



## **Measurement and Monitoring, Methods and Applications to Coral Bleaching: Methods and Findings of the Hawaii Coral Reef Monitoring Program (CRAMP)**

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Coral reef monitoring programs range in complexity from purely volunteer "no cost" efforts to well-funded university/government programs. CRAMP is an example of the latter—an integrated regional program that employs state of the art technological innovations not generally available in developing countries. At the high end of the scale such regional programs cost from US\$300K to \$1000K annually and depend on local availability of highly trained scientists and graduate students and on a high degree of local technical support.

Ideally, investigations of coral bleaching should be viewed in an ecological context in which numerous interacting factors may contribute to the bleaching phenomena and to eventual reef decline. The CRAMP experimental design addresses such subtle issues. CRAMP was initiated in 1998 in response to increasing environmental problems being faced by researchers and managers in Hawaii. A major limitation had been the absence of a comprehensive coral reef research and monitoring program and consequently the lack of information on environmental changes on our reefs. CRAMP is an integrated statewide program designed to describe the spatial and temporal variation in coral reef communities in relation to natural and man-made disturbances. The design is such that CRAMP can address environmental questions from the local to the global scale. At the local level, CRAMP is designed to identify changes at selected sites. Viewed from a broader perspective, CRAMP can describe statewide environmental trends. CRAMP experimental design allows local scientists to investigate global changes through collaboration with other regional monitoring programs.

The CRAMP monitoring design includes sites focused on questions concerning a wide range of acute and chronic impacts. Degradation of reefs in many areas of Hawaii continues due to increasing human population and human activity. Impacts affecting Hawaiian coral reefs include; overuse (over-fishing, anchor damage, ship grounding, diver damage, etc.), sedimentation, nutrient loading, coastal construction, urbanization, catastrophic natural events (storm wave impact) global warming (bleaching), and introduced species invasions.

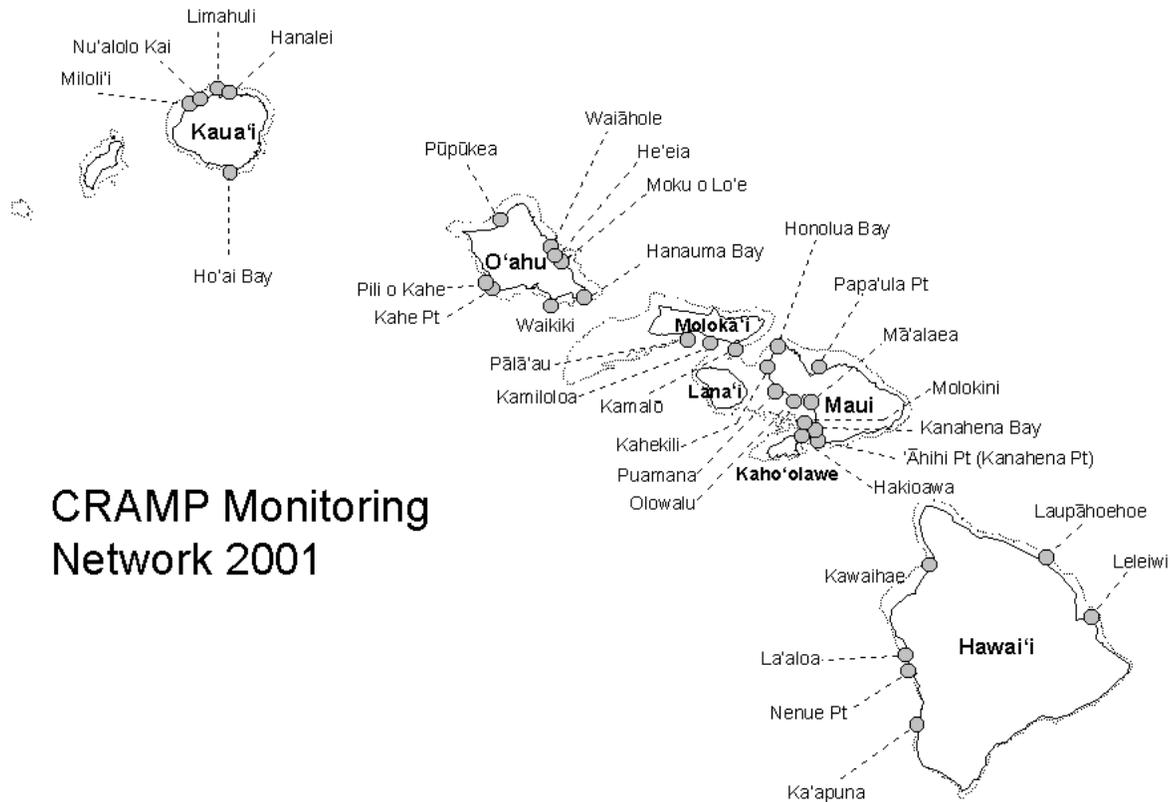
### **General Experimental Design - "Problem Focused" Research**

