"Development of Coral Reef Biocriteria for Hawai‘i" Final Report

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Abstract: The Hawai‘i Coral Reef Assessment and Monitoring Program (CRAMP) has made considerable progress in developing metrics to be used for establishing state standards. The Quality Assurance Project Plan that detailed the methodology for data and modeling used in this investigation was approved during the grant period. We have further expanded, developed, and refined biocriteria and presented it in a format easily used by managers. In the process of achieving this goal we presented to four management agencies, gave 23 presentations at workshops, symposia, and public venues and conducted model use training sessions. Information, data and the Ecological Gradient Model (EGM) were widely disseminated. Other outreach through media, publications and reports further circulated our results. Two collaborative efforts were established to link our reef index with a watershed index and to serve as a template for a developing cultural index.

One of the primary goals of this project was to develop coral reef biological criteria for the State of Hawai‘i and work with the Hawai‘i Department of Health (DOH), and the Hawai‘i Division of Aquatic Resources (DAR) in order to bring current activities in the state into line with the emerging US EPA “Development of Assessment Tools for Coral Reef Biocriteria” program at the national level. CRAMP has worked in close association with State and Federal resource managers with the intent of eventually reaching consensus on establishment of biocriteria standards for Hawai‘i. This iterative process with feedback from agency personnel proved to be challenging. There has been positive feedback and growing interest from agencies such as NMFS PIRO, DLNR NARS, NPS, DOH, various researchers, consultants and elements of DAR. Publication of the EGM in a peer reviewed journal has established credibility and increased interest in the approach. Progress was made with the DOH in developing water quality standards for reefs, but the current budget crisis in Hawai‘i has led to reduction of staff at DOH and is slowing activity in this area. Further development of the EGM is being actively pursued by incorporating the model as a component of comprehensive ecological and climate change studies, with two applications pending and other applications under development.

1.0 Project description

1.1 Project purpose and goals

The purpose of this project was to expand, develop and refine the Coral Reef Assessment and Monitoring Program’s (CRAMP) Ecological Gradient Model and evaluate its biocriteria. A main objective was to work in close collaboration with Federal and State management agencies to promote the development and implementation of appropriate biocriteria for coral reefs into the State of Hawai‘i water quality standards. Another goal of this project was to explore the possible addition of supplementary sensitive bioindicators such as coral recruitment, growth and mortality based on analysis of existing CRAMP photoquad data. In addition, we proposed to increase the numbers of watershed parameters used in the analyses in order to define the relationship between water quality, watershed characteristics and condition of the biotic coral reef communities. With the aim of dissemination of biocriteria results we proposed to widely distribute our results by allowing free access to the data and download of the model through our CRAMP website. We intended to notify interested parties of the availability of the information through various networks, presentations at symposia, presentations at EPA and other workshops and culminating in publications in peer-reviewed journals. The community outreach segment of this project involved presentations and interactions with several community groups that have been very active in the protection of coral reefs, and have been very effective at identifying problems.

1.2 Evaluation of success

1) To promote the development and implementation of biocriteria in the State of Hawai‘i and thereby improve the ability of the regulatory agencies to protect the environment, the primary standard for measuring success of this project is the degree of progress towards the establishment of biocriteria for coral reefs as part of the State of Hawai‘i water quality program. This was attempted through six management community presentations to four agencies (see section 4.2). Their input was used to further refine the model. Significant progress has been made in furthering familiarity with our model and biocriteria by State and Federal agencies. There has been considerable advancement in establishing water quality standards for Hawai‘i's coral reefs. The process of establishing biocriteria for coral reefs that will be adopted by all State and Federal agencies is a slow and arduous process at best. Numerous obstacles prevent consensus by all management agencies with jurisdiction over Hawaiian reefs. Our work with the Department of Health to develop water quality standards has been the most promising.
2) Other tangible evidence of success is the availability of the completed model in a user friendly format available as a complimentary download at http://cramp.wcc.hawaii.edu/. Instructions on use and information on development of the model including metadata are also available on this website.
3) The original database was expanded and refined to include more detailed and representative wave regimes, a wider range of depth categories, additional locational and spatial data, and adjustments for a more user friendly format.
4) Quarterly reporting and a comprehensive final report details the project's timeline, budget, objectives, and achievement of goals.
5) Publication in a peer reviewed journal (see Appendix III). The article entitled, "Quantifying the Condition of Hawaiian Coral Reefs" by Ku‘ulei S. Rodgers, Paul L. Jokiel, Christopher E. Bird and Eric K. Brown was published in the peer-reviewed journal Aquatic Conservation: Marine and Freshwater Ecosystems. The development, acquisition, and selection of biocriteria for use in the development of the Ecological Gradient Model (EGM) to determine reef condition is described in this article.
6) The EGM model is currently widely available to researchers, managers, students, and other interested groups or individuals. It is disseminated through the CRAMP website as a free download with accompanying information.
7) There has been widespread dissemination of information to the public, community groups, and to federal, state and non-governmental agencies (see section 4.0). This was accomplished through workshops, symposia, presentations, reports and articles, website information, and model use training (see section 5.0).
8) This project has resulted in a collaborative effort to link biological coral reef data with watershed data (see section 3.2.1). This collaboration with the Hawai'i Stream Research Center's Watershed Health Index (WHI) can act as an important bridge to water quality data and other information that can lead to the development a regulatory coral reef index.

9) There is growing interest from agencies such as NMFS PIRO, DLNR NARS, NPS, DOH, various researchers, consultants and elements of DAR. Publication of the EGM in a peer reviewed journal has established credibility and increased interest in the approach. Building a strong scientific basis for the use of biocriteria is vital to its eventual acceptance and implementation by management agencies. Progress was made with the DOH in developing water quality standards for reefs, but the current budget crisis in Hawai‘i has led to reduction of staff at DOH and is slowing activity in this area, but there is still substantial commitment to biocriteria development. Further development of the EGM is being actively pursued in collaboration with other researchers at HIMB by incorporating the model as a component of comprehensive ecological and climate change studies, with three applications pending and another under development. This model will be used to justify a long-term ecological study with the National Science Foundation. In addition, the EGM is an integral part of proposals submitted to NSF’s Comparative Analysis of Marine Ecosystem Organization, and an EPA doctoral fellowship. Other proposed uses currently under development for submission to the Hawai‘i Undersea Research Laboratory will include determining changes in Hawaiian coral reefs.

2.0 Quality Assurance Project Plan

The first task to develop and submit an EPA Quality Assurance Project Plan (see appendices: I. Quality Assurance Project Plan) to cover the types of data and modeling approach used in this investigation was completed by Drs. Ku‘ulei Rodgers and Paul Jokiel. This 44 page document was reviewed and approved by Quality Assurance Project Manager: Eugenia McNaughton, Environmental Scientist at the EPA Quality Assurance Office: Richard Frietas, and EPA Project Manager: Dr. Wendy Wiltse. Final approval and acceptance of the plan was received on 28 July, 2008.

Biocriteria was used to develop a model to assess reef condition and compare reefs with one another. This Ecological Gradient Model (EGM) integrated concepts from EPA’s Index of Biotic Integrity (IBI) that applies metrics to produce a ranking to evaluate the severity of impairment with the theory of habitat classification used by the Army Corp of Engineer’s Hydrogeomorphic Model (HGM). The biocriteria used in this model was carried out within the framework of the Hawai‘i Coral Reef Assessment and Monitoring Program (CRAMP), which has been monitoring Hawai‘i’s coral reefs throughout the state since 1998. Additional information was gathered during this project to expand and strengthen the model.

In order to ensure the data generated by CRAMP and used by EPA, the Department of Health (DOH) and other state and federal agencies, and non-governmental organizations are of known quality and are scientifically valid the Quality Assurance Project Plan was required. It was determined that CRAMP methodology follows rigorous procedures in permitting, sampling, analyzing, and conducting quality control in all aspects of data collection, shipment, storage, processing, and laboratory and computational analyses in both field and laboratory settings. This includes all primary and secondary physical and biological data consisting of measurements, handling and processing of sediments, and benthic digital photos and data on topographical relief, depth, and fish. Quality assurance and quality control (QA/QC) of all logbooks, field notes, data sheets, forms, and labeling of photographs and collections were approved. Methodology for field replicates and statistical techniques were determined to be thorough and accurate. All field and laboratory equipment used to gather or analyze samples and/or data was also approved within the project plan (see appendices: I. Quality Assurance Project Plan).

3.0 Research Activities

3.1 Refinement and distribution of model

The Ecological Gradient Model (EGM) prototype was revised and macros were adjusted to allow ease of use by managers and scientists. The features added include:

- Modification of the initial query to select a depth range rather than a single depth value
- The ability to select more than one wave regime for comparison with the evaluation site
- Gradient symbols on the data map with size of symbol increasing with index level
- Hidden macros for user simplicity
- Drop-down parameter comments with methodology descriptions and references
- Parameter revision to reflect most widely used parameters
- A text worksheet to view the queried data showing comparison sites, locations, and index values
- Ability to print individual graphs of either weighted, unweighted or CRAMP weighted indices
- A link to a Transverse Mercator Calculator to convert latitude/longitude co-ordinates to co-ordinates in UTMs used in EGM on a Transverse Mercator projection with bulk conversion capabilities

Instructions for model use and detailed description of methodology were written and placed on the CRAMP website under the heading "Ecological Gradient Model." This revised version and the accompanying documentation are currently available for download at http://cramp.wcc.hawaii.edu/. Notification of the availability of the information and model was disseminated through various networks such as presentations at symposia, workshops, and public forums (see Section 5.0 Community Outreach) and culmination in a publication in a peer-reviewed journal (Appendix III). Individuals from different user groups are currently assessing the model: Greg Piniak (modeler at NOAA Center for Coastal Fisheries and Habitat Research (CCFHR), Eric Brown (NPS marine resource manager) Danielle Jaywardine (NOAA Pacific Island Resource Office).

3.2 Further expansion and development of indicators

3.2.1 Integration of Project with Regional Watershed Planning

A recent focus on integrated watershed-reef management has emerged to support ecosystem health, resource management, and ecological restoration efforts. This "ridge to reef" paradigm of linking terrestrial with marine systems has currently become a familiar theme throughout the Pacific (USGS, 2008, Richmond et. al 2007).

In the Hawaiian Islands this integrated coastal management concept is fundamentally a modern version of the ancient *ahupua'a* system. This traditional structure of land division and resource management combined watersheds, streams and coastal regions as integral interacting components of an ecosystem (Williams 1992). Today, recognition of the impact of land-derived materials on near-shore regions is a central premise in ecological science that is analogous to this early vision of native Hawaiians. Statewide research and education strategies have been formulated to include integrated, interdisciplinary studies based on this "mountains to the sea" concept. Although numerous examples exist in Hawai'i, the most pervasive include the collaborative Federal and State management Hawai'i Local Action Strategy (Anonymous 2004) and the standards based curriculum "Project *Ahupua'a*" developed by the State of Hawai'i's Department of Education (Hawai'i Department of Education www.k12.hi.us/~ahupuaa).

Although there is general acceptance of the "reef to ridge" connection there has to date been little quantitative evidence of a widespread relationship until now. Two programs examining ecosystem health have developed independently in Hawai'i over the past decade. The Coral Reef Assessment and Monitoring Program (CRAMP) is directed at the assessment of inshore reefs (www.cramp.wcc.hawaii.edu) and the Center for Conservation Research and Training's (CCRT) Hawai'i Stream Research Center (www.hawaii.edu/ccrt) focuses on the condition of streams and watersheds. Both programs developed indices of ecological "health" or condition based on widely accepted quantitative metrics.

Many indices have been developed that include quantifiable ecological metrics that correspond to the structure and function of a system that can be used as indicators for system evaluation. An integrated index can be of great significance in the assessment of relative condition or value of an ecosystem. The extensively used Environmental Protection Agency's multi-metric Index of Biotic Integrity (IBI) (Karr and Chu 1999) was developed to evaluate the health of rivers and streams while the Army Corp of Engineers' hydrogeomorphic model (HGM) has been widely applied to functional aspects of wetlands (Brinson 1993; Magee 1996). These approaches have been used to communicate research findings based on complex scientific data to a broad audience in a straightforward and comprehensible manner.

Although numerous indices have been developed, to the best of our knowledge, no prior research on the correlation of independent indices to validate the "ridge to reef" linkages has been conducted. Collaboration was instigated with Mike Kido of Hawai'i Stream Research Center to explore whether or not there is a relationship between watershed condition as defined by Edmonds and Kido (2006) and reef condition as defined by Rodgers (2005).

Preliminary comparison of the Ecological Gradient Model (EGM) with the Watershed Health Index (WHI) developed by the UH Center for Conservation Research and Training has been completed. Comparison shows correlation between the two indices Table 1). Initial evaluation shows a significant relationship between the watershed and reef indices overall and at south facing sites (Table 1, Figure 1). Results are statistically significant when all sites are compared. This trend is primarily driven by the south facing sites. Within the south facing sites the shallow sites (0-5 m) show the strongest correlation with the watershed because they are most heavily influenced by their proximity to land. Sites located on north and west facing shores are not closely linked to the watershed because they have higher water motion than south facing sites. Terrigenous deposits from the adjacent watershed can contain high levels of organics and small grains that can be indicative of heavily degraded reef communities. Factors highly correlated with coral communities and fish populations include silt and organic sediments. The distance from a reef to a perennial stream also explains a high percentage of the variability in coral factors (Rodgers 2005). This direct linkage from the watershed to the nearshore reef through stream discharge is reflected in the results shown in Table 1. Fine grains of sediment can settle on corals causing suffocation, blocking light, and preventing recruitment. High water motion removes silt thus effects of sedimentation at sites exposed to high water motion and storm surf can be minimized due to the winnowing effect of waves.

Table 1. Linear relationship between reef and watershed indices. Statistically significant correlations in bold.

Pearson's correlation	r value	p-value	r value	p-value	r value	p-value
	0-5 m		**5.5-10 m**		**10.5+ m**	
North	-0.303	0.254	0.144	0.61	N/A	N/A
South	**0.938**	**0**	0.637	0.065	0.543	0.265
West	-0.113	0.79	0.416	0.232	-0.12	0.647
Sheltered	-0.355	0.046	0.154	0.528	0.563	0.023
Combined sites	**0.244**	**0.001**				

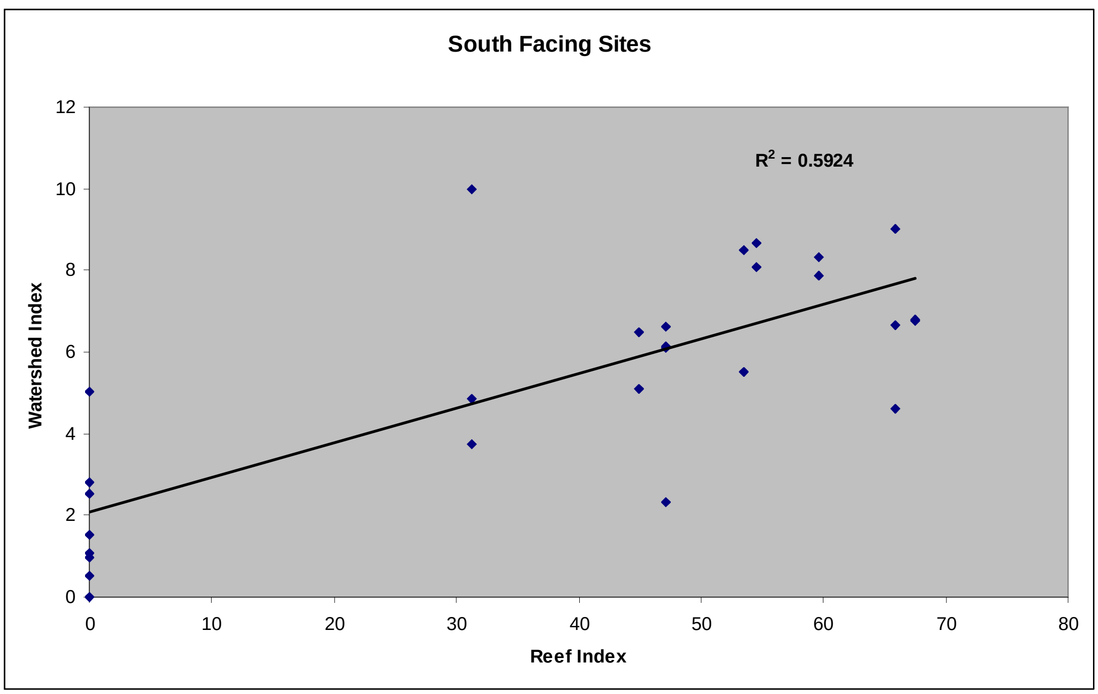

Fig. 1 Correlation of reef index with watershed index for south facing shores of the Main Hawaiian Islands.

Linking these models to water quality data and other information may lead to additional development and further refinement of an acceptable regulatory coral reef index of biotic integrity and/or other biocriteria. Advanced comparison of the EGM with the WHI continues. Dialog of the results with Michael Kido (CCRT) and Linda Koch of the Dept of Health will guide further analyses.

3.2.2 Statistical review

Biostatistician Leska Fore president of Statistical Designs, an environmental service company that specializes in survey design, statistical analysis, regulatory decisions, and integrated monitoring conducted a statistical appraisal at the request of EPA project manager Dr. Wendy Wiltse. Ms. Fore has previously worked with the EPA in testing biological indicators of coral reef condition against human disturbance. She has published extensively on developing bioassessment tools and biological indicators for corals.

A detailed account of her findings can be found in Appendix IV: Statistical Review and Recommendations. She recognizes that the CRAMP biomonitoring program has been successful in "underwater logistics, precision of sampling protocols, selection of candidate metrics, identification of natural driving variables for coral and fish metrics, initial metric testing, data management, and outreach to other stakeholders." In depth suggestions are include in her evaluation. A synopsis of the core recommendations follows:

- *Determine which biological metrics are reliable indicators of human disturbance.*
- *Limit IBI metrics to measures of biological condition.*
- *Consider collecting additional data.*

The iterative process of developing biocriteria from the CRAMP data has been accelerated due to the insightful comments and recommendations specified in this review. In further development of bioindicators for coral reefs we intend to apply some of the specific tests suggested to test biological metrics for association with human disturbance. We have added an option in the EGM to select individual metrics. This is the first step towards including a separate worksheet in the model interface that includes only biological metrics. Additional data will be included as assessments continue. This will increase the statistical power of the database.

3.2.3 Facilitation of cultural index development

Hawaiian cultural indicators have developed over centuries through a plethora of observations and have proven to have practical uses in marine management throughout Hawaiian history. Due to major shifts in social, political and cultural systems over the past century, Hawai‘i has gradually developed a western form of marine and environmental management. Few aspects of the traditional system of marine management remain today. However, recent interest to incorporate some of these traditional practices into the existing management system has arisen. Integrating the large knowledge base, stewardship principles, and management practices of the native people with contemporary science can facilitate in strengthening the ability of modern mangers to insure sustainability of marine resources. Collaboration with He’eia State

Park and Papahānaumokuākea Marine National Monument for development of a cultural index through Traditional Ecological Knowledge (TEK) was established using the ecological gradient model as a template. Paepae o He‘eia (He‘eia Fishpond) Director, Hi‘ilei Kawelo proposed a joint partnership to culturally and biologically assess the health of Kāne‘ohe Bay's coral reefs. The foundation of this project is the ecological gradient model (EGM) to be used to develop a similar index using cultural and biological indicators. This project serves as an exemplary example of the benefits of merging the efforts of traditional and contemporary science to improve management techniques and protect valuable marine resources.

3.3 Publications and reports

The article entitled, "Quantifying the Condition of Hawaiian Coral Reefs**"** by Ku‘ulei S. Rodgers, Paul L. Jokiel, Christopher E. Bird and Eric K. Brown was published in the peer-reviewed journal Aquatic Conservation: Marine and Freshwater Ecosystems during the grant period. This article describes the acquisition and selection of a suite of biocriteria for use in the development of the Ecological Gradient Model to describe reef condition. "Aquatic Conservation is an international journal dedicated to publishing original papers that relate specifically to freshwater, brackish or marine habitats and encouraging work that spans these ecosystems. This journal provides a forum in which all aspects of the conservation of aquatic biological resources can be presented and discussed, enabling greater cooperation and efficiency in solving problems in aquatic resource conservation." Following submission on 15 Oct, 2008, response to reviewers comments along with revisions were submitted on 3 Feb, 2009. The article was accepted by the publisher on 23 March, 2009, proofs were received 4 April, 2009, corrections were made 15 April, 2009, early view of the final published version became available on 3 June, 2009.

The Response to Climate Change Workshop was held at the Hawai‘i Institute of Marine Biology, from Sept 1-5, 2008 by NOAA and the Papahānaumokuākea Marine National Monument. Presentations and discussions on biocriteria, the ecological gradient model, the cultural index, and reef resilience were made by Ku‘ulei Rodgers. Paul Jokiel presented on climate change, bleaching, reef restoration, and indigenous practices on coral reefs. The following publication was finalized in March, 2009.

Carvalho, K.K., B.A.A. Parker, and K. Rodgers. 2009. Proceedings of the fourth Responding to Climate Change: A Workshop for Coral Reef Managers. Marine Sanctuaries Conservation Series NMSP. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. pp 20.

Seven quarterly reports were submitted to the EPA project manager Dr. Wendy Wiltse throughout the grant period. The project concluded with the submission of the final report on 1 Nov, 2009 (Appendix II).

4.0 Other Activities

4.1. Development of reef quality standards for the State of Hawai‘i

Three meetings/working groups were convened by Robin Knox and Linda Koch of the Hawai‘i Department of Health in order to comply with the Clean Water Act requirements for revising state water quality standards. An Integrated Water Quality Reporting Working Group was established to develop water quality standards for Hawaiian coral reefs. Drs. Ku‘ulei Rodgers and Paul Jokiel served on this task group to provide direction and input into developing these standards for reefs. We presented a tool (EGM) and metrics needed to evaluate reefs in a meaningful, simple, and flexible manner. At the present time in Hawai‘i, coral reef environmental protection regulations are based on water quality, but there is increasing interest in supplementing standards with additional biocriteria.

The focus of the working group is on developing coral reef biocriteria that will ultimately be used to supplement water quality standards in the regulatory framework of the DOH. The Clean Water Action Section 101(a) is intended “to restore and maintain the chemical, physical and biological integrity of the Nation’s waters”, yet we do not have a solid understanding or measure of “biological integrity” for coral reefs. Further, Section 303(c) (2) (A) requires that State water quality standards shall protect and propagate a balanced indigenous populations of fish, shellfish and wildlife. Water quality standards alone might not achieve this aim and we have insufficient biological information to support or refute the efficacy of water quality at meeting the goal of protecting reef communities. Use of tools such as the Ecological Gradient Model may bring the state closer to achieving this goal by bringing biological evaluations into the process of protecting coral reefs.

- May 7, 2008 Department of Health Integrated Water Quality Reporting Working Group to develop Ecological Gradient Model for reef quality indicators.
- June 23, 2008 Department of Health Integrated Water Quality Reporting working group. Present workgroup goals, current procedures and regulatory requirements, list of issues for discussion, formation of task groups, task group assignments and schedules.
- Sept 4, 2008 Department of Health Integrated Water Quality Reporting working group. Methodology, rules, and tools.

4.2. Management community presentations and input

During the project period we worked in collaboration with Federal and State management agencies to promote the development and implementation of appropriate biocriteria for coral reefs into the State of Hawai‘i water quality standards. We conducted presentations to the Division of Aquatic Resources (DAR), the Dept. of Health (DOH), and the National Oceanographic and Atmospheric Agency’s Pacific Island Resource Office (NOAA PIRO). We received agency feedback from local managers at DAR and DOH and revised our approach accordingly. Public presentations attended by local managers also became a venue for information dissemination (see Section 5.0 Community Outreach).

- April 27, 2008 Biocriteria presentation with multiple agencies (Division of Aquatic Resources, Department of Health, Environmental Protection Agency). Held at Kalanimoku Building DAR conference room.
- Dec 11, 2008 Dept of Health/EPA Presentation/meeting on biocriteria/indicators to develop water quality standards. DOH conference room.
- Sept 17, 2009 Office presentation and instruction in use of EGM model.

5.0. Community outreach

In addition to presentations to the management community, formal and informal public presentations and community outreach through media coverage were conducted during the three year grant period from 1 Nov 2007 through 31 October, 2009. Twenty-four presentations using data or models derived from this project were given at local, national, and international venues. Four other outreach efforts involved information disseminated through media activities. All presentations, lectures, and interviews were conducted by either Drs. Paul Jokiel or Ku‘ulei Rodgers.

2007

- 19 Sept, 2007 Hanauma Bay public lecture series presentation, “Spatial and Temporal patterns of Hawai’i’s Coral Reefs”. Hanauma Bay Classroom.
- 28 Sept, 2007 Outrigger Hotel Lobby lecture and display in conjunction with the Papahānaumokuākea Marine National Monument.
- 14 Aug, 2007 Hawai‘i Association for Marine Education and Research (HAMER) presentation on monitoring, assessments and modeling University of Hawai‘i Marine Science Building lecture hall.
- 7 Nov, 2007 Kapiolani Community College Ocean 101 class lecture on climate change and bioindicators.

