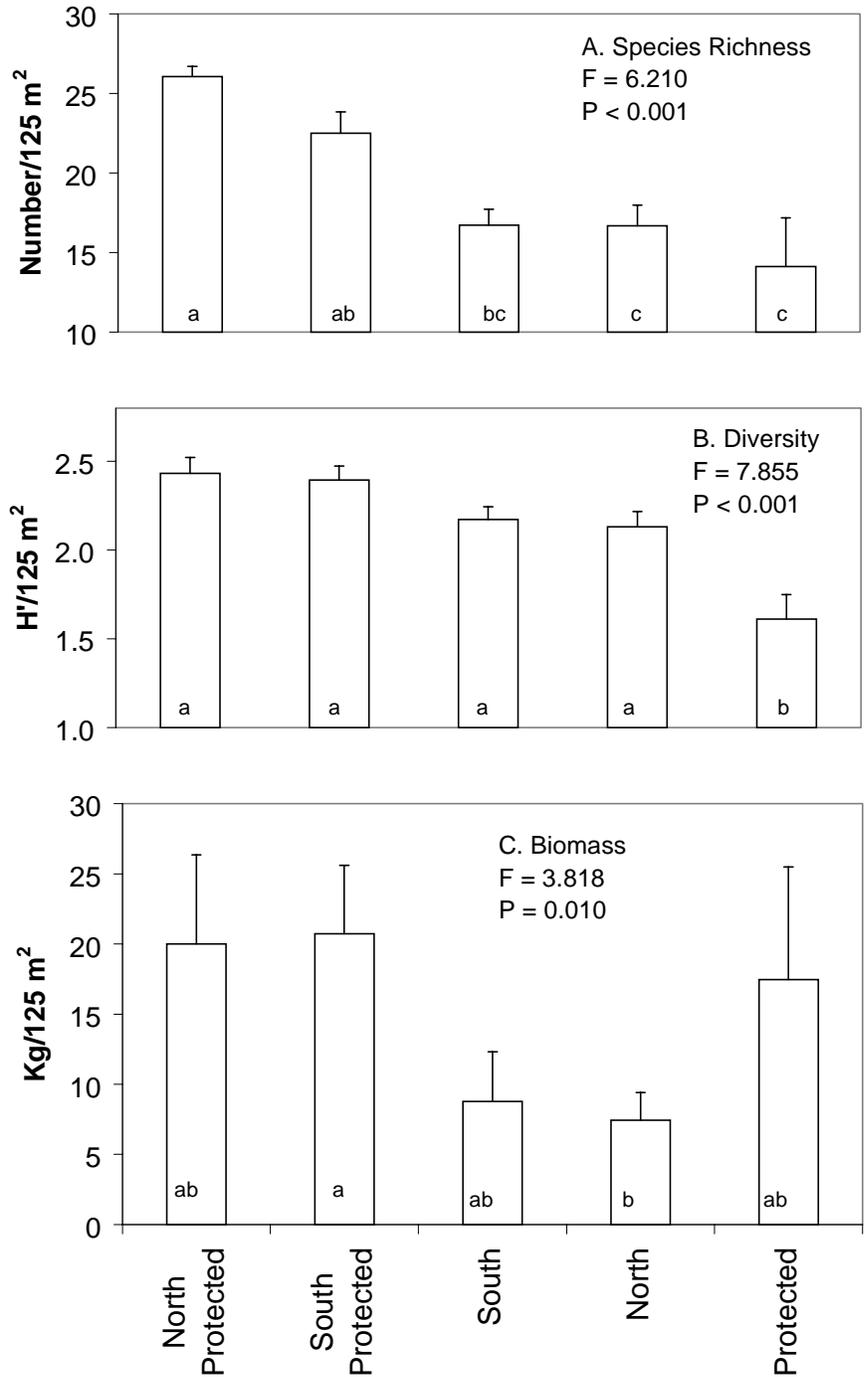


Figure 4-4. Detrended correspondence analysis (DCA) of coral reef fish assemblages for 44 locations in the main Hawaiian Islands based on level of protection from fishing. A. DCA by number of individuals. B. DCA by biomass (kg). P = areas protected from fishing including MLCDs, NARs, and the Kaho`olawe Island Reserve (N = 14), N = areas where fishing is permitted (N = 28), PP = areas of partial protection (Pupukea MLCD) (N = 2).

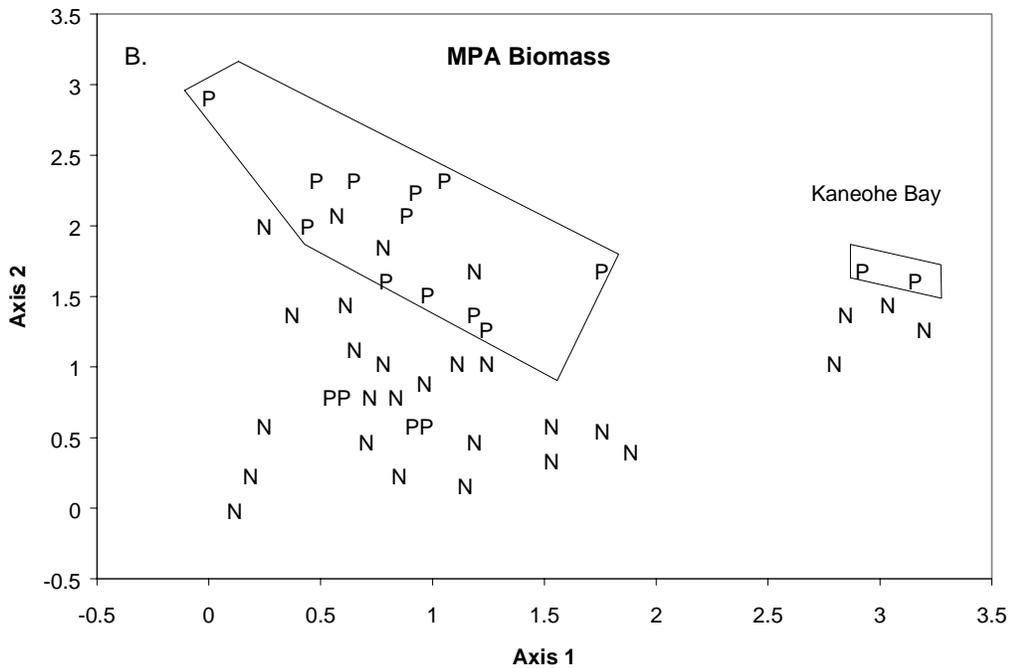
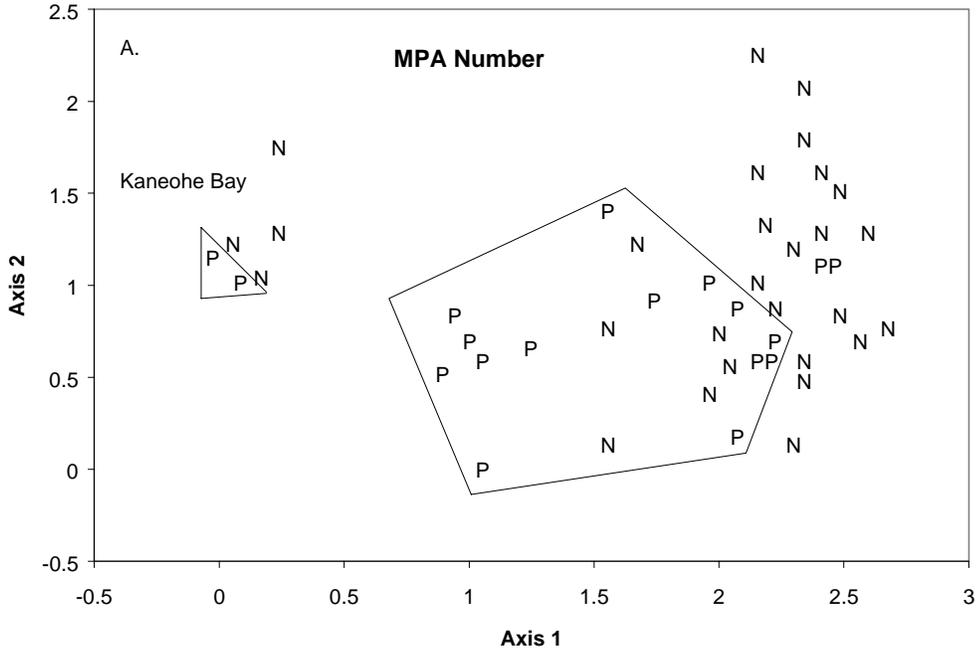


Figure 4-5. Comparison of fish assemblage characteristics among areas protected from fishing, areas with partial protection (Pupukea MLCD), and areas not protected from fishing. Locations within Kaneohe Bay are not included in these analyses. Kruskal-Wallis H statistic with Dunn's Multiple Comparison Procedure. Locations with the same lower case letter are not significantly different at  $\alpha = 0.05$ .