CRAMP experimental design allows detection of changes that can be attributed to various factors such as overuse (overfishing, anchor damage, aquarium trade collection, etc.), sedimentation, nutrient loading, catastrophic natural events (storm wave impact), coastal construction, urbanization, global warming (bleaching), introduced species, algal invasions, and fish and invertebrate diseases. The experimental design provides vital information on all of the above issues, but the emphasis is on the major problems facing Hawaiian coral reefs as listed by managers and reef scientists during workshops and meetings held in Hawaii during 1997-1998. These are: overfishing, sedimentation, eutrophication and algal outbreaks. CRAMP experimental design gives priority to areas where baseline data relevant to these issues were previously collected. CRAMP continues to synthesize existing data into the experimental design, and conduct further work in order to test hypotheses concerning the role of various environmental factors in the ecology of coral reefs.

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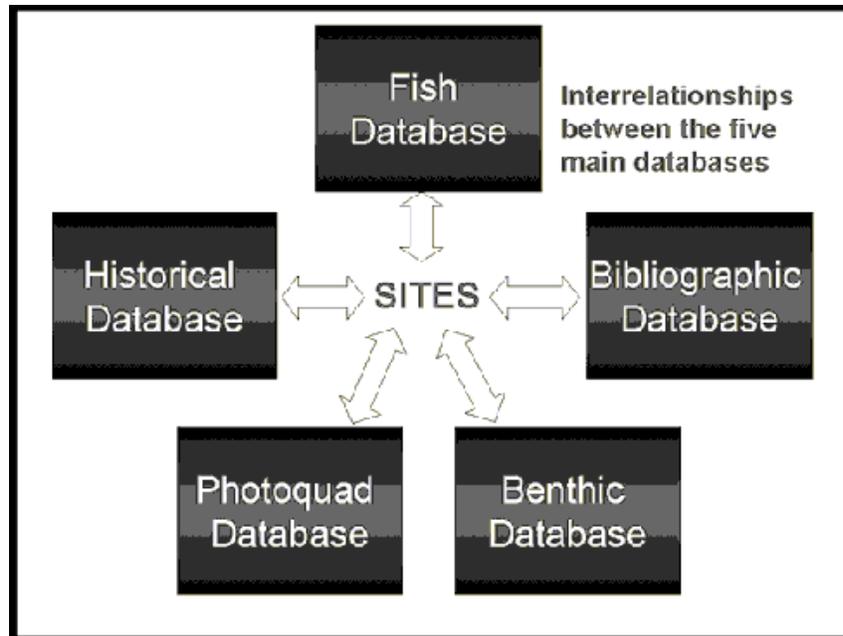
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*Research Sites* - CRAMP has installed and initiated monitoring at 30 research sites on Kauai, Oahu, Maui, Molokai, Kahoolawe, and Hawaii. The overall network provides an excellent cross section of reefs across the main Hawaiian Islands with regard to habitat type, degree of environmental degradation due to various human and natural factors, and rates of recovery in damaged areas.



## CRAMP Monitoring Network 2001

*Survey Techniques* - Each research site consists of ten transects and five photoquadrats at two depths (3m and 10m). CRAMP employs several methods to address changes in overall coral/algae cover and growth, as well as measurement of recruitment and mortality of the corals. Digital video is used to record images along each benthic transect for later image analysis and archiving. The protocol detects changes in coral coverage of less than 10% between samplings with high statistical power. Fixed benthic photoquadrats are used to examine trends in growth, mortality and recruitment of individual organisms. Five randomly selected permanent photoquadrats along the 3 meter and 10 meter depth contours were established with stainless steel marker pins at each corner to ensure accurate repositioning of the frame during subsequent resurveys. Sediment samples are taken at each location, and other parameters such as rugosity, depth, slope and wave exposure are also measured. Reef fish are quantified along the transect (four belt transects of 5m x 25m). This standardized protocol produces data on fish diversity, abundance and biomass. Meteorological data, adjacent land use information, water quality records, and other data are available at most sites from various sources.



*Database* - Recent advances in computer and communications technology enables CRAMP to collect, process, and summarize data in a form readily available to researchers and managers. Perpetuity of the database and easy access are insured through redundant archiving of information in systems with expected longevity. The CRAMP database system is can be queried to analyze and generate information from spatial and temporal data.

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

The five database elements shown above contain the following information:

1. Fish Database: Consists of information on sites, taxa, surveys, and survey data (both from the past and from on-going projects). Monitoring information includes data on abundance and size estimates for fish species present at each study site.
2. Benthic Database: Consists of information on sites, taxa, surveys, and survey data (both from the past and from on-going projects). Monitoring information includes coverage data on coral, algae, and other invertebrates at study sites.
3. Photoquadrat Database: Consists of information on growth, mortality, and recruitment of sessile benthic organisms.
4. Bibliographic Database: Consists of a bibliographic ID field linked to the survey reference information table, species, keyword and location information fields, bibliographic information, publication abstract where possible, and links to or the full text of publication. The bibliographic table is continually expanded to cover pertinent publications and unpublished documents and reports.