2008

- 22 Jan 2008 Public presentation at Maui Ocean Center “Local and Global Impacts on Coral Hawai‘i’s Coral Reefs” included EGM model demonstration Attended by DAR biologist Skippy Hau, MCC professors, students, and public.
- 8 April, 2008 Kamehameha Schools Marine Science Classes (4) bioindicator and climate change presentations.
- 7-11 July 2008 “Use of replicated coral reef mesocosm studies to establish the potential impact of ocean acidification.” by P. L. Jokiel, K. S. Rodgers, I. B. Kuffner, A. J. Andersson, E. F. Cox, F. T. Mackenzie. Broward County Convention Center Fort Lauderdale, Florida.
- 29-31 July 2008 “Impact of global warming and ocean acidification on Hawaii’s coral reefs” by P. L. Jokiel, K. S. Rodgers, I. B. Kuffner, A. J. Andersson, E. F. Cox, F. T. Mackenzie. Hawaii Conservation Conference. Island Ecosystems: The Year of the Reef, Hawaii Convention Center, Honolulu
- 29-Jul-2008 - 31-Jul-2008. 2008 Hawai‘i Conservation Conference, Hawai‘i Convention Center, Honolulu, HI. Presentation: Developing and Evaluating Coral Reef Biocriteria.
- Sept 1-5, 2008. NWHI-NOAA-HIMB Bleaching workshop, Presentations: The development of an ecological index using biological and environmental indicators

to assess the condition and compare Hawaiian reefs and Reef Resiliency Field Activity. Moku o Loʻe, Kāneʻohe, Hawaiʻi.

- 3 Sept 2008 "Techniques for Bleaching Assessments". NOAA Climate Workshop, HIMB
- 4 Sept 2008 "Reef Restoration" by Paul Jokiel. NOAA Climate Workshop, HIMB
- 5 Sept 2008 "Indigenous Practices on Coral Reefs". NOAA Climate Workshop, HIMB
- 13 Nov 2008 "Impact of global warming and ocean acidification on Hawaii's coral reefs" Northwestern Hawaiian Islands Joint Symposium. Windward Community College

2009

- Jan 5, 2009 Rollins College presentation on climate change and bioindicators.
- April 5-7, 2009. Climate Change Symposium. Local and global panel member and moderator. Exploratorium. San Francisco, CA. "Impacts of Climate Change in the Hawaiian Islands" and "Impacts of Climate Change on Coral Reefs in America"
- March 2-6, 2009 Pacific Science Inter-Congress in Tahiti French Polynesia Climate Change Symposium "Impact of ocean acidification on Hawaiian coral reefs in the 21st century"
- April 5-7, 2009. Climate Change Symposium. Local and global panel member and moderator. Exploratorium. San Francisco, CA. "Impacts of Climate Change in the Hawaiian Islands" and "Impacts of Climate Change on Coral Reefs in America"
- May 7 NWHI semi-annual symposium presentation "Coral Reef Health and Response to Climate Change".
- May 30 Coast Guard Auxiliary presentation on bioindicators and climate change
- June 29 Hawaii Youth Conservation Corps (HYCC) presentation on indicators and monitoring.
- March 2- March 6, 2009. Impact of ocean acidification on Hawaiian coral reefs in the 21st century. P. L. Jokiel and K. S. Rodgers 11th Pacific Science Inter-Congress Sheraton Tahiti in Tahiti, French Polynesia
- May 27-28, 2009. Effects of Climate Change on Ecosystem Services Provided by Hawaiian Coral Reefs P. L. Jokiel The Plight of Ecosystems in a Changing Climate Impact on Services, Interactions and Responses Workshop, EPA Region 10, Plymouth Church, Seattle, WA

Outreach through media

- Jane Liaw- Science Writer Ocean Acidification Interview
- UH Chancellor's office personnel Climate Change Presentation HIMB
- Feb 5, 2009 ScienCentral filming on climate change-Jack Penland
- July 20, 2009 Honolulu Advertiser: Living Green Change Agent on Ocean Acidification

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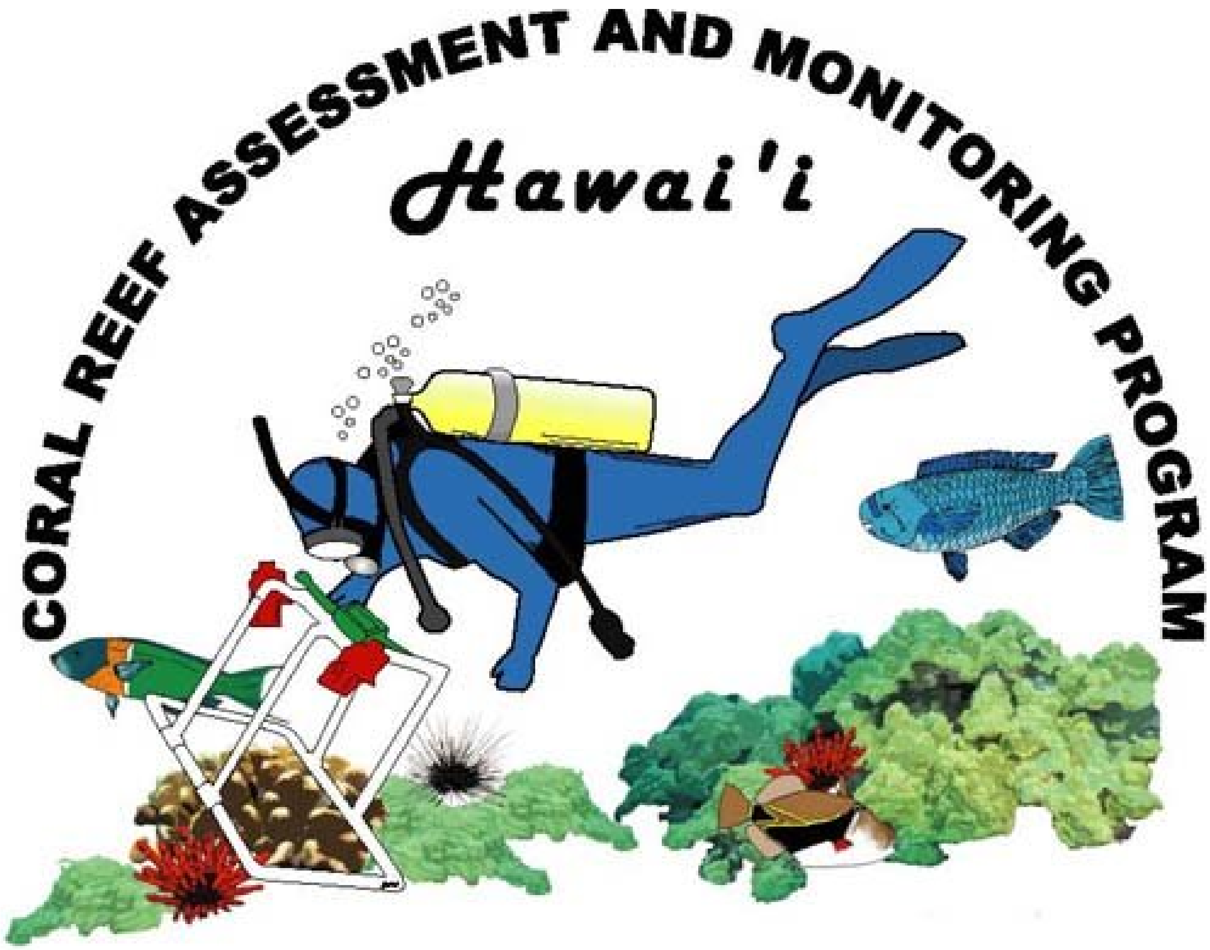
Appendices
Appendix I. Quality Assurance Project Plan

Hawai'i Coral Reef Assessment and Monitoring Program
Quality Assurance Project Plan



1 August, 2008

Development of Coral Reef Biocriteria for Hawai'i
Principal Investigator: Paul Jokiel

TITLE

AND
APPROVAL PAGE

Development of Coral Reef Biocriteria for Hawai‘i

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1. Approved by Project Manager: Date:

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2. Approved by Project QA Manager: Date:

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3. Approved by U.S EPA Region 9 Quality Assurance Manager: Date:

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4. Approved by EPA Project Manager: Date:

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Individuals receiving official copies of this QA Project Plan and subsequent revisions:
Project Manager
Project QA Manager
Region 9 QA Manager
EPA Project Manager
CRAMP Monitoring Team

Individuals receiving official copies of the final QA Project Plan:
Quality Assurance Project Manager: Eugenia McNaughton
Environmental Scientist, Quality Assurance Office: Richard Frietas
EPA Project Manager: Dr. Wendy Wiltse
CRAMP Monitoring Team: Dr. Paul Jokiel, Dr. Ku‘ulei Rodgers, Ann Farrell
Hawai‘i Department of Health: Linda Koch

1.0 PROJECT DESCRIPTION

1.1 Project Purpose and Problem Definition

The purpose of this project is to develop coral reef biological criteria for the State of Hawai‘i working with the Hawai‘i Department of Health , and the Hawai‘i Division of Aquatic Resources to bring current activities into line with the emerging U.S. EPA "Development of Assessment Tools for Coral Reef Biocriteria" program at the national level. This assessment of function of coral reefs will include reefs within the main Hawaiian Islands (MHI). Biocriteria will be used to develop a model using an Index of Biotic Integrity (IBI) to assess reef condition.

1.1.1 Project Goals

Project goals include:

- Refine and extend previous work on biocriteria: Working in close association with State and Federal resource managers with the intent of eventually reaching consensus on establishment of biocriteria standards for Hawai‘i will be a priority. This must be based on an iterative process with feedback from the agency personnel at various points along the way in biocriteria development.
- Addition of additional sensitive bioindicators: Coral recruitment, growth and mortality based on analysis of existing CRAMP photoquad data will be explored. These data are needed in order to define the relationship between water quality, watershed characteristics and condition of the living coral reef communities.
- Integration of Project with Regional Watershed Planning: Key watershed metrics have been an important part of the initial biocriteria and IBI analyses (Rodgers 2005) and will continue to be vital components of analyses undertaken in this project. Watershed area, human population on the watershed, watershed condition and watershed uses are all metrics that will be incorporated. We will work closely with Hawai‘i's Local Action Strategy to Address Land-based Pollution Threats to Coral Reefs (CRLBP LAS). LAS has listed the development of a long-term monitoring program using pollution sensitive indicators as a priority area.
- Addressing Regional Priorities: Development of biocriteria is a priority for Hawai‘i which is not currently being addressed by State agencies due to lack of resources, although there is interest in moving ahead in this area. This project will provide leadership and give the State of Hawai‘i the opportunity to begin the process of developing biological criteria which is already moving ahead in other Region 9 Pacific island areas. The project will provide input to these areas through networking with the Commonwealth of the Northern Mariana Islands under Peter Houck, in Guam under Mike Gawel and in American Samoa under Edna Buchan and Mike Gawel. We also anticipate networking with Lesa Meng and others who are in the process of developing IBI metrics for the Caribbean.
- Addressing National Priorities by strengthening comprehensive state/tribal comprehensive wetland programs in all five major areas:
  1) Regulation; The development and implementation of biological criteria to the Hawai‘i State water quality standards will add an additional dimension that will strengthen regulation.

2) Monitoring and Assessment; Determination of which of the many possible metrics is most important in defining coral reef health will simplify and strengthen monitoring and assessment activities. Only the most relevant metrics need to be assessed or monitored.
3) Restoration; Defining the key metrics of a healthy coral reef system in a given habitat will enable agencies to set standards for restoration. Biological criteria can define the end point of a restored coral reef and allow standards to be set to govern such restoration.
4) Water Quality Standards; Preliminary work (Rodgers 2005) demonstrated that sites that scored the lowest using biological criteria were all on the "most impaired" site list that was established using water quality criteria. Therefore, biological criteria hold promise of supporting and strengthening the value of water quality standards.
5) Public – Private Partnerships; CRAMP has formed a number of effective partnerships in both the public and private sectors. In the private sector we are working closely with the Hanalei Watershed Hui and Limahuli Garden on issues regarding coral reefs.
6) Coordination with other water programs; This project will rely heavily on interaction with the State of Hawai'i regulatory agencies that are responsible for setting biocriteria. Also, we will need to continually interact with programs developing and using biocriteria in American Samoa, CNMI, Guam and the Caribbean.

All of the work done under the proposed project will be carried out within the framework of the Hawai'i Coral Reef Assessment and Monitoring Program (CRAMP), which has been monitoring Hawai'i's coral reefs throughout the state since 1998. Additional information gathered during this project will expand and strengthen the CRAMP efforts in the fields of monitoring and assessment.

1.1.2 Measurement of Success

Measures of Success of this Project:

- The primary standard for measuring success of this project will be the degree of progress towards the establishment of biocriteria for coral reefs as part of the State of Hawai'i water quality program.
- The inclusion of project evaluation seminars will give us an interim mechanism for evaluation and will allow us to avoid possible pitfalls.
- Other tangible evidence of success will be the availability of the completed model, expanded data base, final report and journal articles. All of these will be widely available. The completed IBI and the complete data base will be available as a working IBI model in Microsoft Excel© available on CD or downloadable from the CRAMP web site (http://cramp.wcc.hawaii.edu/).

1.1.3 Anticipated Accomplishments

Relevant Applications:

- This project will promote the development and implementation of biocriteria in the State of Hawai'i and thereby improve the ability of the regulatory agencies to protect the environment.
- The development and testing of a multivariate statistical model to predict conditions at sites not previously surveyed will be valuable in establishing management priorities, regional policy and evaluation of existing programs in the Hawaiian Islands. Application of a model would allow management to implement a preventative approach to environmental degradation.
- Baseline conditions for biological communities will be established. These data will provide a foundation for investigating spatial and temporal change and elucidate the need for protection of future designated marine protected areas and sanctuaries in Hawai'i.

Quality assurance when generating data is an important part of CRAMP activities. To ensure the data generated and used by EPA, DOH and other state and federal agencies, and non-governmental organizations are of known quality and are scientifically valid, CRAMP will follow rigorous procedures in sampling, analyzing, and conducting quality control.

1.2 Project Area Description

A wide suite of factors have been evaluated (Table 1) at 184 transect locations (stations) at 52 sites throughout the MHI (Figure 1). These data will be used to fully develop biological criteria for the state. Station locations can be found in Table 2. Transect numbers for long-term monitoring Coral Reef Assessment and Monitoring (CRAMP) stations are by depth in meters (eg. 3=3m). Rapid Assessment Transects (RAT) stations are numbered in the order they were surveyed due to considerable overlap in depth. Often surveys at stations at the same site were conducted at identical depths.

CRAMP stations are located at long-term monitoring sites to track temporal changes. There are ten 10m benthic transects at each station and four 25m fish transects. RAT stations are an abbreviated version of the CRAMP transects designed to cover a larger spatial area. RAT's include one 10m benthic transect and one 25m fish transect. This assessment technique is robust enough to detect relationships among environmental factors and spatial distributions of reef organisms but not designed to detect changes over time. This RAT protocol was designed to produce quantitative spatial data, consistent and comparable to data recorded at the CRAMP permanent monitoring sites. At both CRAMP and RAT transects depth and topographic relief is recorded and sediments collected.

Table 1 Physical and biological variables evaluated.

Physical Factors		Biological Factors		
Other variables	**Sediment variables**	**Coral Assemblage Characteristics**	**Fish Assemblage Characteristics**	**Algal Assemblage Characteristics**
Rugosity	Composition Organics $CaCO_3$	Total coral cover	Abundance Numerical Biomass Diversity Evenness	Macroalgae Calcareous Turf
Substrate type (sand, silt)	Grain-sizes Medium sand Fine sand Very fine sand Silt/clay	Species *Porites lobata* *P. compressa* *Montipora capitata* *M. patula* *M. flabellata* *Pocillopora meandrina*	Trophic guild Corallivores Detritivores Herbivores Mobile Invertebrate feeders Sessile Invertebrate feeders Planktivores Zooplanktivores	
Human population within 5 km within 10 km Watershed		Species richness	Size classes <5 cm 5-15 cm >15 cm	
Precipitation Distance from a perennial stream		Species diversity	Endemism status Endemic Indigenous Introduced	

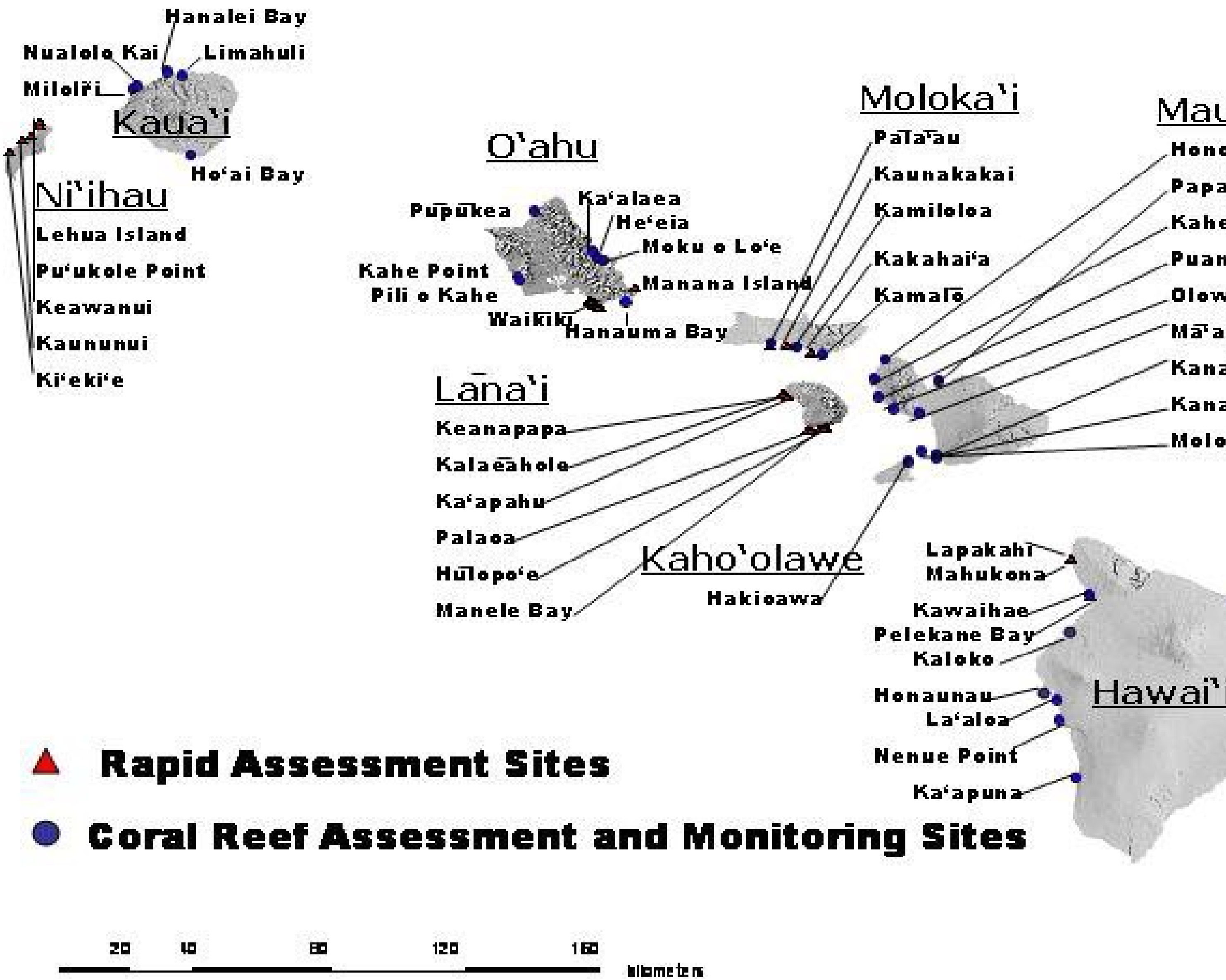

Figure 1 Map of the main Hawaiian Islands showing the reef sites involved in this study. A large body of information on the benthos, reef fish communities, physical environment and watershed characteristics have already been developed for each of these sites and will be used as the starting point of this project.

Table 2 Geographic locations in latitude/longitude for all stations used in development of biocriteria for coral reefs in Hawai‘i.

Site Name	transect	latitude	longitude	Site Name	transect	latitude	longitude
Waikiki	2 RAT	21.260742	-157.829437	Palaoa	4 RAT	20.732122	-156.960351
Waikiki	14 RAT	21.282131	-157.843301	Hulopoe	1 RAT	20.729997	-156.953228
Waikiki	19 RAT	21.250378	-157.799597	Hulopoe	2 RAT	20.733248	-156.949392
Waikiki	24 RAT	21.276219	-157.834991	Kaloko	1 RAT	19.664503	-156.032164
Waikiki	31 RAT	21.257872	-157.828505	Kaloko	2 RAT	19.687830	-156.036499
Waikiki	33 RAT	21.273512	-157.839311	Kaloko	3 RAT	19.686498	-156.035666
Waikiki	38 RAT	21.249226	-157.811671	Kaloko	4 RAT	19.692333	-156.045662
Waikiki	42 RAT	21.264530	-157.827258	Kaloko	5 RAT	19.681667	-156.035002
Waikiki	4 RAT	21.272565	-157.831637	Kaloko	6 RAT	19.675504	-156.034668
Waikiki	22 RAT	21.274340	-157.832288	Kaloko	7 RAT	19.690164	-156.039001
Waikiki	27 RAT	21.252464	-157.809747	Kaloko	8 RAT	19.670663	-156.030163
Keanapapa	1 RAT	20.888888	-157.062505	Kaloko	9 RAT	19.674167	-156.033501
Keanapapa	2 RAT	20.888851	-157.062429	Kaloko	10 RAT	19.671501	-156.031168
Keanapapa	3 RAT	20.889028	-157.062100	Kaloko	11 RAT	19.670000	-156.028832
Keanapapa	4 RAT	20.888703	-157.062133	Kaloko	12 RAT	19.689021	-156.038117
Keanapapa	5 RAT	20.889080	-157.061859	Kaloko	13 RAT	19.675261	-156.035244
Keanapapa	6 RAT	20.889051	-157.061744	Kaloko	14 RAT	19.678666	-156.035353
Kalaeahole	1 RAT	20.877416	-157.053629	Kaloko	15 RAT	19.673375	-156.031991
Kalaeahole	2 RAT	20.877344	-157.053611	Kaloko	16 RAT	19.679358	-156.034053
Kalaeahole	3 RAT	20.878020	-157.053535	Kaloko	17 RAT	19.668387	-156.027890
Kalaeahole	4 RAT	20.877912	-157.053546	Honaunau	1 RAT	19.414062	-155.908066
Kaapahu	1 RAT	20.865816	-157.041440	Honaunau	2 RAT	19.419895	-155.915548
Kaapahu	2 RAT	20.865846	-157.041757	Honaunau	3 RAT	19.423420	-155.913692
Kaapahu	3 RAT	20.865815	-157.041392	Kaapuna	4 CRAMP	19.269974	-155.893775
Kaapahu	4 RAT	20.865794	-157.041152	Kaapuna	10 CRAMP	19.269972	-155.894145
Kaapahu	5 RAT	20.866662	-157.041996	Kawaihae	3 CRAMP	20.028791	-155.832499
Kaapahu	6 RAT	20.866827	-157.042176	Kawaihae	10 CRAMP	20.027849	-155.834351
Kaapahu	7 RAT	20.866652	-157.041938	Laaloa	3 CRAMP	19.589162	-155.972121
Kaapahu	8 RAT	20.866722	-157.041688	Laaloa	10 CRAMP	19.589131	-155.972950
Kakahaia	1 RAT	21.047906	-156.944458	Laupahoehoe	3 CRAMP	19.990941	-155.239161
Kakahaia	2 RAT	21.049198	-156.940775	Laupahoehoe	10 CRAMP	19.991240	-155.238810
Kakahaia	3 RAT	21.047839	-156.944873	Leleiwi	3 CRAMP	19.733860	-155.017922
Kakahaia	4 RAT	21.050302	-156.943935	Leleiwi	10 CRAMP	19.734397	-155.018147
Kakahaia	5 RAT	21.053699	-156.945581	Nenue	5 CRAMP	19.512218	-155.957877
Kakahaia	6 RAT	21.055468	-156.947722	Nenue	10 CRAMP	19.511802	-155.958399
Kakahaia	7 RAT	21.051165	-156.948127	Hanalei Bay	3 CRAMP	22.210926	-159.512125
Kakahaia	8 RAT	21.049635	-156.938085	Hanalei Bay	8 CRAMP	22.210837	-159.511756
Kakahaia	9 RAT	21.057119	-156.950585	Hoai	3 CRAMP	21.879283	-159.474567
Kamiloloa	1 RAT	21.062764	-156.996008	Hoai	10 CRAMP	21.878057	-159.473450
Kamiloloa	2 RAT	21.064334	-156.992812	Limahuli	1 CRAMP	22.224689	-159.575817
Kamiloloa	3 RAT	21.062859	-156.997171	Limahuli	10 CRAMP	22.226813	-159.575487
Kamiloloa	4 RAT	21.065501	-156.996039	Milolii	3 CRAMP	22.152398	-159.719401
Kamiloloa	5 RAT	21.068869	-156.997514	Milolii	10 CRAMP	22.153714	-159.719873
Kamiloloa	6 RAT	21.070631	-156.999838	Nualolo Kai	3 CRAMP	22.160740	-159.701870
Kamiloloa	7 RAT	21.065740	-156.991023	Nualolo Kai	10 CRAMP	22.163274	-159.702823
Kamiloloa	8 RAT	21.067600	-156.992470	Hakioawa	3 CRAMP	20.592518	-156.551066