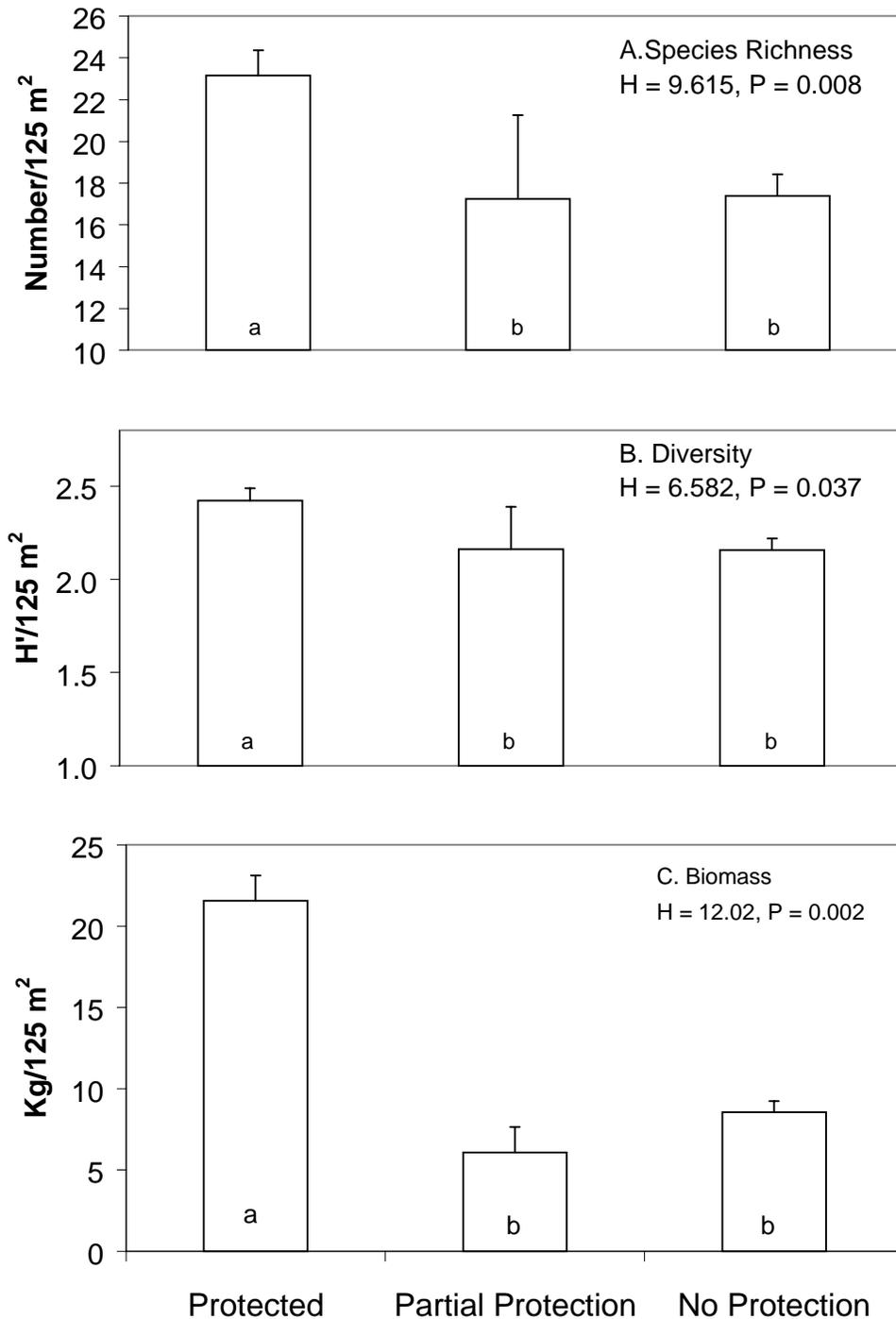


Figure 4-6. Comparison of fish assemblage characteristics for locations protected from fishing.

N = 14. Values are mean number per 25 x 5 m transect.

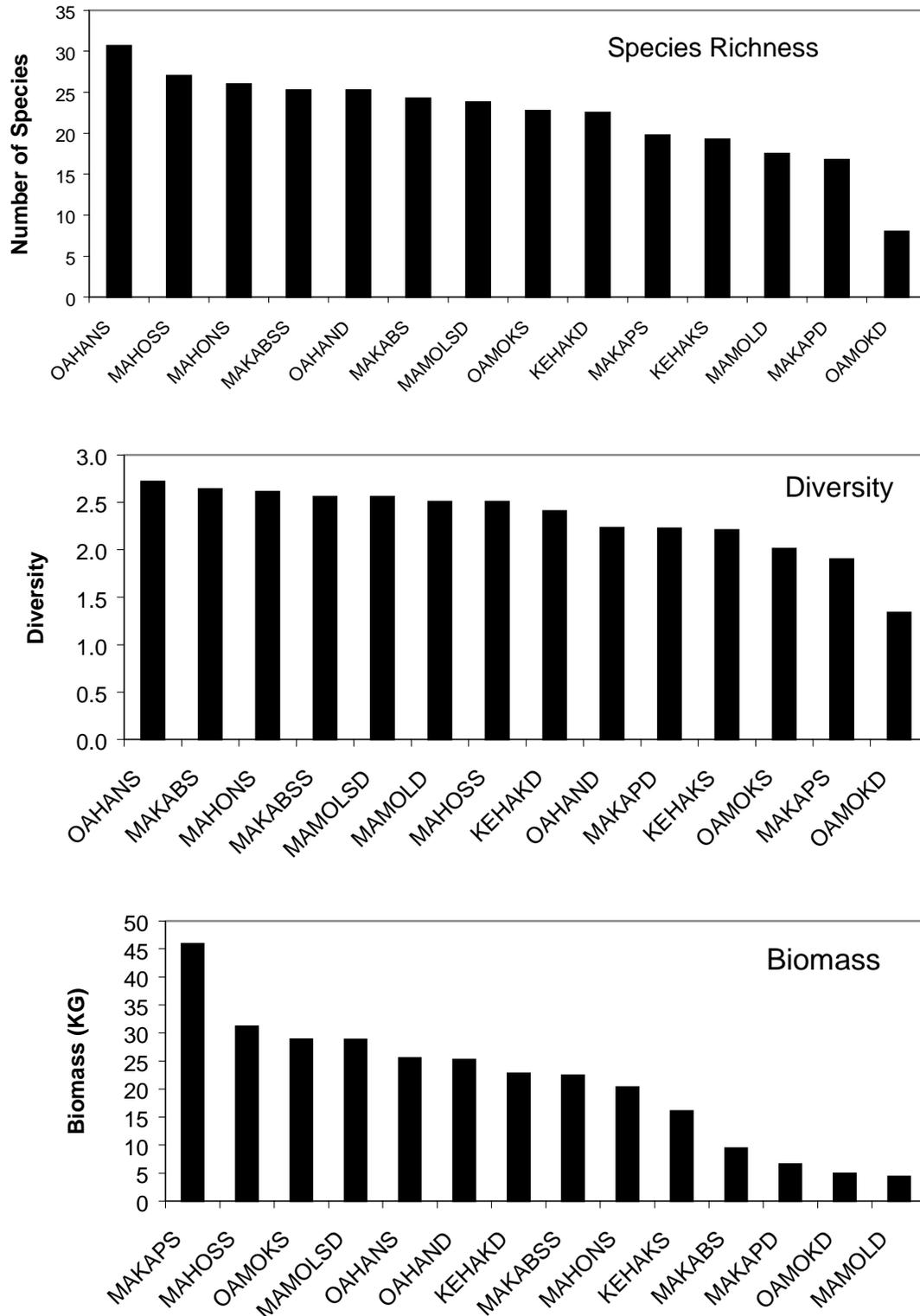
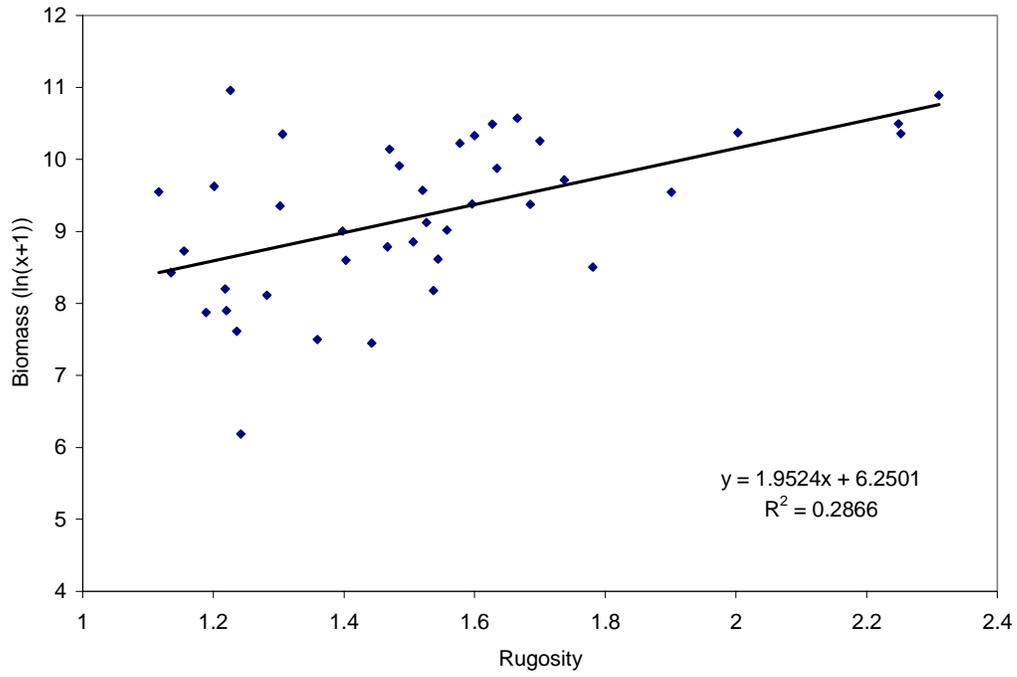