5. Historical Database: Consists of fields that contain additional site information from previous historical collections at study sites throughout the state. This includes not only the CRAMP sites but also sites surveyed by other researchers and consulting companies.

### Accomplishments:

1. During the first two years of operation CRAMP met the challenge to develop and implement statistically valid survey techniques for detecting change in benthic and fish communities in Hawaiian waters. This involved installation and quantification of transects at over 30 monitoring sites in the State of Hawaii. CRAMP completed the first cycle of monitoring and data analysis and began the second cycle.
2. CRAMP has designed and implemented a well-designed database that will allow rapid access to a very large amount of data being taken as part of the project. In addition, the database includes bibliographic and historical data for Hawaiian waters.
3. CRAMP is now in position to evaluate short-term impacts of episodic events.
4. CRAMP is positioned to evaluate long-term effects of global warming (bleaching), CO<sub>2</sub> impact on calcification, nitrification, sedimentation, etc.
5. CRAMP will continue to monitor the completed network with increasing emphasis on integration of monitoring activity with state-wide assessment, habitat mapping, information synthesis and information dissemination through partnerships and co-operating agreements.

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

- Exposure (wave energy) was shown to be a significant factor in determining the structure of Hawaiian benthic and fish communities.
- Bottom relief (rugosity) is a significant factor in determining fish habitat quality, with a significant relationship between rugosity and fish biomass.
- All three monitoring sites in Kaneohe Bay, Oahu show rapid decline of coral cover and increasing algae cover.
- Average coverage for all CRAMP sites is approximately 23%. All transects are positioned on hard substratum. The sites were selected over a representative cross section of Hawaiian coastal environments, so this is probably a reasonable estimate for coral cover on hard substratum over the entire main Hawaiian Islands in the depth range sampled. Published literature values generally show coverage estimates higher (mean of the previously published values is approximately 35–40% cover). Previous studies often targeted high coral coverage areas rather than selecting a good cross section of reefs throughout the state.
- The reefs of Hawaii are best described as "*Porites reefs*," being overwhelmingly dominated by massive and encrusting *Porites lobata* and branched *Porites compressa*. *Montipora capitata* (= *Montipora verrucosa*) and *Montipora patula* (= *Montipora verrilli*) also account for a significant amount of the coverage. *Pocillopora meandrina* is common in shallow turbulent environments.
- A latitudinal gradient in the coral community composition is not evident in these data. Coral cover appears to be controlled primarily by local variation in dominant environmental factors such as wave energy, bathymetry, watershed influences, substrate type, etc.

- Coastal sites with high wave exposure (e.g., Pupukea, Hoai Bay) have the lowest cover while bays and wave-protected coastal areas (e.g., south Molokai) have the highest coral cover.
- The most significant anomaly in coral coverage and reef conditions occurs off south Molokai. Coral cover along this coast is extremely high. The two sites with highest coral cover in the state (Palaau and Kamalo) are located here. A large zone of damaged reef occurs in the middle portion of the south Molokai coastline, between these two high-cover survey sites. Within this damaged zone is another survey site (Kamiloloa), which has the lowest coral coverage in the state.
- Areas protected from fishing have distinct assemblages and had higher biomass compared to areas where all fishing was permitted.
- The marine protected areas that were fully protected from fishing showed a much higher fish biomass than partially protected or open access sites. However, degree of protection did not show a relationship with coral reef community structure, probably because corals are protected and are not being harvested anywhere in the state.
- Surgeonfishes were the dominant fish family observed on transects, and herbivores accounted for over 70% of the total reef fish biomass over all locations.
- Fish assemblages in Kaneohe Bay, Oahu were very distinct and differed greatly from all other fish assemblages around the state.
- Initial assessment suggests that Hawaiian coral reefs are in better condition than in many other geographic locations. However, many of our reefs are presently undergoing degradation. The remainder may be dangerously close to the rapid decline that has been documented at other regions, such as the Florida reef tract.

### **Recommendations Related to this Workshop**

1. A number of carefully chosen "Alpha Sites" must be monitored with high statistical power using contemporary digital image technology for benthic analysis. Standardized fish transects to quantify species abundance, size and biomass for the fish community. Physical parameters such as temperature and wave energy must be documented. A well-designed database is an integral part of such a program.
2. There must be a long-term commitment to any such monitoring and data base effort on the part of the funding organization. There is no point in starting a long-term program without such support.
3. General qualitative observations from trained local observers or one time only quantitative assessments are a valuable source of supplemental spatial information, but only in reference to the "Alpha Site" measurements. Aside from major environmental disasters, detection of trends in coral reef condition can only be established by proper monitoring techniques.