Table 2. continued

Kamiloloa	9 RAT	21.067992	-157.000509	Hakioawa	10 CRAMP	20.592821	-156.550831
Kaunakakai	1 RAT	21.080257	-157.037643	Honolua N	3 CRAMP	21.015357	-156.639113
Palaau	1 RAT	21.082583	-157.108785	Honolua S	3 CRAMP	21.013829	-156.639608
Puhi Bay	1 RAT	19.732365	-155.047309	Kanahena B	1 CRAMP	20.617407	-156.437392
Puhi Bay	2 RAT	19.735523	-155.049412	Kanahena B	3 CRAMP	20.616897	-156.438321
Lapakahi	1 RAT	20.173866	-155.901921	Kahekili	3 CRAMP	20.936373	-156.693296
Lapakahi	2 RAT	20.174299	-155.900871	Kahekili	7 CRAMP	20.936657	-156.693638
Lapakahi	3 RAT	20.174799	-155.901607	Kanahena Pt	3 CRAMP	20.601428	-156.436959
Lapakahi	4 RAT	20.174226	-155.901322	Kanahena Pt	10 CRAMP	20.601154	-156.437999
Lapakahi	5 RAT	20.173270	-155.901379	Maalaea	3 CRAMP	20.789634	-156.510116
Lapakahi	6 RAT	20.173135	-155.901917	Maalaea	6 CRAMP	20.788873	-156.509927
Lapakahi	7 RAT	20.174309	-155.900421	Molokini Is	8 CRAMP	20.631476	-156.496576
Mahukona	1 RAT	20.184012	-155.901405	Molokini Is	13 CRAMP	20.632331	-156.496379
Mahukona	2 RAT	20.183472	-155.902554	Olowalu	3 CRAMP	20.808594	-156.611522
Mahukona	3 RAT	20.184021	-155.901415	Olowalu	7 CRAMP	20.805806	-156.612315
Mahukona	4 RAT	20.183914	-155.902029	Papaula Pt	4 CRAMP	20.921780	-156.426196
Mahukona	5 RAT	20.183249	-155.901659	Papaula Pt	10 CRAMP	20.924371	-156.426181
Mahukona	6 RAT	20.183995	-155.900995	Puamana	3 CRAMP	20.856101	-156.667192
Pelekane	1 RAT	20.027041	-155.825534	Puamana	13 CRAMP	20.855306	-156.668491
Pelekane	2 RAT	20.027308	-155.825328	Kamiloloa	3 CRAMP	21.037470	-156.897571
Pelekane	3 RAT	20.026557	-155.824722	Kamiloloa	10 CRAMP	21.069651	-157.000227
Pelekane	4 RAT	20.027271	-155.825749	Kamalo	3 CRAMP	21.068169	-157.000920
Pelekane	5 RAT	20.026677	-155.823822	Kamalo	10 CRAMP	21.041603	-156.897282
Pelekane	6 RAT	20.027063	-155.826221	Palaau	3 CRAMP	21.089200	-157.107672
Manana	1 RAT	21.326636	-157.662389	Palaau	10 CRAMP	21.087050	-157.108498
Manana	2 RAT	21.326355	-157.658863	Hanauma Bay	3 CRAMP	21.268430	-157.695355
Manana	3 RAT	21.326907	-157.658983	Hanauma Bay	10 CRAMP	21.267801	-157.693520
Manana	4 RAT	21.326695	-157.659640	Heeia	2 CRAMP	21.447812	-157.809703
Manana	5 RAT	21.327237	-157.659664	Heeia	8 CRAMP	21.447757	-157.809597
Manana	6 RAT	21.327049	-157.660910	Kaalaea	2 CRAMP	21.476647	-157.831483
Kiekie	1 RAT	21.893313	-160.218032	Kaalaea	8 CRAMP	21.476664	-157.831242
Kiekie	2 RAT	21.893400	-160.225737	Pili o Kahe	3 CRAMP	21.372266	-158.141917
Kaununui	1 RAT	21.940690	-160.163332	Kahe Point	3 CRAMP	21.356407	-158.132404
Kaununui	2 RAT	21.940718	-160.163333	Moku o loe	2 CRAMP	21.436210	-157.786698
Keawanui	1 RAT	21.961147	-160.130196	Moku o loe	8 CRAMP	21.436110	-157.786650
Keawanui	2 RAT	21.960990	-160.129400	Pupukea	4 CRAMP	21.646270	-158.065079
Puukole Pt	1 RAT	22.003990	-160.097231	Pupukea	8 CRAMP	21.646872	-158.066147
Puukole Pt	2 RAT	22.004947	-160.097316	Maunalua Bay	1	21.269756	-157.730597
Lehua Is	1 RAT	22.014505	-160.099976	Maunalua Bay	2	21.270407	-157.721214
Lehua Is	2 RAT	22.014165	-160.099470	Maunalua Bay	3	21.265023	-157.715257
Palaoa	1 RAT	20.738703	-156.883881	Maunalua Bay	4	21.272765	-157.731892
Palaoa	2 RAT	20.741368	-156.885399	Maunalua Bay	5	21.271314	-157.734854
Palaoa	3 RAT	20.730906	-156.956787	Maunalua Bay	6	21.272660	-157.726467
Ala Wai	3 RAT	21.68680	-157.507750	Maunalua Bay	7	21.271210	-157.720995
Ala Wai	10 CRAMP	21.167860	-157.50825	Mahinahina	3 CRAMP	20.574360	-156.412520
Ahihi Kinau	1 CRAMP	20.57434131	-156.371986	Mahinahina	10 CRAMP	20.574610	-156.413360

1.3 Responsible Agency and Participating Organizations

The Coral Reef Assessment and Monitoring Program (CRAMP) will take the lead conducting this project. CRAMP is part of the University of Hawai‘i's Hawai‘i Institute of Marine Biology. We will work closely with Hawai`i's Local Action Strategy to Address Land-based Pollution Threats to Coral Reefs (CRLBP LAS). LAS has listed the development of a long-term monitoring program using pollution sensitive indicators as a priority area.

Development of biocriteria is a priority for Hawai‘i which is not currently being addressed by State agencies due to lack of resources, although there is interest in moving ahead in this area. This project will provide leadership and give the State of Hawai‘i the opportunity to begin the process of developing biological criteria which is already moving ahead in other Region 9 Pacific island areas. The proposed work in Hawai‘i will provide input to these areas through networking with the Common Wealth of the Northern Marianas under Peter Houck, in Guam under Mike Gawel and in American Samoa under Edna Buchan and Mike Gawel. We also anticipate networking with Lesa Meng and others who are in the process of developing IBI metrics for the Caribbean.

We are currently working with EPA regional manager Wendy Wiltse to develop biocriteria for Hawai‘i. She has arranged meetings, presentations and workshops with state agencies including the Hawai‘i Department of Health, the Division of Aquatic Resources, and the National Oceanographic and Atmospheric Administration. Dr. Wiltse and the CRAMP team are currently in the process of working with the Hawai‘i Department of Health (DOH) Water Quality Monitoring and Assessment Program. DOH has initiated an Integrated Water Quality Reporting workgroup to bring together diverse expertise and experience necessary to upgrade their water quality evaluation toolbox. Their objective is to establish meaningful, yet simple methods to determine designated use attainment with limited data to develop methods to accurately monitor the quality of Hawai‘i's reefs. Currently, no method exists other than our biocriteria data and we are working with Dr. Wiltse and others to integrate this into their program. She has also arranged collaboration with Leska Fore to further develop biocriteria. Leska Fore is a statistician and biologist working as a statistical consultant for EPA and specializing in issues related to biological monitoring.

1.4 Project Organization Roles and Responsibilities

Overall administrative and program development for the development of biocriteria lies with the Principal Investigator. The PI is responsible for daily activities and has the overall responsibility for assuring quality data are generated and used by CRAMP. Dr. Paul Jokiel will serve as our project quality assurance manager. The Assistant Researcher is responsible for coordinating and overseeing all activities of the CRAMP Monitoring Team while conducting this project. This responsibility will be under the jurisdiction of Dr. Ku‘ulei Rodgers. This includes survey and sample design, data collection, supervision of analytical procedures, validation of data, and preparation of data reports. CRAMP divers will be conducting surveys and collecting data. CRAMP consists of the following individuals (and their roles). See section 5.0 for a detailed description of data collection techniques.

Principal Investigator – Paul Jokiel
QA Officer
Project Leader
Assistant Researcher – Ku'ulei Rodgers
Benthic Data Collection
Co-Project Leader
Benthic and Fish Data Collection
CRAMP Team Members – Ann Farrell, Fred Farrell, Kanako Uchino
Benthic, Fish, Coral, rugosity, and sediment data collection
Assist with underwater equipment

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Hawai'i State Department of Health: Environmental Planning Office-Bioassessment Coordinator Linda Koch
919 Ala Moana Blvd., Rm 312
Honolulu, Hawaii 96814
ph. 808-586-4349 fax. 808-586-4370 <http://www.state.hi.us/health/environmental/env-planning/index.html>

1.5 Permits for Collection of Environmental Measures
The majority of CRAMP sites are in open access areas (Figure 1). Permits for marine protected areas (MPA) have been approved for site installations, data collection and surveys conducted at CRAMP sites within the state of Hawai'i. These include the following.

1) Special Activity Permit # PRO-2008-52 State of Hawai'i Department of Land and Natural Resources Division of Aquatic Resources Issued to: Dr. Ku'ulei Rodgers West Hawai'i Regional FMA1) State of Hawai'i , Department of Land and Natural Resources, Division of Aquatic Resources (DAR) Permits for marine protected areas. Marine Protected Areas included in the permits include Honolua-Mokuleia, Molokini, Pūpūkea, and Puako. All Fisheries Management Areas on the West Coast of Hawai'i were added as a rider to the Honolua-Mokuleia permit PRO-1999-65 and have been renewed annually. These permits are departmental permits and are reissued upon request up to a month prior to expiration. The permits allow placement of stainless steel pins on the inner and outer reef at all sites to identify changes in fish density and coral cover. Placement of settlement plates and sediment traps are permitted activities included in the

Honolua-Mokuleia permit application. These permits have been renewed annually since 1998 by Richard Sixberry of DAR. A Conservation District Use Permit (CDUP) was not required for the activity requested. Copies of the appropriate permits are in the possession of the CRAMP team when activity is occurring in these protected areas. The Department of Conservation and Recreation Enforcement (DOCARE) is informed prior to work at these sites. No activity is conducted until approval and receipt of final permits.

2) State of Hawaiʻi, Department of Land and Natural Resources, Natural Area Reserve System Commission.

A special use permit issued by the Department of Land and Natural Resources for the site ʻĀhihi-Kīnaʻu on the island of Maui, was approved by the Natural Area Reserve System commission (NARS). Prior to field entry NARS and DOCARE staff are notified in advance. This permit is renewed on an annual basis to accommodate long-term monitoring.

3) State of Hawaiʻi, Department of Land and Natural Resources Collecting Permit (covers all sites except MLCD and NARS)

CRAMP scientific collecting activity is covered under a permit issued to the Hawaiʻi Institute of Marine Biology by the Board of Land and Natural Resources. This permit allows collection of certain organisms including all corals, under Section 187-A-6, Hawaiʻi Revised Statutes and other applicable laws. This permit allows collection from all state waters excluding marine protected areas. Results of all collecting activities performed under authority of this permit are reported annually to the Division of Aquatic Resources within a month after expiration, as required. Report of collecting includes the following information: Date of collection, location, common or scientific name, quantity collected and the disposition of specimens.

4) State of Hawaiʻi, Department of Land and Natural Resources, Land Division Site Plan Approval for Monitoring Hawaiʻiʻs Reefs SPA ST 00-20.

This permit was granted for activities and placement of pins at all CRAMP sites under Section 13-5-22, 11-200-8 and 11-200(8)5 of the Hawaiʻi Administrative Rules which allows basic data collection, research, education and resource evaluation. This permit has no expiration date and will be valid until revoked.

5) State of Hawaiʻi, Department of Land and Natural Resources, Kahoʻolawe Island Reserve Commission (www.state.hi.us/kirc/main/home.htm)

ecological changes (http://www.state.hi.us/kirc/ocean/monitoring.html). The KOMP recognizes the need for approaches that complement existing monitoring programs within the state. Goals of KOMP relevant to our common objectives include use of quantitative approaches to monitoring, assuring data integrity and accuracy of data, and making the best use of limited funding resources. CRAMP will continue this partnership in compliance with existing and future regulations and ensure responsible scientific research that is in accordance with KIRC policies and with the KOMP.

1.6 History, Previous Studies, Regulatory Involvement

CRAMP long-term monitoring sites were established in 1998 in response to management needs for temporal monitoring data. Additional rapid assessments were added to encompass as wide a spatial range as possible and to assess spatial variability. Sites on all eight main Hawaiian Islands are included in the sampling design: Hawai'i, Maui, Kaho'olawe, Lānaʻi, Moloka'i, O'ahu, Kauaʻi and Niʻihau (Figure 1). A diverse spectrum of environmental conditions was selected to provide accurate representation of the main islands in the State of Hawai'i. The following criteria were used in the site selection process:

- A range along a gradient of anthropogenic impact from heavily impacted sites to sites with limited human activity;
- Sites with specific impacts including fishing, sedimentation, eutrophication and introduced species ;
- Naturally occurring conditions as close to original as possible;
- Sites that encompass the entire scope of wave exposure and direction;
- Sites that provide a wide range in human population;
- A range of legal protection including sites with various levels of marine protection and open access;
- Wide spatial gradients to encompass longitudinal differences;
- Accessibility.

Permanent monitoring sites are relocated using navigational GPS. Rapid Assessment transects are randomly selected by generating 99 random points onto habitat maps using GPS Pathfinder Office 2.8. To assure adequate coverage of the different habitats and full representation of each site, a stratified design is employed. Points are stratified within depth ranges (<5 m, 5 to 10 m, and >10 m) and habitat types (coral, sand and macroalgae). One-third of the 99 points (33) are used in each of the 3 depth ranges. Within each depth range 1/3rd of the points (11) are generated within each habitat type. Not all habitat types are present at every site. If habitat types are not present, points are divided among the remaining habitat types. Navigational GPS is used in the field to determine the exact position of each point, marking the beginning of a transect. Where habitat maps are not available, a visual assessment of habitat type is conducted and depth is determined using either a depth gauge or fathometer. A random number of fin kicks is used to designate the beginning of each transect.

1.7 Project Schedule

This project two year project is broken down into quarterly tasks (Table 3).

Table 3 Project Schedule

Quarter	**Research Activity**	**State/Federal Agency Feedback on Biocriteria Development Community Outreach**	**Product**
1	Develop EPA Quality Assurance Project Plan Review CRAMP Biocriteria	Initial Presentation on Development of Biocriteria Agencies for Input.	Qtr. Rpt. 1 July 2008
2	Re-analyze data and models	Revise approach as indicated from initial input	Qtr. Rpt. 2 Aug. 2008
3	Testing and Additional Field Studies	Meet with DAR biologists individually from each of the major islands.	Qtr. Rpt. 3 Sept. 2008
4	Complete initial Proposed CRAMP Biocriteria	Present revised model to agencies. Present at Hawai‘i Conservation Alliance Conference	Qtr. Rpt. 4 Quality Assurance Plan Dec. 2008
5	Analysis of data, refine biocriteria and model	Sea Grant Reef Talk Kamuela, Hawai‘i	Qtr. Rpt. 5 Mar. 2009
6	Field test biocriteria and model	Presentation to Molokai Community Association and Hanalei, Kaua‘i community	Qtr. Rpt. 6 June 2009
7	Prepare draft final report on biocriteria –	Solicit additional input from agencies. Hanauma Bay Lecture Series, O‘ahu	Qtr. Rpt. 7 Draft Final Report Sept. 2009
8	Revise and prepare Final Report	Sea Grant Reef Talk Kona, Hawai‘i Final Presentation to Agencies	Qtr. Rpt. 8 Final Report Oct. 2009

2.0 PROJECT DATA QUALITY OBJECTIVES (DQO)

2.1 Data Quality Objectives and

2.2 Data Quality Indicators for Field Activities

Field sampling QC consists of recording and checking survey sheets. The following accuracy checks are conducted on site. Field QC is intended to support a number of data quality goals:

- Fish datasheets are reviewed immediately following the survey by the recorder and one other survey team member to check for misspelling, unusual data, and legibility.
- All field data is entered into a computer spreadsheet at the end of each field day.

The model QC consists of evaluating values and checking accuracy:

- If the ecological index provides a low overall station value (< 2.0) representing impaired conditions then a more detailed assessment will be conducted to confirm the severity of the degraded station. This will include a qualitative visual assessment of the benthic and fish populations.
- If any single metric provides a value outside the normal range of values (±3.0) for comparable stations then a thorough data review will be instigated. Checks of original field datasheets, computer spreadsheets and calculations, and model input will be performed.
- Any outliers or anomolies will be investigated to determine if they are factual. If no inaccuracies are found then the outlier or anomaly will be retained and noted in the statistical analyses.

It is the goal of CRAMP and cooperating agencies to ensure that the reported results from this project are reliable. This goal can be accomplished only by strictly adhering to established procedures in data collection techniques. Prior to CRAMP monitoring surveys, one entire year (1998) was spent on QA/QC to assure the best methodology was applied to answer the questions asked. Where applicable, each measurement parameter used in the development of biocriteria (see Table 1) was assessed for statistical power to ensure the accuracy and precision of the data met our needs.

2.3 Data Review and 2.4 Data Management
The CRAMP ecologists check all data sheets from each survey within 24 hours of its collection. Data checked includes:

- misspellings
- unusual observations
- legibility
- date/time
- blank sections (eg. observer initials)
- site/station name
- species acronyms
- meteorological/oceanographic observations

The observer of any suspect data is questioned to verify the accuracy of the data. The final decision to accept or reject data resides with the CRAMP ecologists, who enter data into an ACCESS database. This database is backed up and stored in several locations.

- Hawai‘i Institute of Marine Biology Coral Reef Ecology Lab, Moku o Lo‘e, O‘ahu, Hawai‘i
- National Parks Service Kalaupapa, Moloka‘i, Hawai‘i Marine Program Office
- Division of Aquatic Resources Regional Office, Maui, Hawai‘i

All photographic images used in data analyses, PhotoGrid files (csv, pgc), Photoquad images, excel files are archived annually at the National Oceanographic Data Center (NODC) located on the University of Hawai‘i campus under the direction of Mr. Patrick Caldwell. The data format is updated as new formats become available (eg. floppy disc to CDs to DVDs). These data and images are also stored at the Hawai‘i Institute of

Marine Biology Coral Reef Ecology Lab, Moku o Lo‘e, O‘ahu, Hawai‘i in two separate buildings to assure perpetuity. Sediment remains after ashing are housed in air tight bottles, labeled, cataloged and placed in secure containers at the Hawai‘i Institute of Marine Biology’s Coral Reef Ecology Lab.

Data management is an important part of any long term monitoring program. Collected data are worthless if they can’t be analyzed and used to make sound management decisions. The five CRAMP ACCESS databases are designed to reflect the objectives of the marine monitoring program (Figure 4).

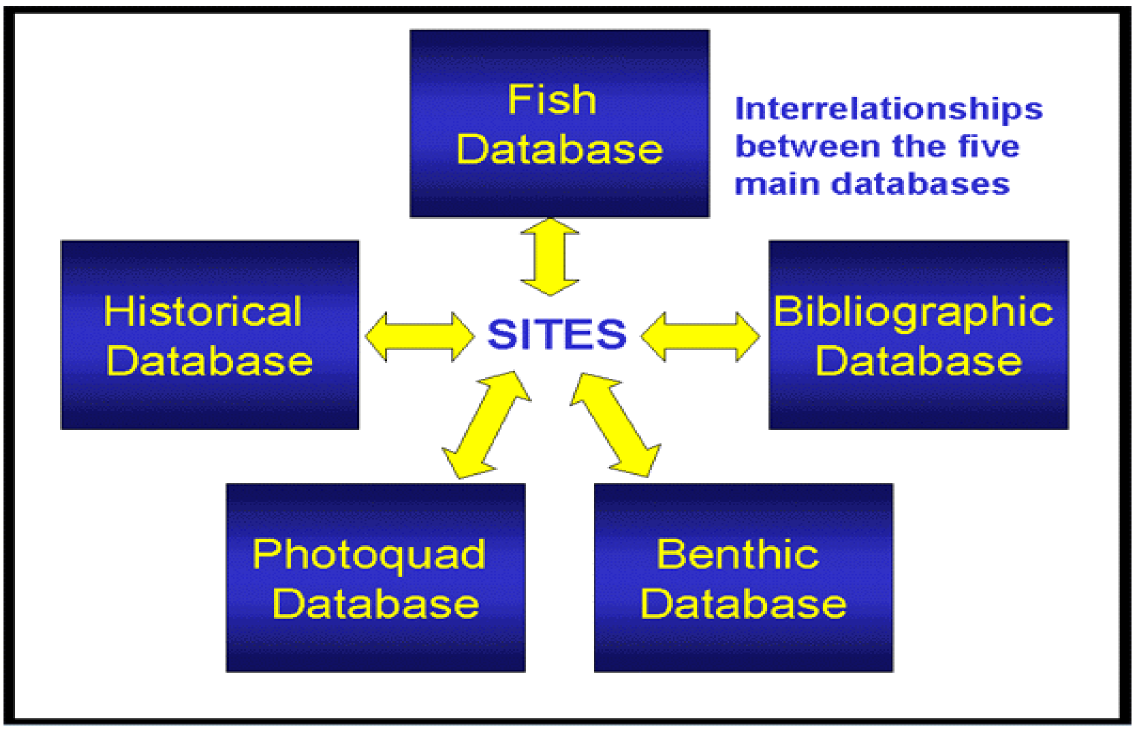

Figure 4. The five databases maintained for this project

.

Detailed records are kept in both hardcopy and digital formats. Records include:

- information on number and names of participants for each survey
- Site name, location, and dates surveyed
- Diving profiles for each dive team
- Tasks completed

CRAMP files all original data sheets and provides copies to the other agencies upon request. The original data sheets are kept on file for a minimum of ten years.
The final decision to accept or reject data resides with the lead biologist. Data is entered into CRAMP ACCESS long-term database. These data are backed up in locations on the islands of O‘ahu, Maui, and Moloka‘i. All electronic media used for photographic and video type surveys is filed indefinitely at the Hawai‘i Institute of Marine Biology. It is also archived for perpetuity at the National Ocean Data Center (NODC). Data is transferred to other media as technology advances. The CRAMP website at

www.cramp.wcc.hawaii.edu has been created and maintained to disseminate results. Request for data are open to any federal, state, non-profit, or educational agency or group. To insure the integrity and accountability of the data a single data manager (Dr. Eric Brown) maintains and updates the original databases.

2.5 Assessment Oversight

The only samples collected and shipped away from collection sites are sediment samples. Samples are processed at the HIMB, Coral Reef Ecology lab. Processing includes grain-sizing and composition determination. Replicate samples are taken from each of two subsamples collected from every transect. No chemical or hazardous processing is conducted. The capability of this laboratory is assessed by the UH Environmental Health and Safety Office (EHSO) which ensures safe campus environments through the development and administration of health and safety programs critical to the university experience. The EHSO Lab Safety Program oversees emergency safety showers, eyewash equipment, and lab ventilation. Any employee exposure to chemical and physical hazards in campus laboratories are identified, evaluated, and controlled. Chemical and lab safety training is required. Labs are certified annually by the EHSO. The HIMB lab has the capability and capacity to provide analytical services for the sediment processing. Standard Operating Procedures are used in sediment processing.

2.6 Acquired and/or Secondary Data or Non-direct Measurements

Data acquired from existing sources have been reviewed by the primary agency disseminating the data. Metadata is supplied for all GIS layers. Data quality assessment to determine their adequacy for use in this project is conducted by the Principal Investigator, Dr. Paul Jokiel and GIS expert, Erin Naughton. The data are reviewed to verify the original source, identify similar uses, and evaluate literature. Secondary data acquired from sources other than CRAMP surveys to aid in identification of indicators include:

- Wave data

Quantification of all wave variables are generated using significant wave height and mean wave direction from Naval Oceanographic WAM models (www.navo.navy.mil). Hawaiʻi forecasts are generated from data collected by instruments on buoys surrounding the Hawaiian Islands. Wave factors used in data analysis include mean, minimum and maximum annual and seasonal wave heights and mean annual wave direction.

- State of Hawaiʻi GIS basemap layers for Watershed, Streams and Precipitation

Terrestrial variables used in statistical analyses include total watershed area, mean annual precipitation, and perennial stream lengths. All geographic information system layers were obtained from the State of Hawaiʻi GIS database (www.state.hi.us/dbedt/gis). The geographic extent of the watershed layer encompasses the eight MHI while rainfall contours cover the six largest Hawaiian Islands. Watershed unit boundaries were originally generated in Arc/Info and GRID using USGS Digital Elevation Model data

(1995). The State Department of Land and Natural Resources served as the original source of median annual precipitation data.

- Political boundaries and administrative layers include census tracts and blocks.

Population data were originally five county layers downloaded from www.geographynetwork.com and merged into a single layer. The geographic extent of the latest 2000 census tracts and blocks covers the entire main Hawaiian Islands (MHI).

- Physical features and basemap layers included; coastline, hillshade, islets and perennial streams.

The Commission on Water Resource Management, Hawaiʻi Stream Assessment Project provided the original perennial stream data (1993).

The data projection for all layers is Universal Transverse Mercator (UTM), Zone 4 (meters), Old Hawaiian Datum. Projection conversions were applied to geographic coordinates for georeference compatibility using the ArcView extension, Hawaiʻi Datums and Projections and the software program, Corpscon. Distances were calculated utilizing the Spatial Analyst version 1.1 extension for ArcView GIS version 3.1.