Figure 4-7. Linear regression analysis of reef rugosity and reef fish biomass.



## CONCLUSIONS

This study examined the relationship between fish assemblages and their associated habitat on a scale consistent with the patterns of both the resources and their users. Degree of wave exposure, amount of habitat complexity, and the level of protection from fishing all proved to be important determinants of reef fish assemblage structure and standing stock.

Surgeonfishes were the dominant fish family observed on transects and herbivores accounted for over 70% of the total reef fish biomass over all locations. Fish assemblages in Kaneohe Bay, Oahu were very distinct and differed greatly from all other fish assemblages around the state.

Fish assemblage characteristics varied depending on the degree of wave exposure associated with each location. Species richness and diversity were highest in locations of moderate wave exposure. Areas in Kaneohe Bay had the lowest species richness and diversity compared to all other types of exposure. This lagoonal-type habitat is unique among the main Hawaiian Islands and the limited heterogeneity of habitats may account for the lower number of species and species diversity at these sites. Biomass was lowest in areas exposed to north and south swells. Areas protected from direct swell activity had higher standing stock of reef fishes. Elsewhere in Hawaii, surf height and degree of wave exposure have been shown to be negatively correlated with several measures of fish assemblage organization (Friedlander and Parrish 1998b). Fish populations may be depressed in these locations owing to the seasonal variability in environmental conditions.

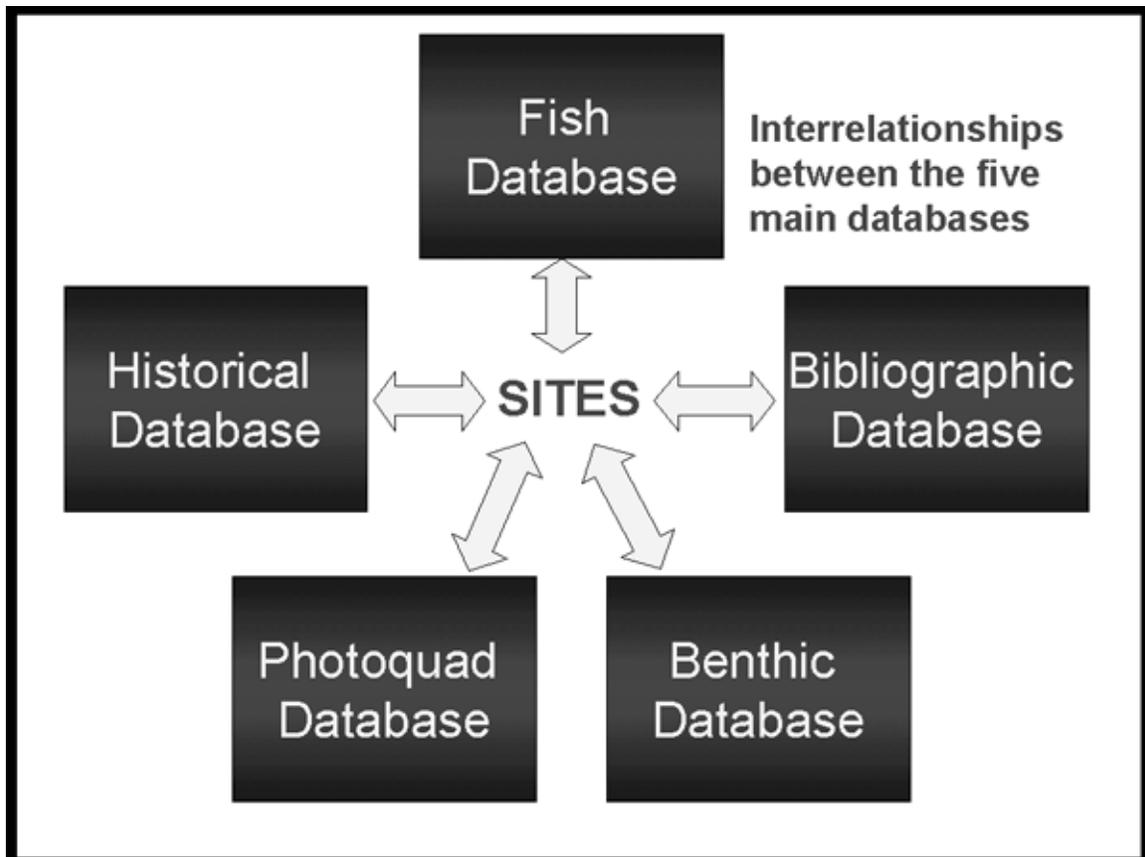
Years of chronic overfishing, particularly around the more populated areas of the state, has led to growth and recruitment overfishing for many coral reef fishes targeted by fishers. Despite the differences in the effectiveness of various marine protected areas in Hawaii (Friedlander in press, Sladek Nowlis and Friedlander in press), most areas protected from fishing appeared to benefit local fish populations. Areas protected from fishing formed distinct assemblages that had higher assemblage characteristics than areas where all fishing was permitted. Fish assemblage characteristics were consistently higher in these protected areas compared to areas where fishing was permitted. The Pupukea MLCB with limited protection from fishing had lower standing stock than areas where fishing was not restricted. Virtually all types of fishing is allowed in this "protected area" and the existing management regime has obviously not contributed to the conservation of these fish populations.

Habitats of high structural complexity often harbor fish assemblages with high standing stock and diversity. A relationship between fish size and reef complexity suggests the importance of shelter as a refuge for certain fishes in avoiding predation (Friedlander and Parrish 1998a). Reef habitat complexity (rugosity) explained almost 30% of the variability in reef fish biomass observed on transects. In a few instances, high biomass occurred in locations with low habitat rugosity that were protected from fishing. This may be a result of migration from adjacent areas where fishing is permitted.

Managers will know better which reefs are most valuable to protect as fish habitat, which may involve selecting reserves or other areas for management of fisheries or other human uses, or making decisions about sites for development projects and other human activities that may affect reefs. The results provide managers with a much better idea of how to manage reef habitat for maximum benefit to fish populations, with the attendant social benefits of improved fishery yield and/or improved results in preservation of fish populations and ecosystems quality. The kind of approach taken in this study, that attempts to make a functional match between habitats and fishes to be preserved, seems appropriate for selection and management of reserves. Knowing what characteristics of reefs contribute most strongly to support fish populations will also assist in plans for reef enhancement, restoration, and artificial reef applications.

## Section 5. Data Base Development

The CRAMP Survey and Bibliographic Database evolved considerably over year 2 of the project. The final form of the CRAMP database will eventually be a web-based GIS compatible system. This aspect is under technical development. The five major elements of this database system presently exist as separate database entities and are operational at present. Ultimately these will be linked through the CRAMP sites in the following manner:



The five database elements shown above contain the following information:

1. Fish Database: Consists of information on sites, taxa, surveys, and survey data (both from the past and from on-going projects). Monitoring information includes data on abundance and size estimates for fish species present at each study site.
2. Benthic Database: Consists of information on sites, taxa, surveys, and survey data (both from the past and from on-going projects). Monitoring information includes coverage data on coral, algae, and other invertebrates at study sites.

3. Photoquadrat Database: Consists of information on growth, mortality, and recruitment of sessile benthic organisms.
4. Bibliographic Database: Consists of a bibliographic ID field linked to the survey reference information table, species, keyword and location information fields, bibliographic information, publication abstract where possible, and links to or the full text of publication. The bibliographic table is continually expanded to cover pertinent publications and unpublished documents and reports. David Coleman of the UH Library and Eric Hill are the primary investigators responsible for developing this section of the database.
5. Historical Database: Consists of fields that contain additional site information from previous historical collections at study sites throughout the state. This includes not only the CRAMP sites but also sites surveyed by other researchers and consulting companies.

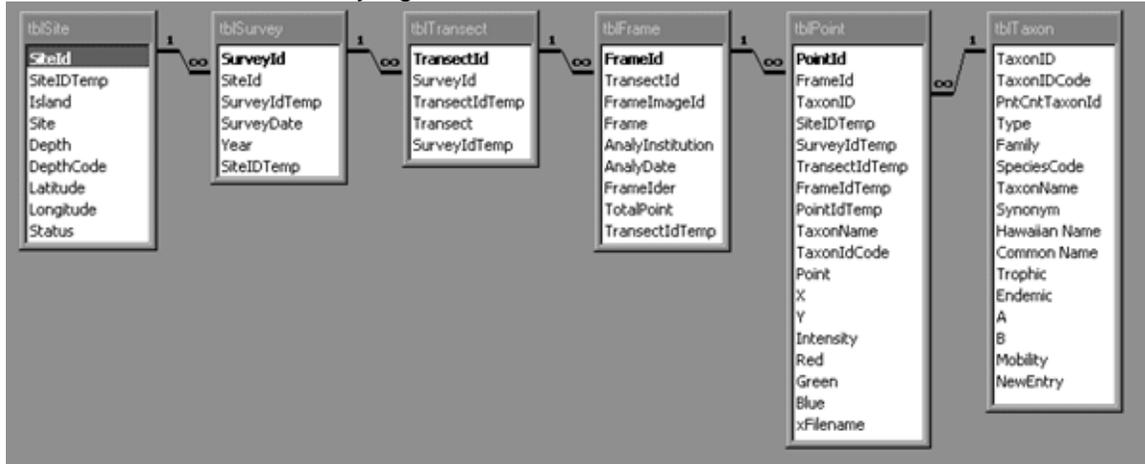
### **Benthic Database**

The benthic database system uses the Microsoft Access 97 windows database software. The database consists of groups of tables that are linked through common fields in a hierarchical fashion. This will also allow easy integration with the eventual GIS-based system:

The database includes the following variables for each site. Tables and fields for the variables prefaced with an asterisk (\*) are not available at present but are being developed.

- 1.) Site statistics (e.g. Island, depth, GPS coordinates, and conservation status)
- 2.) Coral and substrate cover for each point within a frame along the transect (PointCount CSV file)
- 3.) Rugosity for each transect
- 4.) Taxon information including full species name, family name, synonym, common name, Hawaiian name, and biological characteristics.
- 5.) \*Other data sources (e.g. ReefCheck, DLNR, Pacific Whale Foundation, Kahe Point, Kaneohe Bay sites)
- 6.) \*Algal species present
- 7.) \*Wave exposure rating/value for each site
- 8.) \*Nutrients

The database was developed in MS-Access 97 for the PC. A relational format was used with the underlying structure shown below.



## The CRAMP database in MS Access

Each box represents a table with the corresponding fields listed within it. The tables are structured in a hierarchical fashion. Starting from the left there is location information for each study site such as latitude, longitude, depth and conservation status. Surveys are conducted at a site and can multiple survey dates. Multiple transects are run on a given survey and for each transect there is detail information in the frame table on frame number, analyzing institution, date of analysis, image analyst, and total number of points analyzed. The point table not only contains substrate identification data for the 50 points but also includes X, Y coordinates and color information for the pixels. This data is imported from a Comma Separated Values (CSV) file generated by PointCount 99©, which does the actual image analysis. Random point locations for each data point are retained so that they can be used for subsequent reanalysis, quality control and recreated in case of file corruption.

Queries within the database organize the raw data into tables that can be readily exported into Statistica©. The preferred method is to use Excel as the transfer medium due to field incompatibilities between Access and Statistica©. For example, the date formats in Access are not interpreted correctly in Statistica©. Statistics will be performed on the data set for homogeneity of variances and normality. If parametric statistics are appropriate then percent cover for various substrate types will be compared across sampling intervals using a repeated measures ANOVA design that incorporates nesting of transects within sites. For sampling intervals that span a major episodic event, contrasts will be used to examine the pre and post coverage of substrate types.

## **Bibliographic Data Base**

The Bibliographic Database contains listings for published and unpublished documents concerned with the coral reefs and inshore marine resources of Hawaii. Information in the data tables includes author, title, date, journal, abstract, comments and key words. These data are also linked to the primary CRAMP study sites.

The CRAMP database traces its history to 1987. At that time the University of Hawaii Sea Grant Program funded a small seed project under Paul Jokiel to develop an electronic bibliographic database for Kaneohe Bay, Oahu. The "Kaneohe Bay Research Record" was programmed in dBase III+ programming language. The database was consisted of six separate files (Author, Study, Location, Keyword, Taxa, and Annotation) that are related by a common study number. The Record contained over 600 references and allowed single searches by author, date of study, keywords, location (latitude and longitude coordinates), taxa, and information on experimental study sites. An earlier paper bibliographic compilation of research in the Bay was published by Gordon and Helfrich (1970). The Corps of Engineers (1975) later updated this work through 1975. The Kaneohe Bay Research Record further updated the collected bibliographic information to 1990 in electronic format.

In 1998, the Kaneohe Bay Research Record was converted to Microsoft Access format by Eric Brown, as the basis of the developing CRAMP Bibliographic Database. In early 1999 Eric Hill developed the web interface, added a bibliographic search features and began adding additional entries from throughout the State of Hawaii. The CRAMP Bibliographic Database became an integral part of the CRAMP website. Dave Coleman, UH librarian, joined the effort and located additional material. Eric Hill, Dave Coleman and others have continued to add additional bibliographic information on a state-wide basis. In 1999 Eric Guinther of AECOS graciously contributed an electronic version of the Hawaii Coral Reef Initiative Computer Interactive Bibliography (HCRIB) as a source of additional references not contained in the CRAMP bibliography. Eric Guinther originally developed the HCRIB in collaboration with Carl Berg and others.

The CRAMP bibliography and database is evolving toward a GIS compatible web based system, which will take a number of years to fully develop. CRAMP is participating in a multi-agency collaborative effort under the USFWS Coastal Program to develop the prototype GIS data base system for bibliographic and historic data sets concerned with Hawaiian coral reefs. The initial focus is on the island of Oahu, with expansion to the other islands at a later date. The system has the capacity to eventually be linked into a web environment.

The CRAMP bibliographic database presently contains over 2500 references dealing with Hawaiian reef ecosystems. The database is continually expanding and being upgraded. Hard copies of all listed documents are being archived at Hamilton Library, University of Hawaii. All of the records in the database will eventually be reviewed and annotated by experts and will have geographic information added so they can serve as a basic resource for the future development of GIS and data oriented programs.

### **Fish Database**

This database contains all of the fish transect data collected at each site during a survey. Data includes site, survey date, observer, transect, abundance and size estimates for all fish species present within the transect boundaries. Multiple queries extract species richness and abundance data for each site. Additional queries convert the size estimates to total biomass and biomass by species for each site. Length estimates of fishes from visual censuses can be converted to weight using the following length-weight conversion:  $W = aSL^b$  - the parameters  $a$  and  $b$  are constants for the allometric growth equation where  $SL$  is standard length in mm and  $W$  in grams. Length-weight parameters are available for 150 species commonly observed on visual fish transects in Hawaii (Friedlander, 1997) and are included in the Taxon table of the database.