3.0 FIELD STUDY DESIGN/MEASUREMENT PROTOCOLS

Transects (184 at 52 sites were selected for use in this project. Site names and location can be found in Fig. 1 and Table 2. Survey data from 2001-2002 was selected for use in this project due to the completeness of the data set. A diverse spectrum of environmental conditions were selected to provide accurate representation of the main islands in the State of Hawai'i. The following criteria were used in the site selection process:

- A range along a gradient of anthropogenic impact from heavily impacted sites to sites with limited human activity;
- Sites with specific impacts including fishing, sedimentation, eutrophication and introduced species ;
- Naturally occurring conditions as close to original as possible;
- Sites that encompass the entire scope of wave exposure and direction;
- Sites that provide a wide range in human population;
- A range of legal protection including sites with various levels of marine protection and open access;
- Wide spatial gradients to encompass longitudinal differences;
- Accessibility.

For each transect that following data is collected:

- 20 photographic images are taken on each 10m transect. Each image covers an area measuring 50x69 cm.
- Fish number, species, and length are recorded along each 25x5 meter transect.
- Two 2 kg sediment samples are taken along each 10m transect where sediment is first found.

- A rugosity measurement is taken along the center of the transect line. Rugosity chain is marked with flagging tape at 1m intervals. Any segment less than 1m is measured against the transect line.

Accuracy Assessment of Benthic Transects

This research program employs proven cost-effective techniques and methods most commonly employed throughout the world by scientists and resource managers to assess impact of natural and anthropogenic change on coral reefs. This approach was selected because resource managers continually report that the amount of money available is too small to allow use of untested, complex and unproven techniques based on molecular, physiological or advanced analytical chemistry. Local managers require biological criteria that can be measured with the skills and budgets currently available to them.

CRAMP was established in 1998 to monitor and detect change in coral cover on Hawaiian reefs. Three steps were used to evaluate appropriate techniques for the program (See Brown et al. 2003)

- First, methods and results from five previous or ongoing monitoring programs in Hawai‘i using different sampling procedures were investigated for precision and statistical power.
- Second, input was solicited from long-term coral reef monitoring programs in Florida, the Caribbean, and the Great Barrier Reef.
- Third, field trials were conducted to examine the following parameters in various sampling designs; Repeatability and appropriate length of the transects, number of transects/samples, number of frames/subsamples, cover estimation techniques, observer variation, and time and monetary constraints.

Historical methods generally had low statistical power to detect change due to low precision and small sample size. Power varied from 0 on transects with quadrats to 0.95 for fixed photoquadrats. Sampling designs with low statistical power had long transects (50m) in heterogeneous habitats with moderate coral cover (20-60%).

Existing programs outside of Hawai‘i highlighted the following;
1.) Video transects were recommended as a cost-effective method to analyze the substrate,
2.) Digital video was preferred over analog due to higher image resolution and better data retention,
3.) Fixed transects were endorsed over random transects,
4.) Statistical power as a tool to evaluate the appropriateness of the selected sampling design was seldom used.

Field trials indicated that repeatability of conventional transects or quadrats had high variation unless efforts were made to reposition the sampling units with greater precision. Statistical Power to detect change in coral cover decreased dramatically when coral cover was greater than 20%. Longer transects (e.g. 25m and 50m) fared well in homogeneous substrates but shorter transects (e.g. 10m) were more appropriate in heterogeneous habitats. Variability between observers analyzing the same data was low in comparison to other sources of error.

Visual estimation techniques were cost effective but did not permit data archiving, collected the smallest amount of data per unit of field time and consequently had lower power. Digital video had the highest initial monetary investment but yielded the largest quantity of data per unit of field effort. Video results indicated that 10m transects could detect a 10% change in coral cover with high statistical power (P>0.80) using 50 points per frame, 20-30 frames per transect and 8-10 transects/depth. Fixed photoquadrats with high precision were also recommended to address questions on recruitment, growth and mortality. Standardized techniques for CRAMP were structured so that resource managers could generate sound decisions based on data collected with a statistically defensible sampling design.

Database storage and initial analysis was conducted in Access 97 and Excel 97. Two separate analyses were conducted; determination of precision of field techniques sampled over a short temporal scale (Sale 1997) and power estimation of previous and current studies. Percent data were subjected to an arcsin-square root transformation prior to testing. Power estimation was calculated for repeated measures ANOVA and nested 2 way ANOVA designs using methods described in Cohen (1988), Green and Smith (1997) and Zar (1999). Paired t-tests were used in the precision comparisons instead of a repeated measures ANOVA due to the unequal sample sizes between different transect lengths.

Repeat photoquadrats and point-intercept quadrat data showed high variability and consequently low precision. Longer transects had higher mean percent difference between quadrats (e.g. 25m at Kāne‘ohe – 15.9% ± 9.8) than shorter transects at the same location (e.g. 10m at Kāne‘ohe – 10.0% ± 14.6). Variability between mean differences for both transect lengths (10m – 7.5% ± 7.6 and 25m – 8.9% ± 6.7) was reduced by placing temporary pins every 2m along the transect. The pins reduced transect movement during the survey and allowed more accurate repositioning of the line during subsequent surveys. At Molokini Island, Maui, transect length of 50m had the lowest precision with the highest mean percent difference (23.7% ± 18.1) among quadrats.
Photoquadrats produced statistically higher estimates of coral cover than planar point intercept for the same quadrats sampled (10m transect, t=-2.7, df=9, p=.025; 25m transect, t=-2.3, df=16, p=.032). The mean percent difference between comparable quadrats, however, was quite similar between methods (Table 4). The variability between quadrats for the 10m transect (10.6% - PPI vs 10.0% photoquadrat) was more comparable than the mean percent differences for the 25m transect (10.9% - PPI vs 15.9%

photoquadrat). Neither method, however, yielded satisfactory precision. Variability between observers analyzing the same data was low for both transect lengths.
The variability in methods prompted CRAMP to place permanent pins every 10m, select transect lengths of 10m, use 20 frames per transect, and generate 50 random points on each frame. This greatly increased precision and accuracy allowing the long-term monitoring transects can detect a 10% change in total coral cover.

Table 4: Precision of repeated measures. PPI= Planar-point intercept, TL = transect length, SD = standard deviation, %CC = percent coral cover

Method	Site	Date1	Date2	TL	N		**Mean % difference**	SD	%CC
PPI	Kāne‘ohe	12/2/98	12/4/98	10m	17		**10.6**	11.8	47.6
		12/2/98	12/4/98	25m	31		**10.9**	9.7	33.5
Photoquad	Kāne‘ohe	12/2/98	12/4/98	10m	20		**10.0**	14.6	55.1
		12/2/98	12/4/98	25m	72		**15.9**	9.8	39.9
	Kāne‘ohe	12/17/98	12/18/98	10m†	20		**7.5**	7.6	41.7
		12/17/98	12/18/98	25m†	50		**8.9**	6.7	40.5
		12/17/98	12/18/98	10m*	10	Same Obs.	**7.5**	7.6	
		12/17/98	12/18/98	10m*	10	Diff. Obs.	**10.4**	10.0	
		12/17/98	12/18/98	25m*	25	Same Obs.	**8.9**	6.7	
		12/17/98	12/18/98	25m*	25	Diff. Obs.	**8.3**	5.5	
	Molokini	10/10/98	10/11/98	50m	32		**23.7**	18.1	35.2

† Pins placed every 1m to reduce transect movement
* Same transects used but different observers on photo analysis

Precision of digital video transects
Analysis of standard deviation in 10 point increments indicated that optimum number of points per frame appeared to be around 50 (Figure 2).

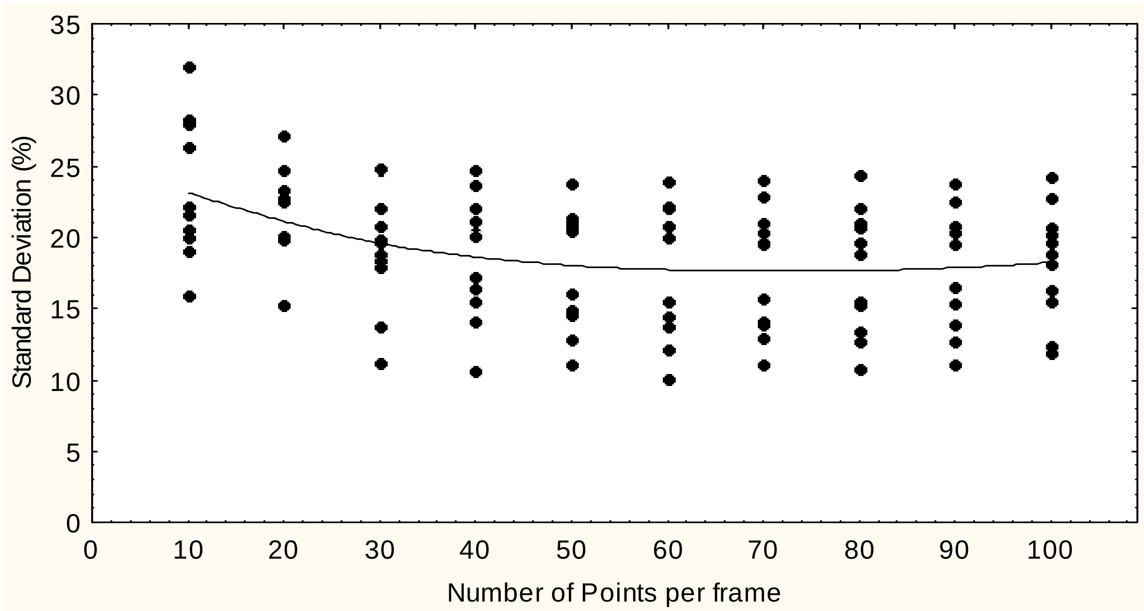

Figure 2. Relationship between standard deviation of mean coral cover versus number of points sampled per frame for transects surveyed in Hanauma Bay.

This was illustrated by the weighted least squares curve leveling off at about 50 points per frame. Precision was higher with more points but so was effort. Another approach to determining optimal number of points per frame was to examine the interaction term in a 2-way ANOVA for transects sampled at 2 times in close proximity. Theoretically, coral cover estimates should be reasonably similar between the surveys and any trends in coral cover should also be similar. Ten points per frame showed a different trend in coral cover over time compared to 50 and 100 points sampled per frame ($F_{2,20} = 8.29$, $p<.0024$).
To examine how accurately the point method characterized true substrate cover we mapped out the coral cover using visual estimation with a grid placed on the screen (Dethier, et al. 1993). A similarity matrix was constructed and different observers had very similar estimates (~95%) using the visual technique. These values also corresponded well to the estimates from 50 and 100 points per frame (> 85% similarity). In contrast, 10 points per frame had less than 80% similarity with the other estimation techniques. Though the sample size was small (N=10 frames), the overall impression was that 50 and 100 points per frame provided a reasonable estimate of what was truly on the substrate from a 2D perspective.

Power analysis for digital video and digital stills
Power curves were constructed for the number of points per frame and number of frames per transect using methods described by Zar (1999). The target sample size (number of transects) was set to detect a 10% change (effect size) in coral cover across 2 time periods. Number of frames was more important in increasing power than number of points though the difference was not substantial (Figure 3).

Statistical power provides a measure of confidence or probability that a false null hypothesis will be correctly rejected (Zar 1999). If there is a change CRAMP would be able to detect it. The null hypothesis is that there is no change in benthic abundances at

CRAMP sites over time. Power analysis was carried out to assess which methods provide enough power to detect this change. Power calculations yield a probability (β) of encountering a type II error (incorrect acceptance of a false null hypothesis) based upon the number of and variance among replicate transects (Zar 1999). Power is directly related to precision which increases with replication.

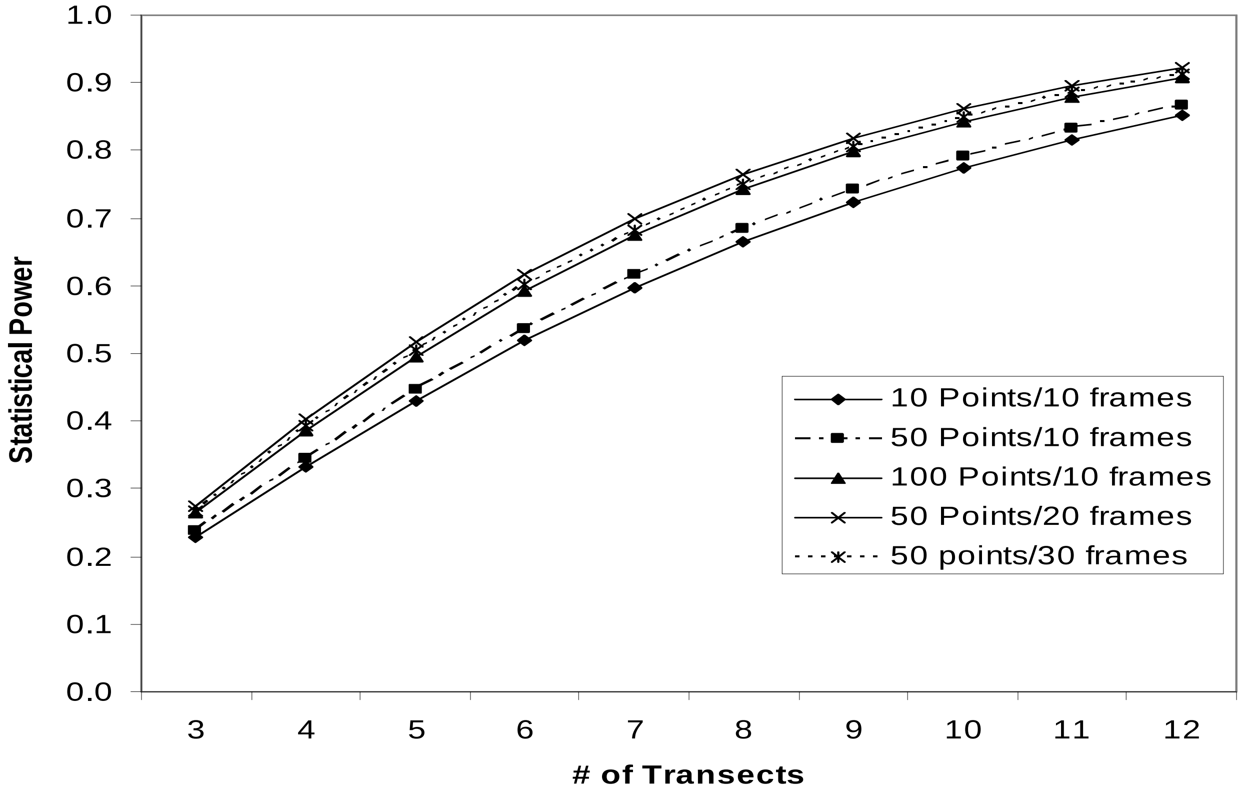

Figure 3 Power analysis for number of transects with different numbers of points/frame and different number of frames/transect (Zar, 1999).

For example, the power for 50 points using 20 frames is higher than 100 points using 10 frames even though the total number of points examined is the same. This is primarily due to the fact that more frames sample a larger portion of the habitat, which incorporates more of the heterogeneity of the substrate. A sample size of 10 transects per site appeared to be adequate for characterizing the coral cover using a power value of 0.8 set as a convention by Cohen (1988).

Accuracy assessment of visual fish census methods

Observer variability was compared each time before a new observer conducted fish transects. This calibration minimized observer variability. Two divers swim parallel 25 by 5-m transects in similar habitat separated by 10 m until there is no significant difference as determined by a students t-test. For example, the first trial conducted on the forereef at Hoai Bay, Kaua‘i, in December 1999 showed there were no significant differences in number of fish 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. All subsequent visual census fish data were collected using only observers calibrated in this manner.

Prior to observer calibrations, biomass estimates derived from underwater estimates of fish lengths during the study were also carefully calibrated. This improves the accuracy associated with fish length measurements. The methodology selected compares observer length estimates with those of plastic-laminated or wooden painted fish models. Fish models ranging in size from 5–30 cm are comprised of several different species with varying shapes. Fish are attached to a weighted line using snap swivels. Each diver swims along the transect line estimating the total length of each fish model. Divers then return along the transect line and measure actual length of models. Fish are changed and trials continued until diver estimates are within one cm of actual lengths.

Spatial and temporal variability of fishes can be extremely high due to mobility and large home ranges. Many fish species are cryptic, rare or transient. There are also diurnal/nocturnal and seasonal sources of variability. Fish surveys are susceptible to highly variable data collection. Complex interactions and numerous causal relationships add to this variability. Causes of variability have been attributed to chance distribution of individuals, local disturbances, animal movement, statistical and methodological limitations, error and environmental heterogeneity. This variability can significantly reduce statistical power (Brown et al. 2003). To quantify absolute values for fish populations an extremely large sample size is required especially for heterogeneous habitats thus, only relative values were used to determine differences between CRAMP sites.

When working with such an extensive, diverse database involving numerous parameters, multivariate techniques are commonly used to group similar sets of samples. This type of analysis is highly efficient in summarizing data for intrinsic analysis of ecological communities (Gauch 1982). Multivariate analysis can reveal the distribution of species along environmental gradients, highlight patterns in the data through spatial comparisons and habitat characterization, clarify habitat relationships and reveal trends and patterns with minimal expression of the noise typical in community data. With ordination techniques, similar entities are placed close to each other while dissimilar species or samples are located far apart in ordination space. In community analysis involving large data sets that have several community gradients and high variability, as in the case of this research, detrended correspondence analysis (DCA) and non-metric multidimensional scaling (MDS) have been shown to be highly effective (Gauch 1982; Clarke and Warwick 2001). These robust methods of multivariate analysis are relatively free from distortion and give equal emphasis to all data. These quantitative techniques are useful in identifying differences in community types and environmental gradients.

3.1 Physical Characteristics

3.1.1 Sediment

Sediment Grain-size Procedure

Standard brass sieves were used to determine size fractions: 2.8 mm, 500 µm, 250 µm, and 63 µm (USA Standard Testing Sieve: A.S.T.M.E.-11 specifications). A brass catch pan was used to collect the silt/clay fraction. Five size fractions were determined: granule (>2.8 mm), coarse and very coarse sand (500 µm-2.8 mm), medium sand (250-

500 μm), fine and very fine sand (63-250 μm), and silt/clay (<63 μm) in accordance with the Wentworth scale (Folk 1974). Each size fraction was collected in pre-weighed Whatman 114 wet strength filters, air dried and weighed to determine the proportion of each size fraction. Extremely large pieces were removed prior to sorting to reduce variability and eliminate overweighting of some samples by a single piece of material. Only the four smallest size fractions were used in the analyses.

Sediment Composition Procedure

Approximately 2 Kg of sediment are collected with a disposable scoop along each transect at each site and secured in Nasco™ Whirlpak 18 oz (532 ml) sample bags. Samples are air dried for two weeks (Parker 1983; McManus 1988; Craft et al. 1991). To determine the inorganic-organic carbon fraction, 20 g of bulk sediment is finely ground using a mortar and pestle. Subsamples are taken from each replicate to determine variability. Samples are then oven dried for 10 h at 100 ^{o}C to remove moisture, placed in a desiccator and massed. To remove the organic fraction, 10 g were burned in a muffle furnace for 12 h at 500 ^{o}C (LOI_{500}), placed in a desiccator and massed (Parker 1983; Craft et al. 1991). For removal of carbonate material, samples are placed in a muffle furnace for 2 h at 1000 ^{o}C (LOI_{1000}), cooled in a desiccator and massed (Craft et al. 1991). The percent organic material and the carbonate fraction are calculated from these data.

3.1.2 Rugosity

Rugosity measurements to determine topographical relief and spatial complexity were conducted along each transect. A 15 m chain marked at 1 m intervals with 1.3 cm links was draped along the length of the transect (10 m) following the contours of the benthos. An index of rugosity was calculated using the ratio of the reef contour distance as measured by chain length, to the linear, horizontal distance (McCormick 1994).

3.1.3 Depth

Depth was determined at each transect with an electronic depth sounder at the surface. To provide a range of depths along the entire transect a digital dive computer (Suunto) was used on the benthos.

3.2 Biological Characteristics

3.2.1 Habitat Assessment

To assess the characteristics of benthic populations, high resolution digital images are taken along a 10 m transect using an Olympus 5050 zoom digital camera with an Olympus PT050 underwater housing. The camera is mounted to an aluminum monopod frame, 1.7 m from the substrate to provide a 50x69 cm image. A 6 cm bar provides a measurement scale. The software program PhotoGrid (Bird 2001) is used to quantify percent cover, richness and diversity of corals, algal functional groups and substrate cover. Images are downloaded and the 20 non-overlapping images from each 10 m transect are imported into PhotoGrid where 50 randomly selected points are projected onto each image. These data are saved in a comma separated values (CSV) file, proofread in Excel and imported into Microsoft Access XP, a relational database. Access data is queried and exported to statistical programs for analyses.

3.2.2 Statistical Analyses

Past analyses were conducted as follows. Any further statistical analyses required will be performed in the same manner.

Transformations

In order to determine whether transformations were appropriate, prior to analyses, residual distribution, partial regression plots and coefficient of variation were examined. Data transformations were conducted to satisfy the assumptions of normality, linearity, and homogeneity of variance required for some of the formal statistical tests performed. To determine the best transformation, histograms and normality plots were generated. Normality was assessed using the Ryan-Joiner test, which is similar to Shapiro-Wilk. Direction and strength of skewness were determined since strong skew can cause leverage problems. Partial regression plots were generated to determine leverage. Since large data sets such as the one this research generated are quite robust against normality violations due to the central limit theorem, data were left in its original form whenever possible. Independent variables that were calculated as percentages and species data containing numerous zero values were transformed.

The transformations used to meet the assumptions of normality and homogeneity of variances included:

- Arcsine square-root, in which variables in percentages were changed to proportions in order to normalize data and obtain a continuous variable. Distributions of proportion data are skewed because they are between 0 and 1 and thus have no tails. Arcsine transformation was used to stretch out the tails on both ends for a more bell-shaped, normal distribution. These are useful in extreme proportions <0.2 or >0.8. Data in degrees was changed to radians.
- Log transformation, in which variables with high positive skewness were log transformed.
- Log (X+1) transformation, in which variables that are counts were log(x+1) transformed to reduce skewness. Variables that contained zero values were also log(x+1) transformed because the log of zero is undefined.
- Square root (X+1/2), in which coral species abundances were square root (X+1/2) transformed since the community ecology matrix is sparse, containing few non-zero values.
- No transformation applied, in which data with a coefficient of variation below 100% were retained in their original form.

Univariate and Multivariate Statistics

Statistics were computed with Minitab 13.0. Explanatory variables were selected from among 23 environmental predictors. To avoid multicolinearity, variables that were highly correlated (>90%) were dropped from the analysis without loss of information (Clarke and Gorley 2001).

Coral species richness data may not be suitable for use as a response variable since it is strongly dependent on sampling effort and observer variability, making it difficult to

compare across sites. Richness values were determined from coral cover data. Some species of corals may be missed in data collection.
Diversity was not used as a response variable since coral diversity is low in Hawai'i and may not be an appropriate indicator of environmental conditions in this region. Hawaiian communities are often dominated by a few primary species where diversity does not decline with decreasing latitude as in other regions (Grigg 1983). Due to geographic isolation, corals in Hawai'i are depauparate relative to the Indo-West Pacific. Only 16 genera containing 42 species have been documented from the Hawaiian Islands. Difficult field identification and detection of cryptic or deep species and low digital resolution may also reduce the predictive ability of diversity.

To determine which environmental variables best explain coral cover and species richness, a general linear multiple regression model was used. Stations without coral were removed prior to analysis. Of the 184 stations at the 52 sites, 12 had no coral cover. Coral cover and species richness were regressed against the following environmental variables: rugosity, depth, sediment composition and grain-sizes, wave parameters, human population parameters, precipitation, distance from a perennial stream, and watershed area. A Best Subsets routine was utilized in Minitab 13.0, applying Mallows C_p and R^2 as the criteria in model selection. A lack of fit test was conducted to verify the model selection. Coral diversity was not used as a response variable since coral diversity is relatively low in Hawai'i and digital quality may restrict detection of small or cryptic species.

Ordination methods were used to highlight patterns in the data through spatial comparisons and habitat characterization. Ordination techniques can clarify habitat relationships and reveal trends and patterns with minimal expression of the noise typical of community data (Gauch 1982). Sample and species relationships are represented in a low-dimensional space with ordination techniques. Similar entities are placed close to each other while dissimilar species or samples are located far apart in ordination space allowing a visual representation of sample similarity.
Multivariate statistical analyses were conducted using Primer 5.0 and Multivariate Statistical Program version 3.0 (MVSP). These include the following statistical tools and techniques:

- Correspondence analysis (CA) was performed on data from the six most abundant coral species in Hawai'i: *Porites lobata, P. compressa, Montipora capitata, M. patula, M. flabellata and Pocillopora meandrina.*
- A site similarity matrix was generated to evaluate coral species distributions.
- A BIOENV procedure was used to link biological data to environmental data so that patterns in coral communities could be identified.
- SIMPER was used to determine the contribution of each species to the dissimilarity between sites.

3.2.3 Fish Data

Fish populations are quantified using standard visual belt transects (Brock 1954). SCUBA divers swim along one 25 m x 5 m transect (125 m^2) at each station recording species, quantity and total fish length. All fishes are identified to the lowest taxon possible.