Statistics on the data are performed using JMP from SAS Co. and Statistica®. The data set is tested for homogeneity of variances and normality. If parametric statistics are appropriate then abundance will be compared across sampling intervals using a repeated measures ANOVA design that incorporates nesting of transects within sites. For sampling intervals that span a major episodic event, contrasts will be used to examine the pre and post coverage of substrate types

### **Historical Databases**

The historical collections database lists information on what type of work has been done at various sites and who has conducted the research. Some of these sites are CRAMP sites but the majority are not. The intention is to provide users with background information on methods used, data collected, and time period of the study at additional sites across the state.

### **Photoquadrat Database**

The Photoquadrat Database consists of all photoquadrat images in digital form taken at all sites. Five photoquadrats are taken at each depth (10 per site), so approximately 300 images are taken per sampling cycle. The photoquadrat database will also contain data on observed changes in the benthic components,

such as increase in diameter and area of corals, mortality, recruitment, overgrowth, etc.

### **Archiving of CRAMP Survey Data**

Data being taken at all CRAMP sites will be deposited in the National Oceanographic Data Center. CRAMP is currently working closely with Mr. Patrick Caldwell, NOAA / NODC Hawaii / Pacific Liaison, Honolulu, Hawaii (to achieve this goal. A unique aspect is that we will archive the digital images of each transect along with the quantitative data. This will provide a permanent record of the benthos that can be used in the future generations of scientists. Scientists can resurvey the exact sites (using GPS and the stainless steel marker pins) and use the images to resolve any question about how the image data were interpreted or can re-analyze the images using other methods.

## **Section 6. Evaluation of Skin Diving and Trampling Damage to Hawaii's Coral Reefs: An important aspect of the human-use problem.**

At the request of managers a series of experiments was designed to quantify the impact of direct human contact on Hawaiian corals. These were carried out during year 2 of CRAMP. The research included: 1. Controlled field experiments designed to relate degree of trampling to coral damage and recovery in experimental plots, 2. Studies of rate of damage and mortality for corals transplanted into areas having various levels of human contact and 3. Engineering studies on structural strength of various Hawaiian reef coral species.

### **Introduction**

The quantification of human use patterns and impact to corals due to direct contact of recreational and commercial tour activities has been the focus of this project. Increasing concerns about the near-shore environment have increased with population pressures. Hawaii's 7 million visitors contributed over \$11 billion to the state's economy in 1998. Over 1,000 ocean recreation companies exist to accommodate the 6 million tourists a year that use our marine resources. Over \$800 million was generated from this industry in 1998.

Direct human contact with corals can result in mortality, fracturing, tissue damage, decreases in gametic production and a reduction in growth yet, quantitative research evaluating the physical and biological impacts of trampling in Hawai'i are almost non-existent. This project established a direct casual link between trampling and coral growth and mortality.

Community level studies evaluated linear growth rates and mortality, determined through coral transplantation into sites that range along a gradient of human use. At the colony level, simulated trampling experiments controlled for all factors affecting growth and mortality. These occurred under experimental conditions to determine the rates of growth, mortality, and recovery of dominant Hawaiian corals subjected to trampling damage. Community and colony level experiments were linked together to establish the causal relationship between coral growth and mortality and impact from trampling. Skeletal strength and breakage rates were also quantified under laboratory-controlled conditions.

### **Assessment of site similarity**

To assess similarity between experimental and control stations and to control for other factors that affect coral growth and mortality, physical, chemical and biological parameters were measured. This provides valuable baseline data for each site. All parameters were measured at least three times at each site.

- Subsurface water samples have been collected and filtered onto preweighed filters for determination of total suspended solids (TSS).

- Water visibility has been measured using horizontal secchi disk distance.
- Salinity was determined with the use of a refractometer.
- Temperature was recorded at 1-hour intervals with waterproof data loggers. Data loggers were deployed when corals were transplanted and remained *in situ* throughout the experimental period.
- Plaster of paris clod cards were used to compare the water motion at each site.
- Visual belt transects to compare number, biomass and diversity of fishes at each site have been completed.
- Percent cover and diversity (H') of coral, algae and non-biological substrate has been completed at each site.

Analysis of variance shows no significant differences between experimental and control stations for depth, visibility, temperature and salinity. Significant differences were found in water motion, favoring the experimental station at the high and low impact site by 12% and 6% respectively, and the control station at the medium impact site by 20%.

As expected, biological differences are apparent due to anthropogenic impacts at experimental stations. Areas with a long history of human impact exhibit lower coral cover, and different fish compositions. Significant differences were found at the high and medium use sites for coral cover and non-biological substrate types.

A clear pattern of decreasing coral cover with increased use emerged along sites. There was an inverse relationship between percent coral cover and use at sites. Community populations at sites with a long history of use are expected to have lower coral cover. This was reflected at the high impact site with <2% coral cover in the impacted area compared to over 34% cover at the station unaffected by trampling.

Baseline data is now available for these three areas of concern to relate to management issues.

## **Experiments to Evaluate Impact of Direct Human Contact on Reefs**

### **Community level experiments**

Three sites were evaluated, representing a gradient that ranged from low to high human use by skin divers and reef walkers. The State of Hawaii, Department of Land and Natural Resources' Division of Aquatic Resources have designated all sites selected as areas of concern. To differentiate between induced and natural damage, a control group was established at each site.

Coral colonies were transplanted into all three sites during July 1999, and remained *in situ* until June 2000 to allow for growth and seasonal variations. The

effects of trampling produced statistically significant reductions in the number of transplanted colonies. Survivorship differed significantly between experimental and control groups at all three sites.

The magnitude of decline was astounding and the progression of mortality was rapid at the high impact site. None of the 20 colonies at the experimental station remained attached after an 11-month period (Figure 6-1). Two dead, unattached partial colonies were recovered. Sixteen live colonies were recovered from the control station at the high impact site. The locale of the 4 remaining colonies was not established.

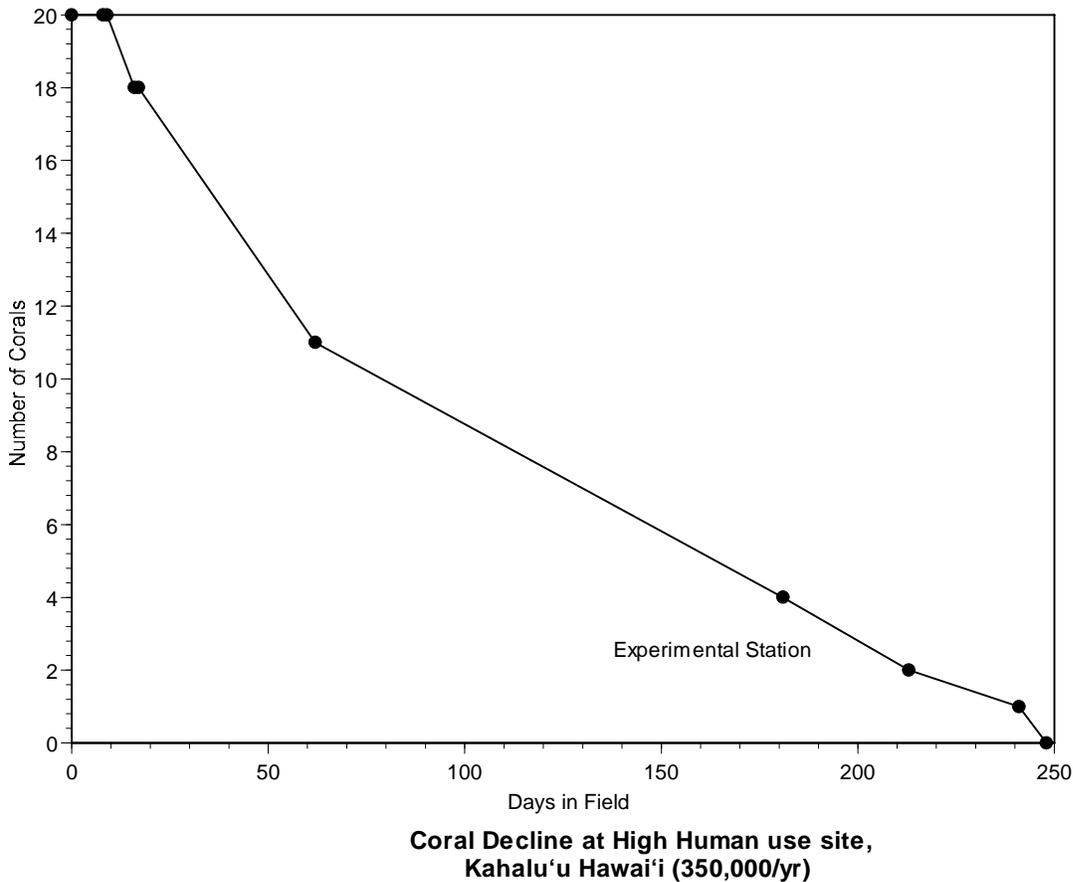


Figure 6-1. Coral decline at high human use site.