Total length is estimated to the nearest cm in the field and converted to biomass estimates (tons/hectare) using length-weight fitting parameters. In order to estimate fish biomass from underwater length observations, most fitting parameters were obtained from the Hawai‘i Cooperative Fishery Research Unit (HCFRU). Additionally, locally unavailable fitting parameters were obtained from Fishbase (www.fishbase.org) whose length-weight relationship is derived from over 1,000 references. Congeners of similar shape within certain genera were used in those rare cases lacking information.
Conversions between recorded total length (TL) and other length types (e.g. fork length FL) contained in databases involved the use of linear regressions and ratios from Fishbase linking length types. A predictive linear regression of logM vs. logL was used in most cases to estimate the fitting parameters of the length-weight relationship. Visual length estimates were converted to weight using the formula $M = a \square L^b$ where M=mass in grams, L=standard length in mm and a and b are fitting parameters.
Any anomalous values are detected by calculating a rough estimate for a given body type. The general trend for a 10 cm fish of the common fusiform shape should be approximately 10 g. Gross deviations were replaced with values from the alternate source.

Trophic levels for fish species are determined using published Fishbase data. The trophic categories included: piscivores, herbivores, detritivores, mobile and sessile invertebrate feeders, and zooplanktivores.

Statistical Analyses

CRAMP transects are standardized to meet statistical compatibility requirements with RAT transects by randomly selecting one of the four 25 m transects at each station. CRAMP and RAT transect differences are explained in Section 1.2 on page 7 of this plan. Minitab 13.0 was used to perform all univariate, formal statistical tests. Spreadsheet and relational database software were used to determine population characteristics including; dominant and rare species, biomass and abundance rankings, feeding guilds and endemism status.

Multivariate statistical analyses included the same procedures used in the analysis of benthic data with the exception of a non-metric, multi-dimensional scaling technique, used to identify groups of similar sites. Environmental variables were overlaid on the ordination to identify the factors and their directions that are most important in structuring of fish communities.

4.0 FIELD PREPARATION AND DOCUMENTATION

4.1 Field Preparation

Prior to field surveys, permitting is required to establish permanent markers at all sites. Additional permitting is required for collection of sediment and to obtain access to marine protected areas. The Coral Reef Assessment and Monitoring Program (CRAMP) has installed pins at survey sites around the state and continues to conduct monitoring and assessment work under permits issued from agencies responsible for managing near shore reefs. CRAMP activity has been conducted under the following permits (see section 1.4 for details):

1) State of Hawai'i , Department of Land and Natural Resources, Division of Aquatic Resources (DAR) Permits for marine protected areas.

2) State of Hawai'i , Department of Land and Natural Resources, Natural Area Reserve System Commission.

3) State of Hawai'i , Department of Land and Natural Resources Collecting Permit (covers all sites except MLCD and NARS)

4) State of Hawai'i , Department of Land and Natural Resources, Land Division Site Plan Approval for Monitoring Hawai'i's Reefs SPA ST 00-20.

5) State of Hawai'i , Department of Land and Natural Resources, Kaho'olawe Island Reserve Commission (www.state.hi.us/kirc/main/home.htm)

Background Information

Background information for sites are gathered from peer reviewed journals, environmental impact statements, governmental reports, and other published sources. Collection of all relevant literature is obtained through the University library system, State archives, government documents, and journals.

Maps, aerial photography and GIS layers are obtained from the State of Hawai'i hawaii.gov/dbedt/gis/download.htm. The Office of Planning GIS Program leads a multi-agency effort to establish, promote, and coordinate the use of geographic information systems (GIS) technology among Hawai'i State Government agencies. The State Office of Planning is responsible for the planning and coordination of activities that are critical to the State's enterprise GIS. The primary goal of the Statewide GIS Program is to improve overall efficiency and effectiveness in government decision-making.

The Benthic habitat maps CRAMP uses to help determine site selection is part of the NOAA's CCMA's Biogeography Branch. NOAA completed an investigation in 2007 to consistently and comprehensively map the distribution of coral reefs and other benthic habitats throughout the main Hawaiian Islands. The product includes the development of a web site and DVD which provides access to digital geographic information system (GIS) data, maps, and imagery depicting the location and distribution of shallow-water seafloor habitats the main Hawaiian Islands. Completion of this project represents a major milestone towards completion of the U.S. Coral Reef Task Force's recommendation to develop shallow-water coral reef ecosystem maps for all U.S. waters. This is the fifth set of major coral reef ecosystem maps produced with support from NOAA/National Ocean Service's (NOS) Coral Reef Conservation Program.

The digital habitat maps can be downloaded from the main Hawaiian Islands website. In addition to digital/georeferenced benthic maps and metadata, digital/georeferenced mosaics of satellite imagery, ground validation data, accuracy assessment data, ground control data, an ArcGis Habitat Digitizer Extension, printable maps, and a methods manual are also available. Thirty-two distinct benthic habitat types (i.e., 4 major and 14 detailed geomorphological structure classes; 8 major and 3 detailed biological cover types) within 13 zones were digitally mapped in GIS (geographic information system) using heads-up visual interpretation of orthorectified satellite imagery. Assessment of these maps indicates that a high degree of thematic and spatial accuracy was achieved. Excellent accuracy, detailed documentation of methodology, and inclusion of a wide range of potential users during all phases of map production has resulted in a suite of products designed to accommodate a broad spectrum of interest groups, and at the same time, complete the project over a 24 month time period. Benthic features were mapped that covered an area1, 310 km^2. In all, 387 km^2 of unconsolidated sediment, 288 km^2 of emergent vegetation, and 915 km^2 of coral reef and colonized hardbottom were mapped. Detailed attention was placed on thematic accuracy (correctly classified habitats) and the geopositional accuracy of map polygons (correct spatial coordinates). Although very small features such as individual coralheads of one meter in size are visible in the airborne imagery, only continuous habitats greater than one acre in size were individually delineated to ensure that maps were completed within a reasonable time frame. The overall thematic accuracy was 98% for the major structure, 90% for the detailed structure, 92% for the major biological cover, and 93.6% for the detailed biological cover classifications. The location of the habitat polygons is generally within three meters of their correct coordinates on the Earth. The georeferenced imagery enables managers and scientists to have the ability to delineate smaller features and modify the classification scheme for their specific project requirements. (http://ccma.nos.noaa.gov/ecosystems/coralreef/main8hi_mapping.html)

Field surveys require survey gear and safety equipment. The following comprehensive list of equipment, materials, and supplies are not inclusive of each field trip. Resources vary depending on the work involved.

- Dive gear

buoyancy compensator, regulator, weight belt with weights, masks, snorkels, fins, dive boots, wetsuits, compressed air tanks, dive computers

- Survey equipment

quadrats, photoquad, monopod, camera and housing, desiccant, transect lines, clipboard, underwater paper, numbered transect clips, maps, data sheets, SS rods, sledge hammers, flagging tape, pencils, sample bags, disposable sediment scoops, 1 gallon bucket for homogenization of sediments

- Field supplies

permits, permanent markers, logbook, GPS, pelican floats, secchi disk, extra batteries

- Safety equipment

alternative air source, O_2 kit, standard first aid kit, dive flags, cell phone, dive plan with emergency contacts, personal floatation devices, flotation ring

Equipment maintenance and calibration is conducted prior to each field survey. Batteries for cameras and GPS units are charged and checked prior to each dive.

All dive gear including dive computers are inspected annually by a licensed inspector in compliance with the UH Dive Safety Office.
Records must be kept for each item from its original acquisition until three years after the date equipment is withdrawn from University service. Each equipment modification, repair, test, calibration, or maintenance service shall be logged including the date and nature of work performed, serial or identification number of item, and the name of the person performing the work.
SCUBA tanks are maintained according to the following University regulations:
SCUBA cylinders must be designed, constructed and maintained in accordance with the applicable provisions of the Unfired Pressure Vessel Safety Orders.
SCUBA cylinders must be hydrostatically tested in accordance with federal Department of Transportation standards.
SCUBA cylinders must have an internal visual inspection at intervals not to exceed 12 months.
SCUBA cylinder valves must be functionally tested at intervals not to exceed 12 months.
SCUBA cylinders and valves which are subjected to usage higher than 15 dives per month or filling by multiple users, must be inspected at a more frequent interval.

The following regulations for the use of Dive Computers (DC's) shall be followed by Scientific Divers while diving under University auspices.
Training Requirements:
The diver must complete a training session on Dive Computer (DC) use, of scope deemed appropriate by the DCB. The training must include the operational guidelines defined below and must include a DCB-approved written examination to demonstrate knowledge mastery of DC use.
The diver must demonstrate proficiency of DC use in a dive checkout with the DSO or his designated agent. The proficiency review must include:
Proper interpretation of the DC indicator system;
Adherence to the DC-prescribed rates of ascent and descent;
Demonstration of proper DC use protocols, as outlined below.
Equipment Requirements:
The DCB reserves the right to designate makes and models of DC's which are acceptable for use during University dives.
A diver must only use those models of DC for which the diver has demonstrated proficiency, as described above.
DC's must be tested for depth accuracy at 6 month intervals
Operational Requirements are also required. See http://www.hawaii.edu/ehso/diving/manual97.doc for these and other details concerning the dive safety requirements.

All auxiliary equipment must be of a type approved by the DSO and/or the DCB.
First Aid Supplies and Emergency Equipment regulations are as follows:
A first-aid kit adequate for the diving operation must be available at the dive location. When used in a hyperbaric chamber or bell, the first-aid kit shall be suitable for use under hyperbaric conditions.
An emergency oxygen supply adequate for the diving operation must be available at the dive location.

Procedures for field health and safety considerations are firmly in place at both the University of Hawaiʻi and the Hawaiʻi Institute of Marine Biology. Requirements include training in CPR, DAN oxygen, first aid, and scientific diving certification. In addition vessel safety inspections and a $1 million insurance policy is required for all chartered vessels. All vessels are required to carry personal flotation devices, rescue tube or ring, flares, and first aid kit.

4.2 Field Notes

4.2.1 Field Logbooks

All field notes, dive times, triangulation relocation maps, GPS coordinates, and field information on oceanographic and meteorologic conditions are written clearly and accurately enough to recreate field activities following the surveys. Documentation has consecutively numbered pages. All entries are clearly legible, organized, and contain only factual, objective language. All field notes are written in a waterproof field tablet (write in the rain™). They are digitally entered into spreadsheets and/or databases immediately upon return from each field trip.
Field notes also include:

- Team members full names and their responsibilities
- Time of arrival/entry on site and time of site departure
- Other personnel on site
- Deviations or variances from sampling plans, site safety plans, and QAPP procedures
- Changes in personnel and responsibilities with reasons for the changes
- Calibration readings for any equipment used and equipment model

4.2.2 Field Data Sheets and Forms

The following data sheets are used in field surveys:

1) Fish numerical abundance and length data sheet
2) Field notes
3) Sediment Collection information data sheet
4) Photograph data sheet

1) Fish numerical abundance and length data sheet

Location Transect Date Observer

Time

Fis com/A ch Ceph argu Lutj kash	
Cirr fasc Cirr pinn Para arcu Para fost	
Mull flav Mull vani Paru bifa	
Para cycl Paru mult Kyph sp	
Chae mult Chae ornat Chae quad	
Chae trif Chae unim Forc flav	
Plac impa Plec john Steg fasc	
Abud abdo Chro oval Chro hanu Chro vand	
Cori venu Hali orna Labr phth Macr geof	
Gomp vari Stet balt Thal ball Thal dupe	
Chlo pers Scar psit Scar rubr Chlo sord	
Cirr vand Acan bloc Acan leuc Acan nigrof	
Acan oliv Acan trio Cten stri	
Naso litu Zebr flav Meli nige	
Meli vidu Rhin rect Suff burs	
Cant dume Cant amb Cant jact	

2) Field notes

Site	Date	Arrival time	Depart. time	Dive time	Triangulation	GPS coordinates	Ocean conditions	Weather conditions	Team member responsibility	Other personnel	Deviations	Personnel change

3) Sediment Collection information data sheet

Sediment Samples								
Site	Date/time	Location/GPS points	Name	Sample ID	Sample type	Sample equipment	Conditions	Desc

4) Photograph data sheet

Data Sheet: Field Photos						
Site	Date/time	Location	Name	Number	Conditions	Description

4.2.3 Field Photographs

Photographs will be taken at the observation locations, sampling locations and at other areas of interest on site or in the sampling area. They will serve to verify information entered in the field logbook. For each photograph taken, the following information will be written in the logbook:

- Time, date, location
- Description of the area photographed
- Name of person taking the photograph
- Number of photographs taken

4.3 Documentation of Sample Collections

The following information is recorded during the collection of each sediment sample:

- Sample location and description
- GPS reading or other specific locational data as an aid for future sampling
- Sampler's name

- Date and time of sample collection
- Type of sample (sand, mud etc.)
- Type of sampling equipment used
- Field observations and details related to analysis or integrity of samples (e.g., weather/ocean conditions etc.)
- Lot numbers of the sample bag, sample identification numbers
- Destination information

4.4 Labeling of Sample Collections

Each sediment bag is assigned a unique sample number. Labels are written prior to collection with permanent markers and checked in the field to verify correct placement of sample into labeled bags. Labels contain the following information: sample location, date of collection, and type of sample.

Information concerning digital photographs are entered into the field books and reentered into computers upon return. All photos are assigned a unique number using the following code: eg. This photo was taken in 2008 on O‘ahu in Waikīkī at 8 meters depth on the 2nd transect and is the 15th image in the series. (08OaWai08m02015)

08= 2008

Oa=first two letters indicate the island location

Wai=the next three letters designate first three letters of the site name

08m=depth

02=transect number

015=fifteenth image along the transect

4.5 Field Variances

As conditions in the field may vary, it may become necessary to implement minor modifications to sampling as presented in this plan. When appropriate and feasible, the EPA Project Officer will be notified before implementing the changes. Minor or temporary modifications will be documented in field logbooks or field data sheets and in the final report as appropriate. Significant or major changes to the approved plan may require prior approval by the EPA Project Officer and will be documented in the final report.

5.0 QUALITY CONTROL FOR SAMPLES COLLECTED FOR OFF-SITE ANALYSIS

Quality control sediment samples collected for off-site analyses are intended to help evaluate conditions resulting from field activities and are intended to accomplish two primary goals, assessment of field contamination and assessment of sampling variability.

To assess the precision and accuracy of the sampling and analysis activities and to gauge if the sample is representative of the area surveyed, subsamples are collected in the field. Replicate samples are then used to determine the variability in sediment composition and grain-sizes (see Section 3.1.1).

5.1 Data Quality Indicators for Off-Site Analyses

The accuracy of measurements is limited by sampling techniques, storage conditions, equipment, and, the capability of the operator. To achieve the best possible results special care is taken to address the level of uncertainty associated with each measurement.

- Accuracy is determined by comparison of a first sample with a second sample collected on the same transect. A replicate sample is a separate sample taken close to the first sample. Each replicate sample is processed and analyzed in an identical manner. Replicates are taken to determine representation of the entire transect.
- Precision is addressed by sediment subsamples. Standard deviations are used as an indicator of agreement. A subsample is a portion of the sample taken as part of the sample. Subsamples are averaged to address within sample variability. Acceptable levels for organics is 0.5% of the sample, for higher carbonate composition, acceptable levels are within 10% of the total sample, and for terrigenous material 5% of the total. This was determined by assessing within transect variability.
- Completeness obtained is >90% of the expected 100% for valid, usable data. Occasional spills are recorded. Mistakes are minimized by weighing and checking all data in triplicate.
- Comparability is assured by requiring all standard procedures are strictly adhered to. All data entry is entered into identical spreadsheets using identical units and formulas.
- Detection limits: grain size sieving efficiency and accuracy increases with smaller sample sizes thus we use a 50 g thoroughly homogenized wet aliquot from each sample. The finer size grains also determine efficiency (Royse, 1970).
- Detection limits for sediment composition all samples are weighted using a Mettler Toledo Model: #AB 104 Certification Type: COC. We weigh sediments to 1000^{th} of a gram. Quality Control Services calibrates this balance annually and has detected very minimal drift. Changes in weight due to humidity are minimized by storage in desiccators between weighings.
- The Isotemp Muffle Furnace 550 Series Model 58 performance characteristics include: Operating range: 50^0C to 1125^0C, Avg Temperature Stability: ±1^0C, Set Point Repeatability: ±1^0C, Set Point Accuracy: ±10^0C, Rise Time: 25 min., Recovery Time: 10 min., and Cool Down Time: 25 min.

5.2 Assessment of Field Variability (Field Duplicate or Co-located Samples)

Sediment samples are homogenized with a trowel in a dedicated one-gallon container. Samples are subsequently mixed thoroughly prior to lab procedures.

5.3 Laboratory Quality Control Samples

Laboratory quality control (QC) samples are analyzed as part of our standard laboratory practice. The laboratory monitors the precision and accuracy of the results of its analytical procedures through analysis of these QC samples. Laboratory QC samples consist of duplicate samples for organic analyses and for inorganic carbonate analyses. Variability for both replicates and subsamples are expected to be low.

A routinely collected sediment sample contains sufficient volume for both routine sample analysis and additional laboratory QC analyses. Therefore, a separate sediment sample for laboratory QC purposes will not be collected.

6.0 FIELD SAMPLE COLLECTION PROTOCOLS FOR OFF-SITE ANALYSES

Sediments are processed to determine grain-size and organic and carbonate composition (as determined by loss on ignition (LOI)). Standard sample collection methods are used for collection of sediment samples for off-site analysis. A Fisherbrand™ Disposable Sterile Scoop (237 ml) capacity is used to collect approximately 1 kg of sediment from the benthic surface layer and placed into a plastic, disposable Nasco™ Whirlpak collection bag (532 ml).

6.1 Field Equipment

Equipment used in the field to collect sediment samples are limited to the following:

- disposable scoop
- Nasco™ whirlpak collection bags
- one-gallon pail

6.2 Sample Collection by Matrix

6.2.1 Sediment Sampling

Sediments are sampled with a scoop from the benthic surface layer. Ocean depth at sites vary from 1m to 20m. Samples are analyzed for grain-size, organic, and carbonate composition as detailed in section 3.1.1. Samples are placed in a sample-dedicated 1-gallon disposable pail and homogenized with a disposable scoop. Material in the pail is transferred with a scoop from the pail to the sieve. No volatile organic compounds are analyzed.

6.3 Equipment Cleaning and Decontamination Procedures

The only field equipment used to collect sediments for grain-sizing and composition analyses is a disposible scoop in accordance with SOP's (refer to section 3.1.1). Sediment

is scooped into disposable Nasco™ whirlpak collection bags intended for one-time use only. All used bags are packaged for appropriate waste disposal.
Laboratory equipment used to process sediments include mortar and pestles, crucibles and sieves. Decontamination for mortar and pestles and sieves include:

- Non-phosphate detergent and tap water wash, using a brush
- Tap-water rinse
- Deionized water rinse (three times) using a pretreatment scale eliminator, ultrapure filter, and Barnstead meter measuring ppm NaCl.

Decontamination for crucibles include:

- 100^{o}C burn in muffle furnace
- scraping with wire brush

7.0 LABORATORY ANALYSES AND SELECTION

7.1 Summary of Laboratory Analyses

Table 5. Sediment analysis type and number of samples, subsamples, and replicates used.

Sediment analysis type	# of locations	# of samples	# of subsamples	# of replicates
Grain-size	184	2	2	2
LOI (loss on ignition)	184	2	2	2

As enumerated in Table 5 sediment samples have been taken at 184 stations at 54 sites and will be taken at an additional 100 stations. Sediment samples are taken from each station. Duplicate samples are taken at each station. Each sample is then subsampled and two replicates are taken from each of the two subsamples.

7.2 Selecting a Laboratory

All sediment processing and analyses are completed by our University of Hawai‘i, Hawai‘i Institute of Marine Biology, Coral Reef Ecology Laboratory. The staff used to collect sediments also process sediments and analyze results. The capability of this laboratory is assessed by the UH Environmental Health and Safety Office (EHSO) as detailed in section 2.5. Laboratory training is also required and provided by the EHSO.
This laboratory has both the capability and capacity to provide analytical services for the project. The laboratory is equipped with all materials, supplies, and equipment necessary to process sediment samples. This includes:

- filtration system for deionized water
- sieves, wash bottles, filters
- balances
- drying oven
- muffle furnace

- crucibles, desiccators

Standard Operating Procedures for methods performed are explained in section 3.1.1.

8.0 SAMPLE SHIPMENT TO OFF-SITE LABORATORY

8.1 Sample Chain-Of-Custody Forms and Custody Seals

Until sediment samples are shipped, the custody of the samples are the responsibility of CRAMP under the direction of Dr. Kuʻulei Rodgers. Dr. Rodgers is the designee that signs the chain-of-custody form and notes, sample numbers, duplicate numbers, date, time, and location of samples. Chain-of-custody forms are kept in the CRAMP logbook transported on each survey. No custody seal is placed on samples. Proper handling and labeling protects the integrity of samples.

8.2 Packaging and Shipment

All sample bags are placed in a strong-outside shipping cooler. The following outlines the packaging procedures that are followed.

- The bottom of the cooler is lined with bubble wrap to prevent breakage during shipment.
- Samples are labeled with indelible ink directly on sampling bags.
- Samples from each site are sealed in heavy duty plastic zip-lock bags with sample numbers written on the outside of the plastic bags with indelible ink.
- Any empty space in the cooler if filled with bubble wrap to prevent movement and breakage during shipment.
- Each cooler is securely taped shut with vinyl, fabric-reinforced, multi-purpose pressure sensitive tape with a soft and tacky pressure sensitive adhesive (duct tape).

Records are maintained by CRAMP's sample custodian (Dr. Kuʻulei Rodgers). Records include the following information:

- Sampling organization (Coral Reef Assessment and Monitoring Program)
- Carrier, method of shipment
- Shipment date and arrival date received by laboratory
- Irregularities or anticipated problems associated with the samples
- Name and location of station and site
- Number of samples

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Appendix II: Quarterly Reports

Development of Coral Reef Biocriteria for Hawai‘i
Principal Investigator: Paul Jokiel
1st Quarter Progress Report-10/1/07-1/1/08

Research Activities: Review Coral Reef Assessment and Monitoring Program (CRAMP) Biocriteria
The development of the EPA Quality Assurance Project Plan is currently in progress.

Presentations: Presentations will be given once model is fully developed

Budgetary Spending:

Category	Description	Awarded	Current Month Expended	Total Expended	Outstanding PO	Total Cost	FMIS Suspense	Available Bal
1100	Salaries & Wages	$32,088.00	$0.00	$0.00	$0.00	$0.00	$0.00	$32,088.00
1105	Fringe Benefits	$7,217.00	$0.00	$0.00	$0.00	$0.00	$0.00	$7,217.00
1107	Materials & Supplies	$4,400.00	$0.00	$0.00	$0.00	$0.00	$0.00	$4,400.00
1108	Travel - Domestic	$7,700.00	$0.00	$0.00	$0.00	$0.00	$0.00	$7,700.00
1117	Others	$9,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$9,000.00
Direct Costs Total		**$60,405.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$60,405.00**
	INDIRECT COSTS	$23,196.00	$0.00	$0.00	$0.00	$0.00	$0.00	$23,196.00
Grand Total		**$83,601.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$83,601.00**

No funds were used in the 1st quarter. Assistant Researcher salary (Ku‘ulei Rodgers) (3 mo) will be used in the 4th quarter and as needed. Additional personnel (RA) will be used in quarters 5 & 6 to assist in field testing of biocriteria. Travel, Supplies, and Other Costs will be used to complete research activity goals and outreach in later quarters.

Development of Coral Reef Biocriteria for Hawai‘i
Principal Investigator: Paul Jokiel
2nd Quarter Progress Report-1/1/08-4/1/08

Research Activities: Re-analyze data and model
In the second quarter the Ecological Gradient Model (EGM) was revised and macros adjusted to allow ease of use for managers and scientists. Features added include:

- Modification of the initial query to select a depth range rather than a single depth value

- The ability to select more than one wave regime to compare the evaluation site against
- Gradient symbols on the data map with size of symbol increasing with Index of Biotic Integrity (IBI) level
- Hidden macros for user simplicity
- Drop-down parameter comments with methodology descriptions and references
- Parameter revision to reflect most widely used parameters
- A text worksheet to view the queried data showing comparison sites, locations, and IBI values
- Ability to print individual graphs of either weighted, unweighted or CRAMP weighted IBI
- A link to a Transverse Mercator Calculator to convert latitude/longitude co-ordinates to co-ordinates in UTMs used in EGM on a Transverse Mercator projection with bulk conversion capabilities

Instructions for model use and detailed description of methodology were written and placed on the CRAMP website under the heading "Ecological Gradient Model." Revised version and accompanying documentation are available for download at http://cramp.wcc.hawaii.edu/

Individuals from different user groups are currently assessing EGM model: Greg Piniak (modeler), Eric Brown (NPS marine resource manager)

Presentations:
1/22/08 Public presentation at Maui Ocean Center
"Local and Global Impacts on Coral Hawai'i's Coral Reefs" included EGM model demonstration
Attended by DAR biologist Skippy Hau, MCC professors, students, and public

Presentation on EGM and reference sites will be presented at the Hawai'i Conservation Conference to be held in Honolulu, Hawai'i from July 29-31. Abstract has been submitted and accepted at http://hawaiiconservation.org/2008hcc_abstracts.asp

Budgetary Spending:

Category	Description	Awarded	Current Month Expended	Total Expended	Outstanding PO	Total Cost	FMIS Suspense	Available Bal
1100	Salaries & Wages	$32,088.00	$0.00	$0.00	$0.00	$0.00	$0.00	$32,088.00
1105	Fringe Benefits	$7,217.00	$0.00	$0.00	$0.00	$0.00	$0.00	$7,217.00
1107	Materials & Supplies	$4,400.00	$0.00	$0.00	$0.00	$0.00	$0.00	$4,400.00

1108	Travel - Domestic	$7,700.00	$0.00	$0.00	$0.00	$0.00	$0.00	$7,700.00
1117	Others	$9,000.00	$500.00	$500.00	$0.00	$0.00	$0.00	$9,000.00
Direct Costs Total		**$60,405.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$60,405.00**
	INDIRECT COSTS	$23,196.00	$0.00	$0.00	$0.00	$0.00	$0.00	$23,196.00
Grand Total		**$83,601.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$0.00**	**$83,101.00**

$500 in budget category "Other" was used for Hawai'i Conservation Conference fees for Paul Jokiel and Ku'ulei Rodgers to be held July 29-31 in Honolulu, Hawai'i. Other funding will be used in later quarters as needed to complete milestone goals.

Development of Coral Reef Biocriteria for Hawai'i
Principal Investigator: Paul Jokiel
3rd Quarter Progress Report-4/1/08-6/31/08

Research Activities:

- Development of the EPA Quality Assurance Project Plan that includes types of data and modeling approach used in this investigation by the Coral Reef Assessment and Monitoring Program (CRAMP).
- Department of Health Integrated Water Quality Reporting Working Group to develop Ecological Gradient Model for reef quality indicators.
- Received agency feedback from local managers at DAR and DOH and revised approach accordingly.
- Biocriteria manuscript preparation.

Presentations:

- April 27, 2008 Biocriteria presentation with multiple agencies (Division of Aquatic Resources, Department of Health, Environmental Protection Agency). Held at Kalanimoku Building DAR conference room.
- May 7, 2008 Department of Health Integrated Water Quality Reporting Working Group to develop Ecological Gradient Model for reef quality indicators.
- June 23, 2008 Department of Health Integrated Water Quality Reporting working group. Present workgroup goals, current procedures and regulatory requirements, list of issues for discussion, formation of task groups, task group assignments and schedules.

Budgetary Spending:

Category	Description	Awarded	Current Month Expended	Total Expended	Available Bal
1101	Salaries & Wages	$32,088	$2,810	$2,810	$29,278
1105	Fringe Benefits	$7,217	$1,012	$1,012	$6,205

1107	Materials & Supplies	$4,400	$0	$0	$4,400
1108	Travel - Domestic	$7,700	$0	$0	$7,700
1111	Utilities & Communication	$0	$18	$18	-$18
1117	Others	$9,000	$0	$500	$8,500
Direct Costs Total		**$60,405**	**$3,840**	**$4,340**	**$56,065**
	INDIRECT COSTS	$23,196			
Grand Total		**$83,601**	**$1,183**	**$3,236**	**$80,365**

Assistant Researcher partial salary was withdrawn at end of the 3rd quarter. Travel, Supplies, and Other Costs will be used to complete research activity goals and outreach in later quarters.

Development of Coral Reef Biocriteria for Hawai‘i
Principal Investigator: Paul Jokiel
4th Quarter Progress Report-7/1/08-9/30/08

Research Activities:

- Approval of the EPA Quality Assurance Project Plan by quality assurance officer Rich Frietas and final approval by quality assurance manager, Eugenia Naughton. Hawai‘i Coral Reef Assessment and Monitoring Program Quality Assurance Project Plan pp. 37.
- Collaboration with Mike Kido of Hawai’i Stream Research Center correlating watershed and biological data.
- Collaboration with He’eia State Park and Papahānaumokuākea Marine National Monument for development of cultural index through Traditional Ecological Knowledge using the ecological gradient model as a template.

Presentations:

- 7-11 July 2008 “Use of replicated coral reef mesocosm studies to establish the potential impact of ocean acidification.” by P. L. Jokiel, K. S. Rodgers, I. B. Kuffner, A. J. Andersson, E. F. Cox, F. T. Mackenzie. Broward County Convention Center Fort Lauderdale, Florida.
- 29-31 July 2008 “Impact of global warming and ocean acidification on Hawaii’s coral reefs” by P. L. Jokiel, K. S. Rodgers, I. B. Kuffner, A. J. Andersson, E. F. Cox, F. T. Mackenzie. Hawaii Conservation Conference. Island Ecosystems: The Year of the Reef, Hawaii Convention Center, Honolulu

- 29-Jul-2008 - 31-Jul-2008. 2008 Hawai‘i Conservation Conference, Hawai‘i Convention Center, Honolulu, HI. Presentation: Developing and Evaluating Coral Reef Biocriteria.
- Sept 1-5, 2008. NWHI-NOAA-HIMB Bleaching workshop, Presentations: The development of an ecological index using biological and environmental indicators to assess the condition and compare Hawaiian reefs and Reef Resiliency Field Activity. Moku o Lo‘e, Kāne‘ohe, Hawai‘i.
- Sept 4, 2008 Department of Health Integrated Water Quality Reporting working group. Methodology, rules, and tools.
- 3 Sept 2008 “Techniques for Bleaching Assessments” by Paul Jokiel. NOAA Climate Workshop, HIMB
- 4 Sept 2008 “Reef Restoration” by Paul Jokiel. NOAA Climate Workshop, HIMB
- 5 Sept 2008 “Indigenous Practices on Coral Reefs” by Paul L. Jokiel. NOAA Climate Workshop, HIMB

Budgetary Spending:

Category	Description	Awarded	Current Month Expended	Total Expended	Available Bal
1101	Salaries & Wages	$32,088	$5,745	$8,555	$23,533
1105	Fringe Benefits	$7,217	$2,068	$3,080	$4,137
1107	Materials & Supplies	$4,400	$1,125	$1,125	$3,275
1108	Travel - Domestic	$7,700	$2,653	$2,653	$5,047
1111	Utilities & Communication	$0	$0	$18	-$18
1117	Others	$9,000	$3,200	$3,700	$5,300
Direct Costs Total		**$60,405**	**$14,791**	**$19,131**	**$41,274**
	INDIRECT COSTS	$23,196			
Grand Total		**$83,601**	**$14,791**	**$19,131**	**$41,274**

Funding was used to complete milestone goals. Salaries and fringe benefits were used for Assistant Researcher and casual hire positions to conduct surveys, enter and analyze data, and revise model. Field and lab materials and supplies were used for surveys and lab work. Travel funds were used to collect additional data from rapid assessments at ‘Āhihi Kīna‘u, Maui to add spatial coverage to the Ecological Gradient Model. Vessel support (Joseph Reich captain of Alyce C.) costs are reflected in the “others” category.

Development of Coral Reef Biocriteria for Hawai‘i
Principal Investigator: Paul Jokiel
5th Quarter Progress Report-10/1/08-12/31/08

Research Activities:

- Submission of manuscript entitled, “Quantifying Condition of Hawaiian Coral Reefs” to journal Aquatic Conservation.
- Outreach to schools and other groups.

Presentations:

- 13 Nov 2008 “Impact of global warming and ocean acidification on Hawaii’s coral reefs” by Paul L. Jokiel and Ku’ulei S. Rodgers Northwestern Hawaiian Islands Joint Symposium. Windward Community College
- Kamehameha Schools Marine Science Classes bioindicator and climate change presentations.

- Youth Conservation Corp. presentations on indicators.

Budgetary Spending:

Category	Description	Awarded	Current Month Expended	Total Expended	Available Bal
1101	Salaries & Wages	$32,088	$10,282	$18,837	$13,251
1105	Fringe Benefits	$7,217	$2,561	$5,641	$1,576
1107	Materials & Supplies	$4,400	$683	$2,828	$1,572
1108	Travel - Domestic	$7,700	$0	$2,653	$5,047
1111	Utilities & Communication	$0	$0	$18	-$18
1117	Others	$9,000	$200	$3,700	$5,300
	Direct Costs Total	**$60,405**	**$13,726**	**$33,677**	**$26,728**
	INDIRECT COSTS	$23,196			
	Grand Total	**$83,601**	**$13,726**	$33,677	**$26,728**

Salaries and fringe benefits were used for Assistant Researcher and casual hire positions to enter and analyze data, and revise model. Materials and supplies were used for dive gear replacement, required University of Hawai‘i dive physicals and lab supplies.

Development of Coral Reef Biocriteria for Hawai‘i
Principal Investigator: Paul Jokiel
6th Quarter Progress Report-1/1/09-3/31/09

Research Activities:

- Preliminary comparison of Ecological Gradient Model (EGM) with Watershed Health Index (WHI) developed by the UH Center for Conservation Research and Training. Comparison shows correlation between the EGM and the WHI. Linking these models to water quality data and other information will lead to development and further refinement of an acceptable regulatory coral reef index of biotic integrity and/or other biocriteria.

Outreach

- Jane Liaw- Science Writer Ocean Acidification Interview
- UH Chancellor’s office personnel Climate Change Presentation HIMB
- ScienCentral filming on climate change-Jack Penland
- Rollins College, Florida Ocean Acidification presentation.

Presentations:

- April 5-7, 2009. Climate Change Symposium. Local and global panel member and moderator. Exploratorium. San Francisco, CA. "Impacts of Climate Change in the Hawaiian Islands" and "Impacts of Climate Change on Coral Reefs in America" Ku'ulei Rodgers
- March 2-6, 2009 Pacific Science Inter-Congress in Tahiti French Polynesia Climate Change Symposium "Impact of ocean acidification on Hawaiian coral reefs in the 21st century" Presenter and moderator "Paul Jokiel

Publications

- Response to reviewer's comments, manuscript revisions, and proof corrections for publication of manuscript entitled, "Quantifying Condition of Hawaiian Coral Reefs" to journal Aquatic Conservation.
- Carvalho, K.K., B.A.A. Parker, and K. Rodgers. 2009. Proceedings of the fourth Responding to Climate Change: A Workshop for Coral Reef Managers. Marine Sanctuaries Conservation Series NMSP. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. pp 20.

Budgetary Spending:

	Description	Awarded	Current Month Expended	Total Expended	Available Bal
	Salaries & Wages	$32,088.00	$3,258.00	$36,780.22	($4,692.22)
	Fringe Benefits	$7,217.00	$76.58	$5,717.58	$1,499
	Materials & Supplies	$4,400.00	$0.00	$1,452.51	($537.46)
	Travel - Domestic	$7,700.00	$0.00	$2,280.01	$5,047
	Utilities & Communication	$0.00	$0.00	$18.27	($18.27)
	Others	$9,000.00	$0.00	$1,235.00	$7,765.00
	Direct Costs Total	**$60,405.00**	**$3,334.58**	**$45,030.28**	**$11,889.77**
	INDIRECT COSTS	$23,196.00	$1,280.48	$17,291.63	$4,566.15
	Grand Total	**$83,601.00**	**$4,615.06**	**$62,321.91**	**$16,455.92**

Salaries and fringe benefits were used for Assistant Researcher and casual hire positions to enter and analyze data, and revise model. No materials and supplies were used this quarter. Travel for PI to present at 11th Pacific Science Inter-Congress in Tahiti French Polynesia is pending and will be reflected in 7th quarter report.

Development of Coral Reef Biocriteria for Hawai'i
Principal Investigator: Paul Jokiel
7th Quarter Progress Report-4/1/09-6/30/09

Research Activities:

- Comparison of Ecological Gradient Model (EGM) with Watershed Health Index (WHI) developed by the UH Center for Conservation Research and Training (CCRT) continues. Comparison shows correlation between the EGM and the WHI. Linking these models to water quality data and other information will lead to development and further refinement of an acceptable regulatory coral reef index of biotic integrity and/or other biocriteria. Dialog of results with Michael Kido (CCRT) and Linda Koch of Dept of Health.

Outreach

- ScienCentral interview on climate change-Jack Penland

Presentations:

- April 5-7, 2009. Climate Change Symposium. Local and global panel member and moderator. Exploratorium. San Francisco, CA. "Impacts of Climate Change in the Hawaiian Islands" and "Impacts of Climate Change on Coral Reefs in America" Ku'ulei Rodgers
- May 7 NWHI semi-annual symposium presentation "Coral Reef Health and Response to Climate Change". Ku'ulei Rodgers
- May 30 Coast Guard Auxiliary presentation on bioindicators and climate change
- June 29 Hawaii Youth Conservation Corps (HYCC) presentation on indicators and monitoring. Ku'ulei Rodgers
- March 2- March 6, 2009. Impact of ocean acidification on Hawaiian coral reefs in the 21st century. P. L. Jokiel and K. S. Rodgers 11th Pacific Science Inter-Congress Sheraton Tahiti in Tahiti, French Polynesia
- May 27-28, 2009. Effects of Climate Change on Ecosystem Services Provided by Hawaiian Coral Reefs P. L. Jokiel The Plight of Ecosystems in a Changing Climate Impact on Services, Interactions and Responses Workshop, EPA Region 10, Plymouth Church, Seattle, WA

Publications

- Early view online for publication of manuscript entitled, "Quantifying Condition of Hawaiian Coral Reefs" to journal Aquatic Conservation.

Budgetary Spending:

	Description	Awarded	Current quarter Expended	Total Expended	Available Bal
	Salaries & Wages	$32,088.00	$3,258.00	$36,780.22	($4,692.22)
	Fringe Benefits	$7,217.00	$76.58	$5,717.58	$1,499
	Materials & Supplies	$4,400.00	$0.00	$1,452.51	($537.46)
	Travel - Domestic	$7,700.00	$4,523.00	$6,803.01	$897
	Utilities & Communication	$0.00	$0.00	$18.27	($18.27)
	Others	$9,000.00	$3,760.96	$4,995.96	$4,004.04
	Direct Costs Total	**$60,405.00**	**$3,334.58**	**$45,030.28**	**$3,233.04**
	INDIRECT COSTS	$23,196.00	$1,338.22	$22,753.12	$442.88
	Grand Total	**$83,601.00**	**$4,672.80**	**$78,520.67**	**$1,594.96**

No salaries and fringe benefits or materials and supplies were used this quarter. Travel for PI to present at 11th Pacific Science Inter-Congress in Tahiti French Polynesia totaled $4,523. The “Other” category included expenses of $3,761 for laser jet color and black and white printers, site license software renewals and toner for printers. Also included in this category are annual mandatory University of Hawai’i dive gear inspections for three sets of gear.

Appendix III: Publication

Quantifying the Condition of Hawaiian Coral Reefs

Ku'ulei S. Rodgers* [1]**, Paul L. Jokiel** [1]**, Christopher E. Bird**[1] **and Eric K. Brown** [2]

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Abstract

1) This investigation developed and tested descriptive models designed to evaluate coral reef ecological condition based on data developed using the basic techniques most often used in coral reef surveys.
2) Forty-three variables at 184 stations were analyzed in order to identify specific factors that are useful metrics for describing reef condition.
3) The common practice of using "reference sites" for paired site comparisons was evaluated by developing a Reference Site Model (RSM). This use of reference sites proved to be subjective and unreliable, especially when multiple factors and multiple sites are involved. However, in some cases the RSM is appropriate in demonstrating severe degradation based on factors such as sediment, coral cover and fish abundance.
4) An objective Ecological Gradient Model (EGM) was developed based on a wide range of metrics at numerous sites. A computer program was developed that allows a quantitative ranking of reef condition along a continuum and can be used to compare reefs across a wide range of conditions. Further, this approach permits the operator to alter and define criteria appropriate to a specific question.
5) Results of this investigation provide ecological insights into the importance of natural and anthropogenic ecological factors in determining coral reef condition.

keywords: ecological model; indicators; reference sites, rank

Introduction

Reef condition is influenced by various natural factors, but over the past century human activity has become a major driver of change on many coral reefs. Increasingly, coral reef biologists are occupied with defining degradation of reefs due to anthropogenic impacts. In order to evaluate the condition of a reef one must be able to define the attributes of a "normal" or "healthy" system. A widely used method is to compare an "impacted" reef to a "control" pristine reef or one that has not been affected by the impact of interest using various metrics. The concepts of "biotic integrity" and "ecosystem health" are used in terrestrial ecology (e.g. Rapport *et al*., 1998) but have not been taken advantage of by the marine science community, even though the ecological theory and concepts are broadly applicable. One exception is the report by Jameson *et al*. (2001) who described an approach designed to develop an index of biotic integrity (IBI) for coral reefs. Such approaches define the normal structure of a system, measure deviations from normal and thereby evaluate severity of impairment. This method has been effective in freshwater habitats (Green and Vascotto, 1978; Lenat 1988; Barbour *et al.*, 1992; Rosenburg and Resh, 1993). Another approach widely used in wetland systems is the Hydrogeomorphic (HGM) approach (Brinson, 1993; Smith *et al.*, 1995). This method measures the capacity of a wetland to perform certain functions by classification according to geomorphic setting, water source, and hydrodynamics. Reference sites are then used to establish the degree to which function has been impaired.

In 1998, the Hawai‘i Coral Reef Assessment and Monitoring Program (CRAMP) (Coral Reef Assessment and Monitoring Program, 2006) began a field programme to develop techniques and compile the data required to quantitatively evaluate the condition of Hawaiian coral reefs.

CRAMP was initially implemented to describe the spatial and temporal variation in coral reef communities in relation to natural and anthropogenic forcing functions (Jokiel *et al.*, 2004). The original CRAMP experimental design utilized a wide range of easily measured key variables (Brown *et al.*, 2004). The present investigation utilized these key variables in the development of an Ecological Gradient model (EGM) that could be used to quantitatively describe coral reef condition. Unlike the HGM and IBI models which rely heavily on reference sites, these were found inappropriate for use in the EGM. Concepts that have similarity with the EGM are the HGM theory of habitat classification and the IBI premise that apply metrics to produce a ranking to evaluate the severity of impairment.

First, a database was developed that generated a matrix of variables by site. Second, factors that were shown to be reliable metrics for reef condition were identified. Third, these metrics were incorporated into descriptive models based on the various reference sites, IBI and HGM approaches. Finally, the models were tested and evaluated in terms of predictive capability.

Methods

1. Development of information database.

Methods used in this study were restricted to inexpensive survey techniques that have been widely used by coral reef researchers and managers for many years. Initial survey sites were selected by expert observers on the basis of degree of perceived environmental degradation, range of spatial gradients to encompass longitudinal differences, level of management protection, human population level, and extent and direction of wave exposure. These sites represent an excellent cross section of Hawaiian coral reef communities (Figure 1). Within each site (location) a number of stations were surveyed based on time, cost and logistical availability. Stations within each site were then stratified by habitat and randomly selected within hard-bottom habitat (Coyne *et al.*, 2003). Data used in the development of the models includes biological and environmental variables from 60 stations within 30 site locations from the CRAMP long-term monitoring program and an additional 124 stations within 22 sites from fully comparable rapid assessments (RATS) (Figure 1).

Initial studies were conducted to develop an appropriate method for measuring benthic and fish communities as described in Jokiel et al. (2004) and Brown et al. (2004). To assess the characteristics of benthic communities, non-overlapping digital images (50 x 69 cm) were taken along each 10 m transect at a perpendicular angle from a height of 0.5

m above the substrate. The software program PhotoGrid was used to quantify percent cover, richness and diversity of corals, algal functional groups, and substrate cover.

Fish communities were enumerated using standard visual belt transects (Brock 1954). SCUBA divers swam along four 25 m x 5 m transects (125 m^2) at each station recording species, quantity, and total fish length (Friedlander et al. 2003). All fishes were identified to the lowest taxon possible.

Rugosity was measured using the chain and tape method described in McCormick (1994).

Two bulk sediment samples (approximately 500 cc each) were collected haphazardly within each study area and each mixed to assure homogeneity. Each sample was then divided into two replicate samples and from each of these two sub-samples were taken. Sediment grain sizes used were in accordance with the Wentworth scale (Folk, 1974). The sediment fraction remaining on each sieve was washed through pre-weighed filter paper (Whatman Brand 114 wet-strength, 25 micrometer) and air-dried to constant weight. The percent weight of each grain size was determined by calculating the ratio of the various size fractions to the total sample weight.

Sediment samples to determine composition were collected and processed according to (Craft *et al*., 1991). This analysis may overestimate absolute percentage values of organic material, thus only relative differences were compared among sites for this parameter. The percent organic material and carbonate fraction was then calculated from these data. Loss on ignition (LOI_{500}) was used as an index of organic material content. The mass loss between LOI_{500} and LOI_{1000} was used as a proxy for the carbonate fraction $CaCO_3$.

Other ancillary variables derived from various sources included the following:
Anthropogenic Factors

1. Total human population within 5 km of each site and within the adjacent watershed was calculated using U.S. 2000 census data (www.census.gov/main/www/cen2000.html).
2. Mean annual rainfall (mm), total acreage of the adjacent watershed, and perennial stream lengths were derived from layers obtained for each site from the State of Hawai‘i GIS website (www.state.hi.us/dbedt/gis).
3. Management status rank was included as a categorical predictor with sites pooled into three categories. A rank of three was assigned to Marine Protected Areas (MPAs) with the highest degree of protection. These include MPA’s that are designated as subsistence fishing only or fully "no take" areas. Rank two included sites with a moderate degree of protection, for example restriction of certain fishing techniques such as gill netting and/or spearing or areas closed to taking of certain species. Rank one consisted of open access areas. These data were entered into MS Access, MS Excel and ESRI ArcView as appropriate.

Natural Factors

4. Mean, minimum and maximum values for offshore significant wave height (m) along with wave direction (compass bearing) were downloaded daily from the Naval Oceanographic WAM model website (http://www.navo.navy.mil) for 2001.

5. Geologic age of the volcano underlying each site was estimated using data from Clague and Dalrymple (1994).

Analysis of the initial data (Friedlander *et al*., 2003) indicated that a much larger spatial array of sites was desirable since the coral reefs of Hawai‘i were diverse and showed high variability for many ecological parameters. Thus, the original data from the 60 monitoring stations were supplemented using a rapid assessment technique (RAT). The RAT is an abbreviated version of the CRAMP monitoring protocol, using a single 10 m transect to describe benthic cover, rugosity, and sediments along with a single 25 m transect to describe fish communities. The power to detect absolute differences in fish populations from one 25 m transect at each station was extremely low, due to high spatial variability in fish populations. However, the power to detect relative differences between sites for numerical abundance of fishes was sufficient using the RAT protocol. This protocol generated the same biological data (i.e. percent cover, species richness, diversity, fish abundances, and biomass) and environmental data (e.g. rugosity, depth, sediment composition and grain-size, etc.) as the CRAMP monitoring dataset. Multiple RAT transects were randomly selected using ARCVIEW spatial analyst. These transects were stratified on hard substrate habitats in a manner similar to the CRAMP monitoring sites but along a larger range of depths. The advantage of the RAT was that it allowed for the rapid acquisition of data suitable to describe the variation in communities and the forces controlling these distributions at a larger spatial scale. Only the first 10 m transect at each of the CRAMP monitoring stations was included to allow for comparisons on the same measurement spatial scale with the RAT data.

<u>2. Identification of major factors.</u>

Parametric (multiple regression) and non-parametric analyses (principal components analysis, and non-metric multi-dimensional scaling) were used to determine which environmental factors were most important in structuring coral and fish assemblages and to narrow the field of variables used in model development.

Data were transformed as appropriate to meet the assumptions of normality, linearity, and homogeneity of variances required for some of the formal statistical tests performed. Statistical analyses were conducted using Primer© 5.0, MVSP© 3.0, and Minitab© 13.0 software to examine both univariate and multivariate aspects of the spatial data sets. The database consisted of 43 variables that were measured at 184 stations within 52 sites.

Statistics and multiple regressions were computed with Minitab 13.0. Explanatory variables were selected from among 23 environmental predictors. To avoid multicolinearity, variables that were highly correlated (>90%) were dropped from the analysis without loss of information (Clarke and Gorley, 2001). Coral species richness was derived from coral cover data and included in the analysis but may not be suitable as a response variable since it is strongly dependent on sampling effort and observer variability. To determine which environmental variables best explained coral cover and species richness a general linear multiple regression model was used. Coral cover and species richness were regressed against the following environmental variables: rugosity, depth, sediment composition, grain-sizes, wave parameters, human population parameters, precipitation, distance from a perennial stream, watershed area, and geologic age of site.

Legal protection rank and Windward/Leeward divisions were included in the model as categorical variables. Model selection was determined by a Best Subsets routine applying Mallows C_p and R^2. A lack of fit test was conducted to verify the model selection.

A general linear multiple regression analysis was also used to determine the best model for predicting fish biomass, numerical abundance and diversity. To obtain a parsimonious model, many of the variables that made only a small contribution to explaining the variability were excluded. This facilitates ecological interpretation and management application.

Multivariate procedures in PRIMER© 5.2.9 (BIOENV and SIMPER) were used to link biological data to environmental data. The results identified spatial patterns in coral communities and determined the contribution of each species to site similarities. Results were later used in the development of the final model to determine weights for each factor.

3. Development of models.

Reference Site Model (RSM)

Many previous studies of coral reef condition have been based on the use of reference sites. In general, a "pristine" reference area or one that has not been impaired by the impact of interest is selected by experts to serve as a comparison to the "impacted" reef under study. Reference site selection is problematic due to the difficulty in determining optimal reef conditions. Sliding baselines that change over time can also make determination of pristine conditions impractical. Without historical data, this hypothetical baseline is elusive. During the present study, knowledgeable coral reef scientists in Hawai‘i provided their opinion on which reef areas would serve as the best reference sites. In general, the designated reference sites were generally remote from human influence or were within marine protected areas. Reference sites used in this analysis were thus determined subjectively by experts using qualitative observations as is generally the case. This avoided a circular argument where the quantified data are used both to select and analyse the sites. Obviously selection of a "control" reef as a comparison to an "impacted" reef as done in most previous studies is a highly subjective process.