A definite pattern of decline emerged along the gradient of impact. While survivorship in the control group remained high, colonies exposed to the effect of trampling declined. Survivorship dropped from 70% at the low impact site to 55% at the medium impact site. Further decline was reported from the high impact site, with 0% of the transplanted colonies surviving (Figure 6-2).

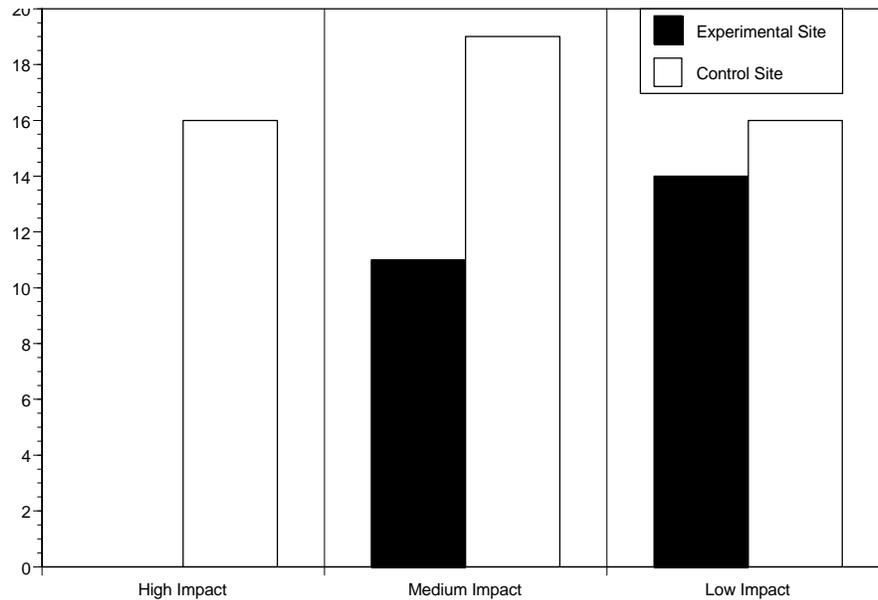


Figure 6-2 Coral survivorship along a gradient of use

## Quantifying Patterns of Human Use Pilot studies

To address spatial and temporal differences between sites, pilot studies were conducted prior to survey implementation. Pilot studies identified daily fluctuations in visitor numbers, variations in activity levels, and types of activities occurring in each area. Identification of peak times and days allowed for survey coverage of the maximum number of users. Data from these studies were then used to design surveys at each site. Types of activities occurring at each site were incorporated into survey sheets to distinguish between activity involving possible contact with corals and those occurring in deeper water or on the surface that would not involve substrate contact.

## Observer variation surveys

To address variability between surveyors, observer variation surveys were conducted prior to implementation of activity surveys. Two independent groups of observers collected data at Kahaluu Beach Park. On June 18, 1999, 16 high school students from the West Hawaii Explorations Academy counted the number of visitors and distribution of activity. Reefwatchers, a volunteer group organized by the Sea Grant extension on the island of Hawaii, collected data on July 17, 1999. Twelve Reefwatchers participated in the observational surveys.

Identical survey forms and verbal and written instructions were provided to all observers. A total of 28 individuals participated in the surveys. Observation variation surveys showed high variability among observers (Figure 3). These surveys were conducted to address issues of precision. To reduce variability, observers were limited to one or two per site. When more than one observer is involved, a method of standardization is necessary to calibrate observer counts relative to each other. Repeated observations were conducted simultaneously to reduce variability between surveyors.

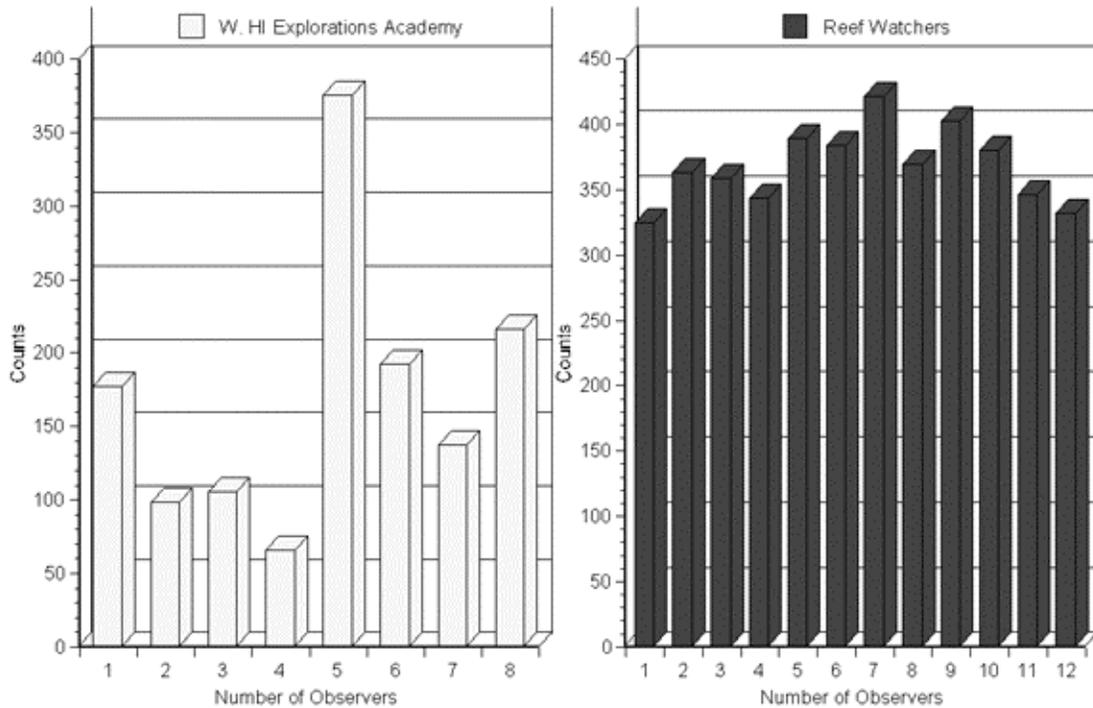


Figure 6-3 Observation variation surveys

### Recreational activity surveys

Recreational activity surveys using standardized survey techniques were employed at all sites. These surveys were correlated with the coral transplantation period. Sample days were randomly selected based on prior pilot surveys that addressed daily fluctuations in visitor numbers and identify peak times and days.

A consistent number of randomly generated weekdays, weekends and holidays were selected each calendar quarter to allow for seasonal variations. All activity occurring at the sites were recorded hourly to address spatial and temporal variations of use.

This quantification of use patterns allowed evaluation of the relationship between various aspects of the reef community and how people use the marine environment. This enabled us to determine the physical and biological impacts to corals directly related to specific anthropogenic factors. This can show a quantified relationship between human use and coral contact. This data will provide the results to back management decisions on marine protected areas.

These community level experiments were an attempt to replicate realism in the affected environment. Although direct cause and effect cannot be established through observational surveys alone, association between impact and mortality is strong. There was 100% coral mortality at the high use site. Trampling is a plausible explanation for coral mortality. Alternative explanations for mortality were ruled out. Flood events and damaging storm surf were not recorded at this site during this period. The higher level of impact was associated with the stronger response and the cause (trampling) occurred simultaneously with the response of mortality.

By itself, even the strong association demonstrated between trampling and mortality is not sufficient evidence to affirm a cause and effect relationship but in conjunction with the colony level manipulative experiments, a direct causal link between coral damage and trampling was determined and established.

### **Colony level experiments**

#### ***In situ* trampling**

Simulated reef trampling occurred under experimental conditions. Four dominant species of Hawaiian corals, *Porites compressa* (finger coral), *Porites lobata* (lobe coral), *Montipora capitata* (rice coral), and *Pocillopora meandrina* (rose or cauliflower coral) were used. Ten of each species were weighed, stained and placed on the reef at Moku o Loe, a marine protected area where outside disturbance is non-existent.

Trampling was simulated daily for a period of 9 days at which time further breakage was minimal. Breakage and mortality was recorded. Recovery time and growth was tracked for a one-year period to determine coral recovery and resilience rates.

From a total of 40 colonies, 554 fragments were recovered. No natural breakage occurred in the control colonies. The species with the highest breakage rate was *Montipora capitata* followed by *Porites compressa*, *Porites lobata* and *Pocillopora meandrina* (Figure 6-4).

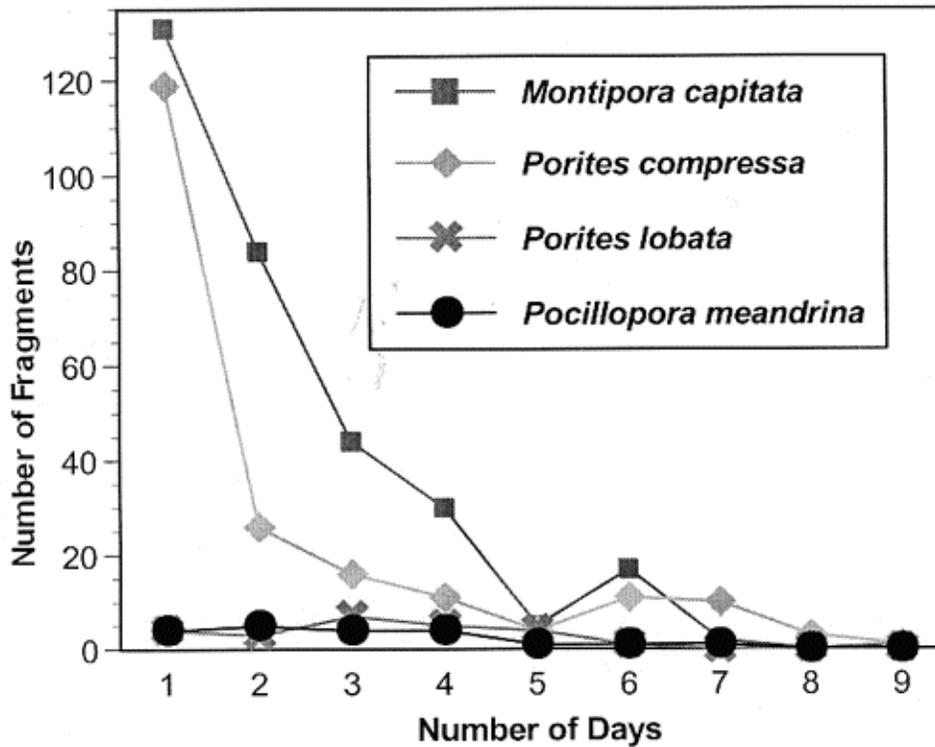


Figure 6-4. Number of fragments produced in simulated trampling experiments

Over 92% of the pieces broken were recovered from *Montipora capitata* and *Porites compressa*. This is consistent with the habitat they inhabit. They often colonize protected, low energy regions. This exposes them to impact from trampling since these are the identical habitats frequented by snorkelers and swimmers.

*Porites lobata* and *Pocillopora meandrina* exhibited very little breakage relative to the other two species. Adaptations to the environment they inhabit resulted in higher skeletal strengths and morphologies more resistant to wave forces. The breakage rates of all 4 species are consistent with their skeletal strength.

Coral mortality in this study was low, resulting in 93% survivorship of impacted colonies compared to 95% survivorship in control colonies (Figure 5). All 4 species in this experiment were highly tolerant of inflicted damage, suggesting that corals can withstand limited pulse events that allow time for recovery.

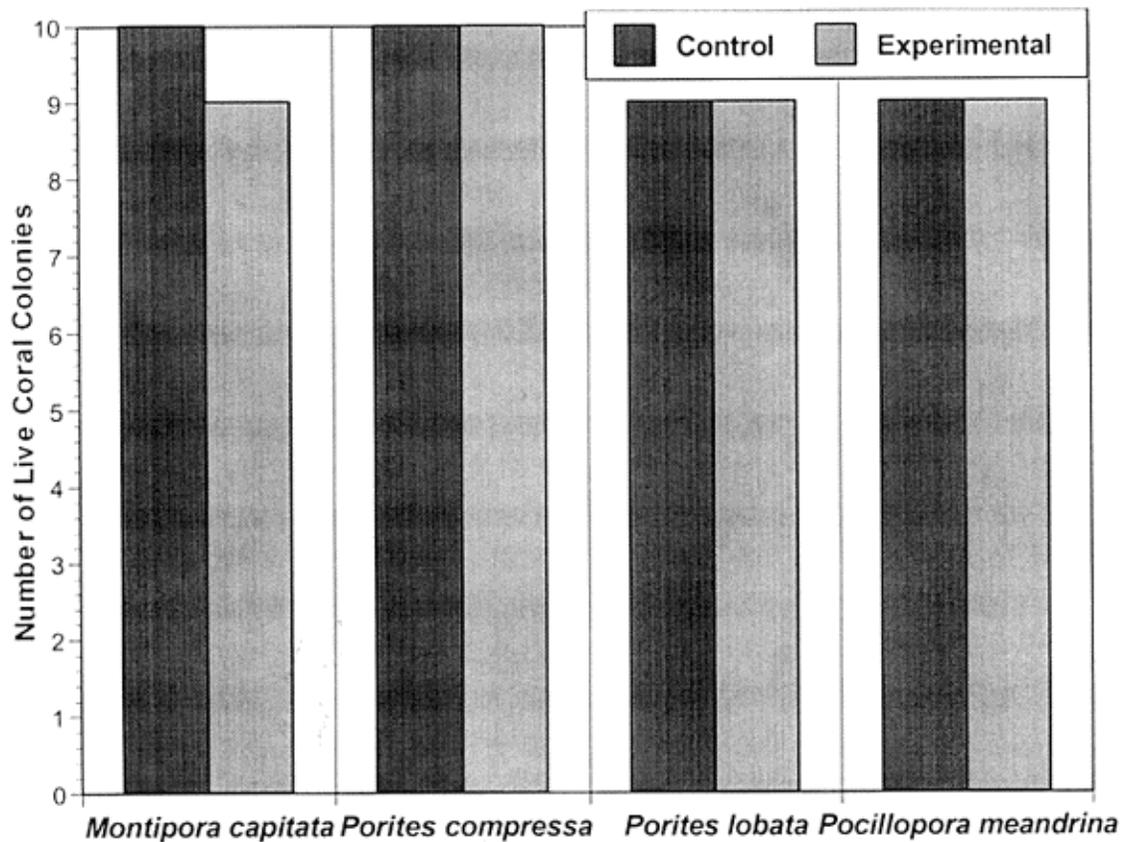


Figure 6-5. Survivorship of trampled coral colonies

Survivorship of fragments is clearly size and species dependent in *Montipora capitata* and *Porites compressa*. Smaller fragments had higher mortality than larger fragments. Fragmentation has been demonstrated as an effective and viable means of reproduction in corals. Natural forces such as waves and currents can serve as a mechanism to enhance and expand coral distribution. Yet, anthropogenic impacts of trampling are of limited benefit to reproduction if corals are subjected to continuous disturbance pressure.

Growth rates were significantly lower in the treatment group of *Montipora capitata*, *Porites compressa* and *Pocillopora meandrina* than in the corresponding control groups. This demonstrates that although survival can be high following impact, growth in some species of corals can be affected even after a one-year recovery period.

Growth in *Porites lobata* was unaffected by trampling, exhibiting analogous linear extension rates in paired comparisons between impacted and unimpacted colonies. The lobate, massive form of this species may provide protection from damage by physical forces if corals are subjected to continuous disturbance pressure.

It is expected that the branching forms of coral will sustain greater damage than massive or lobate forms. Yet, even the species of corals with the highest skeletal strength and the morphology most likely to withstand impact exhibit breakage when subjected to trampling forces.

Corals can recover and mortality can be low once the impact has been removed and a sufficient recovery period allowed. Yet, most accessible near-shore environments throughout the state receive continuous press-type impacts with little or no time for undisturbed recovery. This study demonstrated that as few as 9 tramples can produce significant changes in growth even after a nearly one year recovery period.