Since depth and wave exposure were found to be highly influential in determining biotic communities (Friedlander *et al*., 2003; Jokiel *et al*., 2004; Storlazzi, 2005), the first attempt at developing a model divided the reference sites into six habitat classes (three depths and two wave exposures) based on these key factors (Figure 2).

Considerable overlap between reference sites and non-reference sites (Figure 3, Table 1) prompted the expansion of the EGM model to 12 habitat classes (three depths and four wave exposures) to reduce the variation caused by depth and wave exposure.

Several analyses were conducted on the reference site data. First, a discriminant analysis was performed to evaluate whether the reference stations were different from the non-reference stations and to determine if the reference sites fell within their predicted habitat class. Second, a cluster analysis was also conducted to determine if the reference sites in each class grouped together. Third, a two-way analysis of variance (ANOVA) was used to determine which variables explained differences or similarities among reference sites and which specific factors were significantly different between habitat classes.

Ecological Gradient Model (EGM)

Initial work showed that the reference site concept created difficulties because of its subjective nature so additional models were explored. A classification system based on depth, degree of wave exposure and wave regime, similar to the geomorphology and hydrodynamic characteristics used in the HGM approach (Brinson, 1993; Brinson et al., 1995; Brinson and Rheinhardt, 1996; Magee, 1996), was implemented to define the major habitat classes. Direction of wave exposure is based on work developed by Friedlander et al. (2003) to evaluate the relationship of fish communities by their degree of wave exposure.

4. Evaluation and testing of models.

Reference Site Model (RSM)

It has been suggested that anthropogenic impacts may be identified for a site if variables within a habitat class deviate from the established ranges of their reference sites (USACE Coral Reef Functional Assessment Workshop, 2004). Two methods were employed in testing this concept.

1. Test sites.

Sites not previously surveyed were compared against reference values to identify departures from reference conditions within the appropriate habitat class and to evaluate the RSM's predictive ability to detect degradation. A site perceived to have high anthropogenic impact and a site with low disturbance were selected to test the RSM. These two sites provided an additional 24 stations for use in model evaluation and testing. Kaloko/Honokōhau, Hawaiʻi is under federal management protection (National Parks Service) and has relatively low anthropogenic influence, while Maunalua Bay, Oʻahu has open access and is perceived as impaired. Variable ranking determined that only three factors (coral cover, number of fishes, and silt-clay) have ranges that are narrow enough to describe site condition. The ranges of these factors within their respective habitat classifications were used to compare with the two test sites. These values were expected to fall within the reference range for their respective classification for Kaloko/Honokōhau and below reference ranges for Maunalua Bay.

2. RSM comparisons.

Non-reference stations were compared against the reference ranges within the appropriate habitat class to determine if these values can indicate general disturbance and stress specificity. The same variables used for the test stations were used to compare non-reference stations. These stations were not used to develop the reference ranges, avoiding a circular argument. Stations were compared against reference standards to determine if the stations perceived as impaired could be detected by the RSM.

Ecological Gradient Model (EGM).

The EGM was designed to rank reef condition within each of the 12 habitat classes in a large number of Hawaiian reefs. The 12 habitat classes were based on depth and wave exposure (Table 1). This method is completely objective and is based on a wide range of metrics that may be linked to specific types of disturbance. Since the values for most factors follow a continuum with high variability, all stations representing a gradient of degradation from severely impacted to relatively pristine conditions were classified into one of 12 environmental groupings based on depth and wave exposure (Table 1).

A model was created in Microsoft Excel© that calculates where a quantified factor lay along the continuum of values. The operator enters a depth, wave exposure and an assessment value for a single factor or a group of factors into the main menu worksheet. A statewide percentile for a particular variable of interest is calculated to evaluate that variable relative to all others in a particular class (Figure 4). For example, the fish biomass at a 5 m station in Waikīkī, Oʻahu located in the center of prolonged, high human activity ranks in the lowest percentile (0%) of all comparable south, sheltered stations (49), between 2.5 and 7.5 m (Figure 5).

In addition to the rank percentile, an overall site index was calculated based on the number of variables input by comparing all other sites in that classification. The index is based on a scale of 0 to 10, where zero represents the most impaired site and ten corresponds to the least impaired site (Figure 5). Each individual factor is weighted based on an objective multivariate analysis of the primary factors defining reef condition. However, the option is also provided that allows the operator to change the weights to suit a particular management or ecological question or leave all factors unweighted. For example, one might wish to create an index that assigns the greatest weight to fish biomass, with little weight assigned to other factors. An index relevant to the question is thereby calculated, and a ranking of sites by fish biomass is produced.

The RSM uses only reference sites, while the EGM takes advantage of the entire suite of sites. Thus, habitat classification was expanded from six groups in the RSM (Figure 2, Table 1) to 12 groups in the EGM due to the increase in sample size. For the first tier, coastal sites were separated into groups based on major wave regime (North Pacific Swell or South Pacific Swell), degree of exposure (exposed or sheltered) and depth ranges (Table 1). The major wave regimes show quite different patterns of wave height, wave periodicity, intensity and seasonality (Jokiel 2006). Slight differences in exposure of coral reefs along exposed coastlines have a profound impact on reef coral development (Storlazzi et al. 2005).

Forty-three physical and biological variables were included in the model (Table 2). Metrics for classification within the second tier include 30 biotic measures to define “biological integrity” and 13 environmental measures to identify signs of anthropogenic stress.

The site selected for model testing is located in Waikīkī, Oʻahu in the centre of anthropogenic activity at 5 m depth. This site has a long history of human activity including nitrification (Laws and Doliente, 1993), extensive shoreline modifications (Crane, 1972), beach replenishment (Marine Research Consultants, 1990), dredging (Belt Collins & Assoc.iates, 1987), and seawall and groin construction (Glenn and McMurtry, 1995). This has considerably reduced substrate and water quality. Much of the imported sands off Waikīkī have filled in low areas in the reef reducing topographical relief important to fish populations. Resuspension of these sands continue to scour the substrate inhibiting coral growth and recruitment.

Results

Identification of major factors

Both natural and anthropogenic factors were influential in structuring coral and fish communities, explaining a considerable portion of the variability (Table 3).

The most important natural factors include depth, wave regime and rugosity. Factors related to anthropogenic impact include human population, silt, and organics. Influencing factors that were negatively correlated with fish communities include silt, turf, coralline algae and degree of management protection (Table 3).

The variation in coral cover was best explained by rugosity, human population within 5 km, depth, distance from a perennial stream, wave direction, and maximum wave height. The variation in coral richness was best explained by sediment organic fraction, wave direction, population within 5 km, distance from a stream, and maximum wave height.

The variation in fish biomass was best explained by nine variables: sediment organic fraction, rugosity, calcareous algae, turf algae, total coral cover, coral diversity, silt, human population within 5 km, and degree of management protection. A negative relationship existed between biomass and human population within 5 km and organics, while all other variables were positively correlated with the response.

Numerical abundance of fishes identified eight metrics: rugosity, organics, total coral cover, coral diversity, coralline algae, turf algae, *Montipora capitata*, and management status. All significant variables except organics and cover by the coral *M. capitata* were positively correlated with the number of fishes observed.

The factors that most strongly influenced fish diversity were organics, human population, coral cover, wave direction, turf algae, sand, rugosity, and coralline algae.

Development of Models

Reference Site Model (RSM)

Based on the environmental variables (Figure 3), many of the reference stations (triangles) clustered together, although some exhibited considerable overlap with the non-reference stations (circles). A total of 74% of the stations were correctly classified and 26% misclassified.

Since some degree of separation occurred between reference and non-reference stations, next it was critical to determine if the reference stations in each of the six habitat classes were different from one another based on biological and environmental factors (Figure 2). To determine if the reference stations fell within the predicted classification a discriminant analysis was conducted. Of the reference stations, only 43% fell into the predicted habitat class. Similar results were obtained when all stations were included (38%). Figure 2 shows considerable overlap of reference stations with no consistent pattern between the six habitat classes.

An ANOVA determined most of the habitat classes were not statistically different from one another for the majority of the variables. Only nine of the 43 variables showed distinct differences between at least two of the six habitat classes. The distinguishing factors included: sand ($F=6.9$, $p<0.001$), *Porites compressa* ($F=6.8$, $p<0.001$), very fine sand ($F=6.7$, $p<0.001$), medium grain-size ($F=4.5$, $p=0.001$), turf algae ($F=3.6$, $p=0.001$), calcareous algae (F=2.9, *p*=0.001), number of fishes (F=2.6, *p*=0.03), total coral cover (F=2.5, *p*=0.04) and silt (F=2.5, *p*=0.04).

<u>Evaluation and Testing of Models</u>

Reference Site Model

1) Test sites

As expected, all stations (17) at Kaloko/Honokōhau exhibited values within the reference ranges, while the majority of the stations (71%) were below reference ranges at Maunalua Bay.

2) RSM comparisons.

Comparisons indicated that the majority of stations at Waikīkī had values for numerical fish abundance and coral cover that were outside the reference ranges for each station's habitat class. Coral cover was below reference levels for their respective habitat class for all 11 transects, while the number of fishes was below reference values at over half of the stations. These results concurred with the established impacts from overuse (Grigg, 1995; Laws and Ziemann, 1995) and identified the specific area within the site where disturbance was occurring. In concordance with the lack of impact by sedimentation at the stations surveyed, silt values at Waikīkī stations were within the reference ranges.

Ninety-nine stations within 26 non-reference sites were compared to maximum reference values for silt. The sites that far exceeded the reference values included: Kakahai'a, Kamiloloa and Pālā'au, Moloka'i, Hakioawa, Kaho'olawe, Pelekane Bay, Hawai'i, and Kāne'ohe Bay, O'ahu. Sites that have silt values slightly higher than reference levels included Puamana, Maui, Laupāhoehoe, Hawai'i and Kamalō, Moloka'i. Of the nine sites that fell outside reference ranges, seven are on the 2002 EPA list of most impaired sites. The two sites detected by the reference model but missing from the 2002 EPA list are Hakioawa, Kaho'olawe and Laupāhoehoe, Hawai'i. The island of Kaho'olawe was not listed in the polluted coastal waters list, but the reefs have been subject to extreme degradation due to siltation (Cox et al., 1995; Te, 2001). The Laupāhoehoe site receives runoff from a large watershed and is subject to extremely high wave energy from persistent NE Trade Wind waves (EPA, 1971).

All five sites detected by the RSM as outside the reference range for fish abundance were included in the 2002 EPA polluted coastal waters list. In addition to Waikīkī, numerical fish abundance was well below reference levels at the majority of stations in Pelekane Bay, Hawai'i; Kamiloloa, Moloka'i; and at deeper stations in Kāne'ohe Bay. One station on the shallow reef flat in Hanalei Bay, Kaua'i was also outside the lower reference range of values. This is in agreement with Friedlander and Parrish (1998) who found the lowest abundance to occur on the reef flats, compared to other substrate types within Hanalei Bay.

All eight sites (Leleiwi, Puhi and Pelekane Bays, Hawai'i; Kamiloloa, Moloka'i; Waikīkī and Kāne'ohe Bay, O'ahu; and Ma'alaea and Puamana, Maui) detected by the RSM as outside reference ranges for coral cover were on the 2002 EPA polluted coastal waters list. The reference values for exposed habitats were confounded by the fact that these sites often had little or no coral cover due to the higher wave energy, thus only sheltered sites were considered in the analysis.

Ecological Gradient Model (EGM)

A Waikīkī station at 5m depth was selected as the model test site. Information on depth, wave exposure and geographic location were input into the main menu of the EGM (Figure 4). These data are used to produce an index and generate a site map of all similar sites.

The Waikīkī station was ranked the lowest of 46 comparable stations with an overall unweighted index of 2.4. Hakioawa, Kaho‘olawe was ranked the highest with an unweighted index of 6.0. A rank and index for each individual factor was also generated by the model. As an example, total coral cover received a rank of 0.02 and an index of 0.2, while fish biomass ranking and index were both 0.0 indicating extremely poor conditions compared to sites within the same classification.

A site map highlighting locations of Waikīkī and all other 46 comparable sites including graphs of site index rankings was generated (Figure 5). This includes an unweighted, CRAMP weighted (based on regression analyses), and user weighted index.

The demonstration program can be downloaded at http://cramp.wcc.hawaii.edu. Additional information is also provided on this website.

Discussion

Results of this investigation demonstrate that defining and quantifying the condition of a complex coral reef ecosystem is a difficult task. These communities are shaped by intricate and highly variable interrelationships between numerous ecological factors. It is unlikely that the condition of a multifaceted coral reef ecosystem can be described using measures of a single factor such as abundance of an “indicator species” or through measurements of a physiological process. However, this investigation offers evidence that a series of key ecological metrics can be used to define the ecological status of a coral reef. The metrics used in this investigation are in wide use, easily measured at low cost, and effective in identifying natural and anthropogenic forces that influence coral reef condition. Fourteen of the 43 metrics evaluated in this investigation had a significant relationship with major reef fish and coral community characteristics.

A similar quantitative evaluation of the “health” and “value” of the Northwestern Hawaiian Islands (NWHI) in relation to the main Hawaiian Islands (MHI) has been presented by Jokiel and Rodgers (2005). Biological information for the NWHI region is very limited due to its extreme isolation, but sufficient data on five important biological indicators were developed for both the NWHI and the MHI. These included: reef fish biomass, reef fish endemics, total living coral cover, population of the endangered Hawaiian monk seal *Monachus schauinslandi*, and the number of female green sea turtles *Chelonia mydas* nesting annually on each island. These diverse data sets were used in a simple integrated scoring and ranking scheme for all the islands of the archipelago. The resulting composite scoring graphically illustrates the diminished condition of reef ecosystems close to human population within the Hawaiian Archipelago. Sensitivity analysis demonstrated that even the use of a small number of well chosen parameters can provide a very useful biological index of reef ecosystem condition.

Reference Site Model (RSM)

The RSM can sufficiently detect sites that strongly deviate from reference values for select factors in sheltered regions. While it is able to detect values that fall outside the reference ranges at highly impaired sites, it is not able to detect marginal degradation because of high variability within reference sites. The RSM based on classification of reference sites and the use of reference values to detect degradation is effective for use in the evaluation of levels of sedimentation. However, ranges suggest that only severely degraded conditions of coral and fishes for specific habitat classes can be detected by this model. Possible degradation can be detected by values of coral cover outside the lower reference ranges at sites with sheltered wave regimes, but not in exposed regions that typically exhibit low coral cover. Furthermore, only strong deviations of numerical fish abundance can be detected, due to high variability. The importance of other influential factors such as sediment composition, fish biomass, fish trophic level, rugosity, and algae can-not be evaluated with this model. The RSM's usefulness and applicability on a broad scale was shown by the agreement with the 2002 EPA's "most impaired site" listing of polluted coastal waters, showing evidence of degradation by sediments, nutrients, or bacteria. This list, revised in 2002, was based on all available water quality data at the time. The majority of listed sites are near streams with a high level of adjacent urban and agricultural activities. South Molokaʻi has a long record of devegetation due to overgrazing which has led to widespread sedimentation on the reef flats (Roberts 2000). Kāne'ohe Bay also has an extensive history of dredging and sewage discharge with considerable urbanization in the surrounding watershed (Hunter and Evans 1993). Both listings, however, are somewhat subjective with the 2002 EPA listing determined largely by water quality and the RSM being derived qualitatively using ecological conditions other than the 2002 EPA criteria.

Use of the reference site approach in this study is further complicated because the legal definition and interpretation of impaired waters versus unimpaired waters is continually changing. This study initially considered the 2002 list (Hawaiʻi State Dept. of Health 2002) (219 stations, 143 sites) to be a valid document produced by resource managers. The list was challenged in court and determined to be inadequate. Further work by managers led to the development of a complicated report in 2006 that was eventually approved by the EPA in 2008 which included (590 stations, 844 sites) (Hawaiʻi Department of Health 2008). This list continues to be contentious and will be subject to further revision. The list is growing due largely to interpretation rather than actual changes in condition of the reefs.

The selection of Kaloko-Honokōhau for a test site (reference category) was made because this is a National Historical Park located along an arid, barren-lava coastline. Subsequent events revealed another weakness of the reference site approach. The site did indeed show values within the reference ranges. However, its status as a fixed reference site might end in the near future. At the southern boundary of Kaloko-Honokōhau National Historical Park, 530 acres of public land is proposed to be developed into a mixed use development. The planned development includes a new 45 acre marina basin with a minimum of 800 additional boat slips, mixed light industrial, commercial and resort components, including timeshares, hotels, and interconnected water lagoons flowing out into the existing harbor. Enlarging the harbor will lead to increased ground water discharge onto the reef. Development is also occurring rapidly upslope to the east of the Park. At present, 13 projects are underway or proposed, as well as infrastructure improvements on water transmission lines, sewer systems and roads. A residential and golf course development is underway at the north end of the Park. Eventually the Park will be in an urban setting. The cumulative impact of these developments on the offshore reefs could be significant.

Results of this investigation show the following limitations of using a “reference site” or a “control reef” in determining reef condition.

1. The reference sites standard cannot distinguish degree of impairment. The extremes of “severely impaired” and “little or no impact” can be defined, but the high variability in range restricts the ability of reference ranges to discriminate on a finer scale.
2. Reference site values have limited power in detecting disturbance. High variability among most variables prevents identification of specific causes of disturbance. Natural heterogeneity increases reference ranges and decreases the ability of reference sites to detect impaired reef condition. For example, high wave energy environments naturally have low coral cover values that are not related to anthropogenic factors compared to degraded sites with reduced coral cover.
3. A small sample of reference sites cannot accurately describe the range of biological integrity encountered among reef communities. There is high spatial and temporal variability that cannot be encompassed by a single reference site or a small number of reference sites. When attempting to integrate a large number of reference sites, conditions can overlap substantially with non-reference sites (Figure 3).
4. Subjective selection of reference sites is flawed, even when the sites are chosen by “experts”. The control and reference sites in most studies are chosen by researchers in order to make a point, and thus may be deliberately or unconsciously biased. No two reefs are exactly alike in all respects, and agreement on appropriateness of any “control” or “reference” reef cannot generally be attained, especially when litigation concerning reef damage is involved. Quantitative analysis showed poor separation between reference and non-reference sites (Figure 3). Determination of optimal reef conditions is obscured by the lack of knowledge of the anthropogenic history of a site and sliding baselines that change over time. The reference concept is defective largely because it does not embrace the diversity of unimpacted reef communities.
5. When comparison of non-reference sites is made against reference sites for use in the evaluation of impairment, comparison among non-reference sites is unattainable.

Although the reference site paradigm was not found to be applicable in the Hawaiian marine environment for the purposes of identifying anything other than severely impaired reef condition because of the complexity and extreme heterogeneity of coral reef ecosystems it may be useful for other applications. The RSM approach may have utility in situations in systems that are less complex than coral reefs. For example, a reference site approach is widely employed in fresh water streams (United States Environmental Protection Agency 2008). Coral reefs are characterized by high biotic diversity and contain orders of magnitude more species than streams. Further, coral reef habitats are diverse and characterized by extreme variation in environmental conditions. Reviews of available information emphasize the difficulties in applying the basic biocriteria concepts to coral reef communities (Jameson et al. 1998, 2001). High variability among candidate reference sites should be expected on coral reefs, so it would be prudent to use more than one site as a reference for any investigation based on the reference site model. The practice of using expert opinion to select reference sites may be of use for certain purposes. For example, the RSM as used in this study was able to identify the most impaired coral reefs. Given the observed variation, it is important to use a group of reference sites rather than a single reference site. In general, however, the use of hand picked reference sites should be avoided. Our conclusions are supported by Wittier et al. (2006) who conducted a comparison of physical and chemical disturbance measures and biotic indices at "handpicked reference stream sites" provided by resource agencies and at sites selected by a probability design. Most of the handpicked reference sites fell into the category of intermediately disturbed, and 12.5% were classified as most-disturbed. Thus only a small subset of the handpicked reference sites represented least-disturbed conditions. The authors concluded that all agencies using reference sites critically review such reference sites with a set of explicit criteria, using field-collected physical, chemical and biological data as well as mapped information.

<u>Ecological Gradient Model (EGM)</u>

The EGM was developed to overcome the limitations noted above for the RSM. Many factors combine to influence coral reef communities, but most explain a very small portion of the variability. Both natural factors (rugosity, depth and wave energy) and anthropogenic factors (organics, human population, management protection and distance from a stream) influence biotic assemblage characteristics (Table 3). Distance from stream is a natural factor, but with an anthropogenic component. Streams are the primary agent in delivery of sediment and other materials from a human impacted watershed to the reef. Although these factors are the most influential in explaining the observed variability in coral community structure, many other factors such as sediment composition and grain size, substrate type, water quality factors, and fishing pressure combine to varying degrees to influence biological populations.

Stratification of coral reef organisms is controlled principally by depth, topographical complexity, and wave regimes. Accretion, growth, and community structure of most coral reefs in the Hawaiian Islands are primarily under the control of wave forces (Grigg 1998). The dominant wave regimes show quite different patterns of wave height, wave periodicity, intensity and seasonality (Jokiel 2006) and slight differences in exposure have a profound impact on reef coral development (Storlazzi et al. 2005). Large waves and strong currents in exposed areas flush contaminants from reefs. In general, anthropogenic impacts dominate in environments where wave forces are not the major controlling factor (Dollar and Grigg 2004). Along open coastal sites, anthropogenic effects often are undetectable relative to natural factors that affect coral community structure (Dollar and Grigg 2004). This observation has led to the suggestion of a management framework that concentrates efforts on embayments and areas with restricted circulation (Dollar and Grigg 2004). That is not to say that we can ignore such wave-swept communities because they are more resistant to loading of pollutants. For example, large volume of sugar mill waste dumped into the ocean along the coastline of Hamakua, Hawai‘i exerted a major negative impact on this wave exposed coastline (Grigg 1985). Upon termination of discharge strong waves and currents swept away the deposits of sediment and cane bagasse and the reefs recovered at a rapid rate. Use of these physical factors to define the major habitat groups is similar to the HGM approach of classifying wetlands based on their geomorphic setting and hydrodynamics (Brinson, 1993; Brinson et al., 1995). This approach is also equivalent to systems of terrestrial botanical zonation, which are primarily based on elevation, topography and rainfall. These oceanic, geologic, and meteorological differences created diverse habitats, supporting varied biotic distributions and abundances making selection of reference sites difficult. Unlike the attributes used to create an index of biotic integrity (IBI) for freshwater systems (Karr and Chu, 1999), most marine attributes are not composed of distinct ranges, but instead follow continuous gradients.

Multiple variables that have an influence on the biological communities follow overlapping and often dissimilar continuous gradients that confound defining of boundaries. Thus, it is advantageous to use a large number of sites within each habitat classification and rank the sites along a continuum by purely objective criteria. In this way the condition of the reef can be defined in comparison to a wide range of other reefs within its habitat classification. The EGM method continues to grow in power as the number of sites, parameters and classifications are increased.

This EGM approach provides a quantitative method for ranking coral reef condition based on extensive data, rather than depending on an arbitrary “reference site” or a rigid set of standards. As shown by the example (Figure 4), the use of computers allows for a rapid comparison of a site under evaluation to a large range of other comparable sites. Furthermore, this approach permits the operator to alter and define criteria appropriate to a specific question. A low ranking can assist management in identifying degraded areas that may need further investigation, monitoring or restoration. A high ranking can identify sites that may be suitable for consideration as marine protected areas (MPA) or avoided for dredging or construction projects. Comparing rankings can aid in assessing compatibility of experimental and control sites for use in manipulative field experimentation. A link to specific types of disturbance may be highlighted in these rankings. For example, a high ranking of silt/clay and organics can be indicative of areas heavily impacted by sedimentation. Different areas within a region can be compared to identify the range and type of impact. The EGM’s quantitative assessment has the capability to be used as a valuable management tool upon which to base effective administrative decisions.

The approach taken in this study was to describe relationships between physical, anthropogenic, and biological parameters on Hawaiian coral reefs. The techniques used in this study are widely used, cost-effective, non-destructive, inexpensive, biologically meaningful and within the technical capabilities of most researchers and managers of coral reef areas. The model uses widely available software for calculations. The work was successful in identifying those coral reef metrics that are useful indicators of general reef condition. Thus physical, anthropogenic, and biological attributes were incorporated into the EGM. The next step will be to develop and test an index of biological response that relates directly to anthropogenic impact. The Index of Biotic Integrity (IBI) was developed by Karr (1981) as a means to identify and classify water pollution problems. The IBI is based solely on biological characteristics, so it is useful to contrast the EGM and IBI and discuss the design and applications of the two approaches. There is a great deal of interest in developing such an IBI for coral reefs, which has proven to be an elusive and formidable task (Jameson et al. 1998, 2001). A potential coral reef IBI can be viewed as a subset of the EGM and could be derived using the biological data (e.g. coral cover, fish biomass, diversity, trophic structure, etc.) contained in the EGM. A ranking based entirely on biological data in the existing model can be achieved simply by setting all physical parameters to 0 and running the model using only the biological data. However, the weight given to each biological factor and testing the validity of the resulting indices in various habitats will require a great deal of effort in the future. The metrics of wave exposure and depth were shown to be the overriding physical factors defining the major habitats on coral reefs of Hawai‘i, so a specific index must be developed within each habitat from biological data contained in the EGM habitat groupings. At the present time the environmental laws intended to protect coral reef resources from pollution in Hawai‘i are based largely on water quality criteria and not biocriteria. Water quality data for reef locations throughout Hawai‘i are very scanty, so a great deal of additional effort will be needed in order to link water quality criteria to the biological criteria if this work is to move forward. Likewise, data on pollutants entering the reefs by stream flow, surface runoff and groundwater is poorly documented. As such data become available, it has been suggested that the biological attributes within each physical habitat grouping of the EGM could be used as “dependent variables” and various physical and anthropogenic factors as “independent variables.” One could analyse such biological indices against water quality, discharge and other anthropogenic factors in order to determine which most strongly influence the biological condition. As a caution, however, it has been shown that the IBI approach is an excellent means for determining that a problem is present, but is not effective at determining the cause of the impairment, especially when multiple dischargers are present and/or the habitat has been disturbed (Seegert 2000). The ability of the EGM to produce a relative ranking of general reef condition for a large number of sites in comparison to a particular site being evaluated is the greatest strength of the EGM at the present time that should be included in the potential development of a purely biological index.