At tourist destinations, impact is concentrated in a small area and high mortality can occur. Severe consequences for higher trophic levels are inevitable when damage is inflicted upon reefs. As the local population and visitor industry expands, increased trampling pressure will intensify.

This small-scale experiment at the colony level isolated the trampling treatment. Environmental parameters that affect coral survivorship and growth were all controlled for in the experimental design. This study, therefore, establishes a causal relationship between trampling and growth. This direct link to the impact also provides a quantitative baseline for these 4 species of Hawaiian corals. Growth comparisons between species provide a baseline for potential damage based on actual created damage.

### **Skeletal strength**

Coral breakage tests were run in the material-testing laboratory in the Civil Engineering Department at the University of Hawaii. There has been no previous research documenting the strength of these Hawaiian corals.

In the natural environment, many corals fracture in tension. Compressive and tensile stresses in corals can be caused by forces applied in various directions or by bending due to applied forces. Corals exposed to current or wave impacts are subjected primarily to bending, while those exposed to trampling are subjected to both compressive forces and to bending, thus, both tensile and compressive tests were applied to corals.

Tensile and compressive strengths of two morphologies and four species of dominant Hawaiian corals were tested. Tensile tests were consistent with core and colony compression tests.

The skeletal strengths of the plate and branching forms of *Montipora capitata* were not shown to be significantly different. All four species of coral were found to be significantly different in skeletal strength. Tensile tests concluded that the skeletal strength order from weakest to strongest was as

follows: *Montipora capitata*, *Porites compressa*, *Porites lobata* and *Pocillopora meandrina*. This was consistent with breakage rates recorded in the simulated trampling experiments (Figure 6-6).

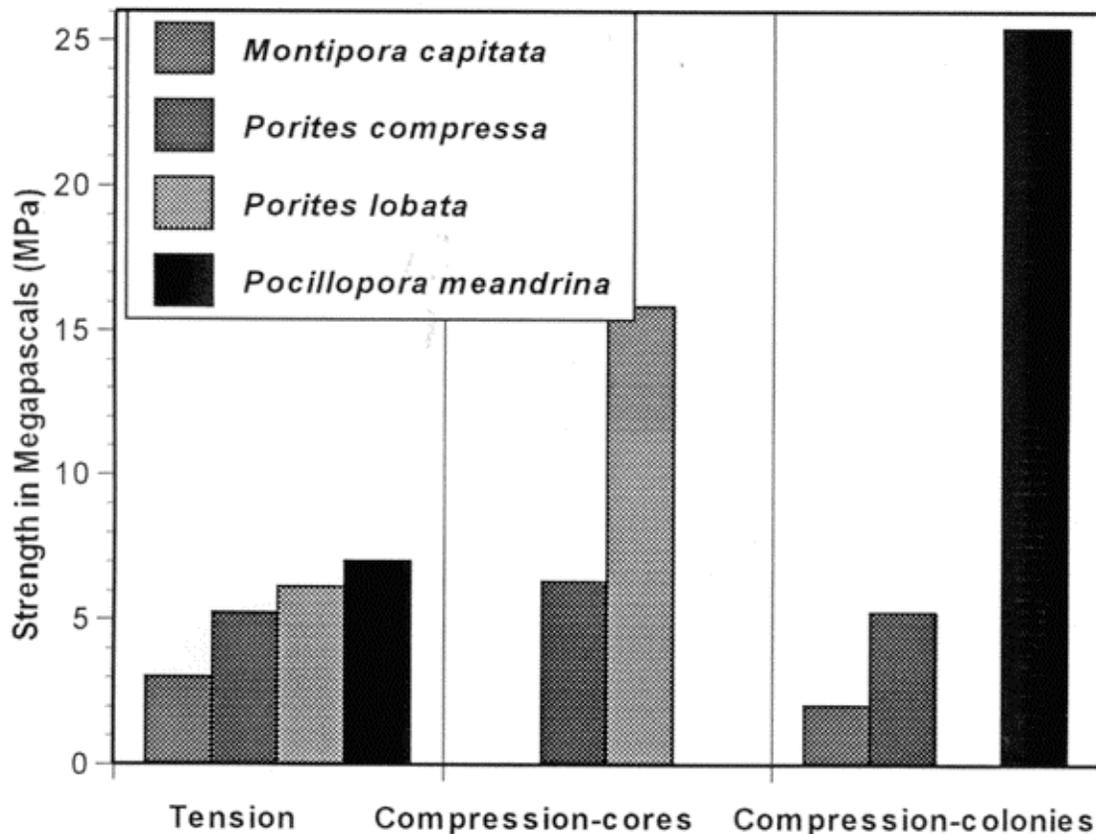


Figure 6-6. Summary of results from tensile and compressive tests

Core and colony compression tests demonstrated that weights over 50 lbs. will break *Montipora capitata*. Average weights of over 100 lbs. must be applied to *Porites compressa* in order for breakage to occur, 450 lbs. for *Pocillopora meandrina* and 1,500 lbs. for *Porites lobata*.

Coral skeletal strength reflects the wave environment in the regions they inhabit. The results of this study suggest that skeletal strength is an adaptive response to hydraulic stress. The species found in environments with high wave energy were more resistant in stress fracture tests than those residing in habitats indicative of limited energy regimes. *P. lobata* and *P. meandrina* are found in high-energy environments and have skeletal strengths and morphologies that resist breakage. The thick, flat branches of *P. meandrina* and high skeletal strength allow recruitment into high-energy environments. Higher coral cover of *P. meandrina* in exposed areas is documented from statewide monitoring sites. The most widespread of the Hawaiian species, *P. lobata* can be found from

intertidal to deeper waters, with depth limited only by light penetration and suitable substrate. It is common in both protected and exposed regions. The encrusting or massive forms of this coral make it highly resistant to breakage. Results of skeletal strength from this study are consistent with its ability to withstand strong forces.

*M. capitata* and *P. compressa* also inhabit environments consistent with the results found in this study. These species are found in lower disturbance regimes and areas protected from strong wave action. High coverage of these species are found at protected sites throughout the state while extremely low cover of these corals are reported from exposed shores. The upright form of these species also makes them vulnerable to trampling damage. Having adapted to lowered wave disturbance while inhabiting near-shore regions has made these species even more vulnerable to anthropogenic disturbance. Trampling impacts occur most frequently in shallow, protected areas that are favored by snorkelers and reefwalkers. The low skeletal strength and highly branched morphology of these species make them vulnerable to damage from trampling.

A comparison with other materials show that coral skeleton is among the weakest material.

Skeletal strength is not independent of other structural characteristics. Colony size and morphology combine with mechanical properties to provide protection against natural and anthropogenic forces.

Analyses of compressive and tensile strengths can be used to establish a relationship between skeletal structure and the ability of corals to withstand diver and trampling impacts. Material strength is also useful in interpreting the paleoecology of corals to understand the life habits, ecology, and habitat ranges of fossil corals. Additionally, skeletal strength can be used to predict species composition in areas with known physical forces. Knowing the mechanical properties of corals and their resistance to trampling can assist management decisions when determining carrying capacities and restricting use.

Corals developed in habitats free from anthropogenic stresses, thus skeletal strength reflects the physical forcing functions in each regime. Mechanical properties of the skeleton helped to determine the range of habitats and conditions corals could be exposed to. The sequence of vulnerability of corals to trampling impacts is consistent with the skeletal strengths of these species, indicating an adaptive response to disturbance. Susceptibility to trampling will continue to increase as recreational activities chronically overlap with coral habitats.

## Discussion

Results of this investigation clearly demonstrate the impact of direct contact (reef walking and snorkeling) on shallow coral reefs in Hawaii. Reef corals in shallow areas with high visitor use (over 300,000 visitors annually) are quickly pulverized by the contact and fail to survive continued exposure to trampling. Experiments suggest that coral colonies can recover from an intense period of trampling if the stress is not continued. The original colonies and most of the larger fragment broken off the colonies will recover. Not all coral communities are equal in their ability to withstand direct human trampling contact. Species typical of high wave energy environments have much stronger skeletons and resist breakage from human contact. In Hawaii, the area of reef being subjected to trampling is quite small compared to the total reef resource. However, the areas being impacted are those areas with high recreation value and high value to the visitor industry. Sites in Kaneohe Bay with moderate levels of visitor activity showed less impact of trampling largely because most of the visitors are supplied with flotation devices that kept them from contacting the bottom.

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