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Table 1. Twelve habitat classifications used in the Ecological Gradient model (EGM) based on depth and wave exposure.

Dominant Wave Regime	**Degree of Exposure**	**Depth Range (m)**
South Pacific Swell	Exposed	<5
South Pacific Swell	Sheltered	<5
North Pacific Swell	Exposed	<5
North Pacific Swell	Sheltered	<5
South Pacific Swell	Exposed	5-10
South Pacific Swell	Sheltered	5-10
North Pacific Swell	Exposed	5-10
North Pacific Swell	Sheltered	5-10
South Pacific Swell	Exposed	>10
South Pacific Swell	Sheltered	>10
North Pacific Swell	Exposed	>10
North Pacific Swell	Sheltered	>10

Table 2. Physical and biological variables incorporated into the ecological gradient model. Variables underlined with subcategories below and units in parentheses.

Physical Factors		**Biological Factors**		
Other variables	**Sediment variables**	**Coral Assemblage Characteristics**	**Fish Assemblage Characteristics**	**Algal Characteristics**
Rugosity (Index)	Composition	Total coral cover (%)	Abundance (no/125 m^2)	Macroalgae (%)
	Organics (%)		Biomass (mt/ha^{-1})	Coralline (%)
	$CaCO_3$ (%)		Diversity (*H'*)	Turf (%)
			Evenness (*J*)	
Substrate type	Grain-sizes	Species	Trophic guild no	
Sand (%)	Coarse sand (%)	*Porites lobata* (%)	Corallivores (no/125 m^2)	
Silt (%)	Medium sand (%)	*P. compressa* (%)	Detritivores (no/125 m^2)	
	Fine/very fine sand (%)	*Montipora capitata* (%)	Herbivores (no/125 m^2)	
		M. patula (%)	Mobile Inverts (no/125 m^2)	
	Silt/clay (%)	*M. flabellata* (%)	Sessile Inverts(no/125 m^2)	
		Pocillopora meandrina (%)	Planktivores (no/125/m^2)	
			Zooplanktivores (no/125 m^2)	
Human population		Species richness (no/125 m^2)	Size classes	
w/in 5km (no)			<5 cm (no/125 m^2)	
w/in 10km (no)			5-15 cm (no/125 m^2)	
Watershed (no)			>15 cm (no/125 m^2)	
Precipitation (mm hr^{-1})		Species diversity (*H'*)	Endemism status	
Stream distance (km)			Endemic	
			Indigenous	
			Introduced	

Table 3. Influential Biological and Environmental Variables

Fish assemblage parameters			**Coral community factors**	
Biomass	**Number of individuals**	**Diversity**	**Coral cover**	**Richness**
Organics t= -4.5, p=<0.0015	Coral cover t=5.0, p=<0.001 Diversity t=2.7, p=<0.001	Organics t= -5.7, p=<0.001	Rugosity t=8.4, p=<0.001	Organics t= -4.6, p=<0.001
Rugosity t=3.5, p=0.001	Coralline t=4.3, p=<0.001 Turf t=2.4, p=0.02	Coral cover t=3.5, p=<0.001	Human Population t= -3.4, p=0.001	Wave direction t= -3.9, p=<0.001
Coralline t=3.9, p=<0.001 Turf t=2.4, p=0.016	Rugosity t=3.3, p=0.001	Human Population t= -3.2, p=<0.001	Depth t= 3.0, p=0.003	Human Population t= -3.8 p=<0.001
Coral cover t=3.9 Diversity t=2.2	Organics t= -2.3, p=0.026	Wave direction t= -3.0, p=0.024	Distance from stream t= -2.8, p=0.006	Distance from stream t= -2.8, p=0.006
Human Population t= -2.3, p=0.021	Management Status t=2.2, p=0.033	Turf t=2.8, p=0.001 Coralline	Wave direction t= -2.7, p=0.009 Wave height	Wave height t= -2.3, p=0.025

		t=2.0, *p*=0.001	t= -2.3	
Silt t= -2.3, *p*=0.023		Rugosity t=2.2, *p*=0.008		
Management Status t=2.3, *p*=0.022		Sand t= 2.0, *p*=0.03		

Appendix IV: Statistical Review and Recommendations

Review of proposed biological monitoring methods for coral reefs in Hawaii

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General comments

The Coral Reef Assessment and Monitoring Program (CRAMP) incorporates many elements of a robust biological monitoring program. Selection of sampling sites to represent a range of human influence and site condition, careful attention to statistical power of the data collection methods, data handling procedures, and community outreach all contribute to CRAMP's potential to protect coral reefs in Hawaii using biocriteria under the water quality standards (WQS) of the Clean Water Act.

For any emerging biomonitoring program, a key step involves teasing apart the influence of natural habitat drivers from the changes caused by humans on the resident biota. Different ecological systems have different natural drivers: for macroinvertebrates in estuaries, it's salinity; for fish in streams, it's width and watershed size. For coral reefs, the authors have identified depth and wave energy. My primary concern is that human stressors and natural environmental drivers are treated somewhat interchangeably throughout the analysis.

To develop a multimetric index, the relevant natural factors should be used to classify habitat types, and biological metrics tested for association with human disturbance within those habitat types. Throughout the materials, the authors identify relationships between human disturbance and measures of coral or fish condition, but they are either included with other environmental factors or they are reported anecdotally. Some work remains to firmly establish a connection between independent measures of human disturbance and the biological response measures in order to define and calibrate metrics for inclusion in a multimetric index.

My primary recommendation is to develop an aggregate index of human disturbance that can be used to directly test metric response within habitat types. Several aspects of disturbance are mentioned without being formally tested. A simple index of human disturbance could be derived from scoring various activities as low (0)/medium (1)/high (2), and then summing the scores; or a more statistical approach could be used, e.g. a PCA axis. The authors know a great deal about how human disturbance alters coral reefs, that knowledge needs to be quantified and formalized for metric testing.

Sample sizes may be too small to test all metrics within every habitat type. If so, it may be possible to combine sites within some the habitat types if metric values do not differ for reference sites within these habitat types. Alternatively, some habitat types may need to wait until additional data become available.

Additional analysis could potentially reveal a more compelling story about how human activities degrade coral reefs, as well as yield a more robust biological index. See "Recommendations" below for some specific approaches that could be applied to the existing data.

Specific comments

This section follows the steps outlined by Jameson et al. (2001) for the development of biocriteria for coral and have been applied in USVI (EPA, 2008b). Numerous CRAMP documents are relevant for the development of coral reef biocriteria in Hawaii (see Appendix A for sources). Rather than review the various reports, journal articles and web pages individually (as for a manuscript review), I selected this framework to organize the elements and steps involved in developing biocriteria for coral reefs. Each heading has a brief overview of the step's purpose and a review of the CRAMP program's efforts.

Although listed in a logical order, the steps are often iterative as we test and re-test different habitat classification schemes for the most parsimonious system while testing and re-testing biological measures to identify which are the most meaningful indicators of biological condition and most responsive to human-induced degradation.

1-A Classify coral reef systems

To define biocriteria for a coral reef, we must define biological expectations in the absence of human influence. Expectations for biological condition typically vary according to different types of habitats. For example, in Florida lakes, expectations for invasive exotic plants would be higher in the southern part of the state where it never freezes than in the northern panhandle (Fore et al., 2007b).

The authors involved with CRAMP have identified several natural features that reliably and consistently predict coral cover, coral taxa richness and fish taxa richness. Depth and wave height and direction were used to classify reefs into natural habitat types. In some of the results a latitudinal difference associated with volcano age and drift north was identified as influential but not for others.

Initial testing of habitat types was done with species level data, a reasonable approach for identifying natural drivers. However, the next step is testing whether these habitat types differ according to the biological endpoints of interest, e.g., coral cover and taxa richness.

NOAA benthic maps have recently become available and can be helpful in identifying habitat types and other potential natural drivers. CRAMP used these maps to randomly select sampling sites within appropriate hardbottom areas.

1-B Develop testable hypotheses about response to human influence

Many hypotheses about how coral reefs respond to human influence have been proposed and tested in the literature. At the initial stages of metric development, there is no penalty for testing as many metrics as seem relevant (Fore, 2006). The second round of testing with a new data set (see 6 below) will eliminate any metrics that were significantly related to disturbance due to chance alone. Before testing, the direction of association with human disturbance should be defined based on knowledge of coral reef ecology. Metrics may be quantified in a variety of ways, e.g., count of taxa, % living tissue, % relative abundance of trophic guilds, etc.

CRAMP identified candidate metrics for assessing coral condition including % coral cover, taxa richness, growth, recruitment and mortality. For algae, metrics related to % cover, taxon, growth, recruitment and mortality were tested. For fish, candidate metrics were based on numerical abundance, biomass, endemism, trophic levels, feeding guilds, species composition, and size distribution.

To test for biological response, measures of human influence included population within a given distance, protection status, organic sediment and silt. Other types of human influence were discussed, but not quantified: sedimentation and erosion, overgrazing, fishing pressure, nitrification, watershed type, dredging, sewage, and shoreline modification.

1-C Define data collection protocols

For many years in freshwater monitoring, chemical measures were collected as surrogates for biological condition (Karr, 1991). We now know that the best indicators of biological condition are biological measures, rather than chemical or physical habitat measures, although these measures are important for diagnosis of what's causing a problem. Much has been learned about which types of biological metrics work best (taxa richness is less variable than abundance, for example).

In contrast, summarizing and quantifying human influence is a much more difficult task. Humans influence biological systems with changes to water quality, homogenization of habitat structure, alteration of flow regimes, changes to food sources, and disruption biological interactions (Jameson et al., 2001).

The CRAMP data collection protocols focus on the endpoint of interest for the protection of coral reefs: the benthic organisms and fish that live there. The protocols used to collect benthic data were carefully considered and compared using an objective analysis of both cost and the statistical power to detect change (Brown et al., 2004).

The authors initially chose video monitoring based on their analysis and later switched to digital stills as technology improved. During the transition, they paid careful attention to intercalibrating the two methods so that the older data would not be orphaned but could still be used in comparisons of long-term monitoring sites.

The authors chose many short transects over a few longer transects. They also implemented a modified version of the protocol (RAT) in order to visit more sites. This approach (less information at more sites) matches the tenets of modern survey design espoused by EPA's EMAP designs (Olsen et al., 1999).

Site condition and human disturbance was not collected in as meticulous a manner. This task is complex and requires identifying diverse information sources. For example, reference sites were based on best professional judgment of local experts rather than a quantification of land use patterns. There are no easy rules when it comes to human disturbance in terms of which measures are best; however, the process can be objective and quantitative.

The careful, but simple, ranking method that the authors used to summarize protection status could be applied to other measures of human disturbance that were discussed in the text but not tested directly. An aggregate index based on simple re-coding according to low, medium, and high values for disturbance has often been used very successfully.

2 Biological sampling

When initiating a biological monitoring program, in order to document that metrics respond reliably and predictably to human disturbance, sites must be sampled across a gradient from minimal from minimal human influence to severely altered. Data must also be collected from a full set of habitat types to ensure that patterns of biological response are consistent.

The authors were very careful to collect data from sites representing a range of site conditions both in terms of natural differences and anthropogenic impact. Their site selection criteria included: naturally occurring conditions as close to original as possible; the entire scope of wave exposure and direction; a wide range in human population; a range of legal protection; and spatial gradients to encompass longitudinal differences.

Given the variety of habitat types (windward/leeward; depth zones; etc.), 60 sites may simply be too few. If 12 habitat types are identified according to depth and wave action, that leaves on average only 5 sites in each category – not necessarily enough to adequately test for differences associated with human disturbance.

3 Screen attributes to define metrics

To withstand a legal or regulatory challenge, biological metrics or indexes used to define biocriteria must show a convincing and consistent response to independent measures of human disturbance (EPA, 2005). Dose-response curves must be clearly documented.

Expectations for biocriteria must also be defined in a reasonable and transparent manner; typically the reference condition approach is used to quantify expectations for biological condition and define how much of a departure from reference condition represents an impairment (EPA, 2006; Stoddard et al., 2006). Many states have defined impairment based on percentiles of reference conditions, e.g., "Index values below the 10th %tile of reference sites are considered impaired." Often a "buffer zone" is added between reference site values and the definition of impairment to include a measure of uncertainty.

Measures of human disturbance and natural physical factors were consistently treated interchangeably in many of the statistical analyses. In Table 1 of Rodgers et al. (MS in prep.), physical factors include measures such as grain size and precipitation, which are certainly independent of anthropogenic influence or biological condition; but under the same heading are included human population, management protection and sediment composition which are measures of human influence. Distance from stream is a combination of natural factors and human disturbance (depending on land use practices in the watershed that can create erosion) and for this type of variable the information needs to be parsed and tested separately. Rugosity also seems like a mix of coral (biological) condition and natural substrate formation.

Multiple regression was a good first cut to identify which variables influence coral cover and taxa richness, but additional testing is needed against a gradient of human disturbance within habitat types to document a close relationship (dose-response) between biological metrics and human disturbance. See recommendations below for alternative approaches for this data set.

The authors had mixed success with comparisons between reference and non-reference sites (Rodgers et al., Ms in prep.). They consider reference designation to be "too subjective." Many states agencies started in a similar way with "best professional judgment" and eventually moved to strict objective criteria for defining reference condition, e.g., using thresholds for land use within the watershed, water quality parameters, habitat condition, or other measures of human influence. Many examples applied by other states (e.g., FL, ID, CA) in other resource types could provide a template of this process for reefs.

The authors comment that "No two reefs are exactly alike in all respects, so agreement on appropriateness of any "control" or "reference" reef cannot be attained in an absolute sense." The authors then seem to solve the problem by first sorting sites according to key physical factors (wave energy and depth) using the "environmental gradient model." Yet, I cannot figure out if this solution worked or not. The authors mention that there was "considerable overlap between reference and non-reference sites" but I can't tell for which variables. I am curious whether the reference and non-reference sites differed in terms of *biological indicators* within the EGM habitat types. If so, this is good evidence that these metrics are reliable indicators of human disturbance.

The authors also conclude from a PCA comparison (and also a discriminant analysis) of "environmental variables" (I'm not exactly sure which variables were used) for reference sites that the high amount of overlap for habitat types indicates a failure of this approach. But is this

the best test? We don't really want to know whether *environmental* conditions at different habitat types differ, we want to know if *biological condition* is differs.
Just when the problem of habitat classification seems to be solved by the EGM, the authors seem to back away from metric testing. The EGM simply combines a variety of likely measures of site condition including biological indicators, physical factors, and human disturbance measures; however, the metrics still need to be tested.
The "IBI" is an average of the values for all these variables (I think), which is not an index of biologic integrity, but simply an average of reef condition measures. Multimetric indexes like IBI only include measures of biological condition. (If I am misinterpreting here, and only biological measures are included, please ignore this comment, I couldn't quite tell how the "IBI" was calculated in the spreadsheet.)
The EGM provides rankings of the various reef condition measures relative to the other sites within the same habitat type. The authors weight the various measures based on other analyses of their relative importance, but a direct comparison between stressors and biological indicators remains to be done.

4 Determine appropriate sampling effort for reliable assessment

Some biological sampling protocols are restricted to a particular time period, e.g., temperate streams are sampled during summer, to eliminate seasonal variability. For freshwater benthic invertebrates the number of individuals identified from a sample must be consistent. For fish, the size of the stream sampled is often defined as 40x the wetted width. The purpose is to make data collected comparable across space and time.
For coral reefs, season is probably less of a concern. The authors identify depth as an important factor and control for depth effects by sampling within specific depth ranges.
Although the authors have extensively evaluated the size and number of sampling transects for coral cover, if other coral or fish metrics are selected for monitoring, this step may have to be revisited.
Currently the authors are comparing stations within sites through time. (If I have this wrong, please ignore this comment). A more powerful sampling design would compare multiple sites through time, e.g., using a paired t-test for data summarized at the site level. This would provide a great sample sizes which would likely be capable of detecting smaller changes through time.

5 Define data handling and analysis protocols

Once protocols for data collection and analysis are finalized, all aspects of the protocol need to be tested for repeatability. Statistical power of the final index for detecting change for a specific statistical test (e.g., linear trend through time for a population of revisited sites) should also be evaluated. QA/QC procedures must also be defined so that people who didn't invent the method can apply all protocols with similar results.
Much of the work for coral cover and fish sampling has been done in terms of testing the repeatability of the CRAMP protocols. If new metrics are added, they should be evaluated as well.
The web site mentions that databases have been defined, and data for benthic, fish and photoquadrats archived. Benthic, fish and photoquadrat daSummary data are available for some sites from the web.

6 Validate decision processes with additional data sets

For any biomonitoring program, validation is a critical step. Hypotheses about biological response to human disturbance are derived from literature and experience and tested with an initial data set.. The best indicators are selected, but they still must be confirmed with a second, independent data set to ensure (and to answer the potential challenge) that associations were real and not random.

The authors had data from only 52 sites, not enough to split the data set into development and validation sets. They started the process of validation testing with 2 sites for RSM and 1 for the EGM. A great deal of work has been done to get this biomonitoring program this far, but additional sites are needed to carry the work to completion.

7 Define biocriteria

Hawaii's WQS define designated uses for Class AA marine waters as "oceanographic research, the support and propagation of shellfish and other marine life, conservation of coral reefs and wilderness areas, compatible recreation, and aesthetic enjoyment." States have been urged to replace these general descriptions of aquatic life uses with more specific language that make the WQS easier to enforce and interpret (Davies and Jackson, 2006; Karr and Yoder, 2004).

Once biomonitoring protocols are in place, expectations for each designated use must be defined, preferably in terms of numeric values for biological indicators. Two approaches can be used to set thresholds, the reference condition approach or biological condition gradient developed by EPA for tiered aquatic life uses (EPA, 2005; EPA 2006). FL Department of Environmental Protection used both approaches which provided very similar biocriteria thresholds for streams (Fore et al., 2007a).

8 Implement monitoring programs

Monitoring programs are typically designed to answer some version of the 5 basic questions:

> *What is the condition of the resource? (Status monitoring)*
> *Is the condition changing? (Trend monitoring)*
> *What's causing the change? (Targeted monitoring)*
> *What can we do? (Compliance monitoring)*
> *Are we making a difference? (Effectiveness monitoring)*

The appropriate survey design depends on the questions being asked.

As CRAMP matures and is implemented as a state-wide program, assessment questions will likely expand. EPA has developed guidelines to address the different types of questions, e.g., survey designs, minimum sample sizes, etc. (EPA, 2008a)

The original CRAMP long-term monitoring sites were not randomly selected, but were selected to be representative of prevalent conditions (judgment sampling). Trends detected for these sites will only apply to these locations (Olsen et al., 1999; Larsen et al., 2001). In contrast, conditions observed at the randomly selected RAT sites can be used to draw inferences about the condition of the entire area from which the sites were selected. Non-random selection is appropriate for many situations such as metric testing across a known gradient of human disturbance. As a monitoring program matures, the questions often change, and survey designs evolve to match program needs.

9 Diagnose causes of degradation for specific sites and implement management programs

Biological monitoring can be used to identify unique resources that merit special protection, manage to reduce the effects of human actions or restore degraded systems.
The authors recognize the importance of biological indicators for diagnosing causes of degradation by including multiple measures of fish and coral. This step is outside the scope of the current study.

10 Evaluate management effectiveness

A strong association between biological indicators and independent measures of human disturbance ensures that the protocol can be used to detect changes in biological condition associated with management policies and actions.
This step is outside the scope of the current study.

11 Communicate results of work to citizens and policy makers

The authors initially engaged local experts, scientists, educators, and managers when they selected the long-term monitoring sites based on ‘hot spots’ and areas of special concern. CRAMP operates as a bridge between science and policy. The web site is easy to read and navigate without sacrificing detail or scientific rigor.

Recommendations

- *Recognize that a great deal of work has been successfully completed.*

Many elements of a successful biomonitoring program have already been accomplished by CRAMP: underwater logistics, precision of sampling protocols, selection of candidate metrics, identification of natural driving variables for coral and fish metrics, initial metric testing, data management, and outreach to other stakeholders.
Development of biocriteria is an iterative process. For example, the first metrics selected may not be the best metrics or initial habitat classification may have more categories than are actually needed. A great deal of good science has gone into CRAMP and the program merits additional support to complete its development of biocriteria.

- *Objectively define reference sites.*

Human disturbance measures can be objectively described in a qualitative or narrative manner. The method used by the authors to rank sites in terms of legal protection status could also be used to define categories for shoreline modification or land use in the terrestrial watershed.

- *Determine which biological metrics are reliable indicators of human disturbance.*

The authors report numerous associations between measures of coral and fish condition with human disturbance, but a relationship between stressors and biological indicators has yet to be clearly demonstrated. The problem is that human land use patterns often follow natural environmental gradients and these relationships confound metric testing because they both contribute to changes in reef condition.

One approach would be to test within habitat types, which the authors did. They found that some of the biological and environmental variables differed, but that the pattern was not consistent. The data need to be simplified. One approach would be to develop an integrated measure of human disturbance. Only factors related to human influence would be included. The index could be an aggregate of scored measures (Table 1) or derived from a PCA axis. This index of human influence would be used to test biological metrics within habitat types.

Testing within habitat types is designed to control for natural environmental differences that may cause coral and fish indicators to differ. The trick is to hold these constant while testing for differences associated with human influence alone.

If environmental factors and human influence are too enmeshed to test across groups of sites, a second approach would be to identify pairs of sites within the data. Sites could be matched as closely as possible in terms of their natural physical features, and the site with greater human influence identified. A simple sign test could be used to determine whether sites with more disturbance have less coral cover or fewer fish species. This approach simplifies the analysis because the types and intensity of human disturbance can vary across sites, only the 'most disturbed' site needs to be identified for each pair.

A third alternative would be to combine sites across habitat types to create a larger pool of sites to test metrics against the index of human disturbance. Sites could be combined if two conditions are satisfied: 1) references sites within the different habitat types do not differ for the metric being tested and 2) measures of human disturbance and natural environmental factors are not correlated for sites within the group.

Table 1. Example of scoring criteria for an aggregate index of human disturbance. An index scores for a site would be the sum of the scores. See Fore et al. (2007a, b) for actual examples of this approach.

Human activity	0 (low)	1 (medium)	2 (high)
Protection status	Full	Partial or limited	None
Organic sediment	< 10 %	10-25%	>25%
Fishing pressure	> 20 km from a marina	> 10 km from a marina; no commercial fishery present	< 10 km from a marine; or commercial fishery present
Urbanization	<10K people in watershed	10-25K people in watershed	>25K people in watershed
Point sources	None	Treated wastewater effluent present	Untreated wastewater effluent present
Erosion	None	Some soil loss on moderate slopes; some grazing	High soil loss on steep slopes or excessive grazing
& etc.			

- *Limit IBI metrics to measures of biological condition.*

Multimetric indexes are designed to summarize attributes of the biological community that respond predictably and reliably to human disturbance. They typically do not include measures of natural or anthropogenic factors. Usually they are developed for a single taxonomic group, e.g., fish, invertebrates, birds.

- *Consider collecting additional data.*

CRAMP has data from 52 sites. In contrast, most states agencies needed at least three times that many sites to develop mature biomonitoring programs. In many cases, state programs sampled more sites than they needed, but still found during the analysis that holes in the data remained. The key is to identify the specific questions to be answered before going in the field to collect data.

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Modeling Hawaiian Coral Reef Ecological Status. (MS. In prep). Ku‘ulei S. Rodgers, Paul L. Jokiel, Christopher E. Bird and Eric K. Brown

Brown E, Cox E, Jokiel P, Rodgers K, Smith W, Tissot B, Coles S and Hultquist J. (2004) Development of Benthic Sampling Methods for the Coral Reef Assessment and Monitoring Program (CRAMP) in Hawai‘i . Pacific Science 58 (2): 145-158.

Extensive, objective comparison of multiple methods in use to survey coral. Comparison based on statistical power to detect change and cost per data point.

Jokiel PL, Brown EK, Friedlander A, Rodgers SK and Smith WR (2004) Hawai‘i Coral Reef Assessment and Monitoring Program: Spatial Patterns and Temporal Dynamics in Reef Coral Communities. Pacific Science 58: 159-174.

Coral cover and coral taxa richness were associated with natural factors (depth, wave type, island age [latitude], rugosity, and sediment grain size) and measures of human disturbance (population size, erosion). Significant increases (n=13) and declines (N=16) in coral cover were found over the 3-year period of the study.

Chapter 3. Coral reef community structure. K. Rodgers thesis.

Provides additional information on relationship between coral species and measures of environmental factors and human disturbance.

CRAMP web site. Pages under “Long-term monitoring” and “Rapid assessment technique.”

Extensive description of methods and development of data collection and analysis protocols.

Ecological gradient model.xls

Interactive program that takes information entered for coral condition, fish assemblage, human influence, and other environmental factors and calculates an average value based on ranks and weightings of these variables within classes of depth and wave direction.

Ecological gradient model instructions.doc

Describes operation and inputs for the Excel model.