NMFS SOUTHWEST FISHERIES SCIENCE CENTER
HONOLULU LABORATORY
CORAL REEF ECOSYSTEM INVESTIGATION

BACKGROUND

Coral reef ecosystems are among the most diverse and biologically complex ecosystems on earth. They provide economic and environmental services to millions of people such as shoreline protection, areas of natural beauty and recreation, and sources of food, chemicals, pharmaceuticals, jobs, and revenues. Coral reef ecosystems are deteriorating worldwide at alarming rates due to multiple stressors including over-exploitation, pollution and marine debris, habitat destruction, diseases, invasive species, and bleaching and climate change. In response to these concerns, the Coral Reef Protection Executive Order in June 1998 established the U.S. Coral Reef Task Force and directed federal agencies to improve their stewardship and conservation of the nation's coral reefs. In March 2000, the Task Force approved the first-ever *National Action Plan to Conserve Coral Reefs*, outlining a series of specific, priority actions to ensure the long-term viability of coral reef ecosystems of the U.S. and around the globe. In May 2000, the Marine Protected Area (MPA) Executive Order was issued to establish and strengthen MPAs in U.S. waters. The Coral Reef Conservation Act of 2000 further increased national efforts to conserve and protect coral reef ecosystems. The NWHI Coral Reef Ecosystem Reserve Executive Order in 2000/2001 established the nation's largest MPA and the second largest coral reef reserve in the world.

In response to the two fundamental themes of the *Action Plan* to 1) understand coral reef ecosystems and 2) reduce adverse impacts of human activities, a small team of biologists and oceanographers at the NMFS SWFSC's HL initiated the development of a comprehensive multi-disciplinary, multi-agency, and multi-platform program to assess, monitor, restore, protect, and conduct applied research on the coral reef ecosystems of the U.S. Pacific Islands. The U.S. Pacific Islands include about 94% of the nation's coral reefs with about 69% being in the NWHI, 15% being in the main Hawaiian Islands (MHI), and 10% in the other U.S.-affiliated Pacific Islands (the Territories of American Samoa and Guam, the Commonwealth of Northern Marianas Islands (CNMI), and the Pacific remote island areas (PRIAs) or unincorporated U.S. Pacific possessions of Wake Atoll, Johnston Atoll, Howland Island, Baker Island, Jarvis Island, Palmyra Atoll, and Kingman Atoll). (Figs. 3 and 4). After thorough program design and development with our NOAA and other federal, state, territorial, and NGO partners, the HL formally established the CREI in April 2001 to: 1) improve understanding and support for science-based management, and 2) reduce adverse impacts to the coral reef ecosystems of the U.S. Pacific Islands.

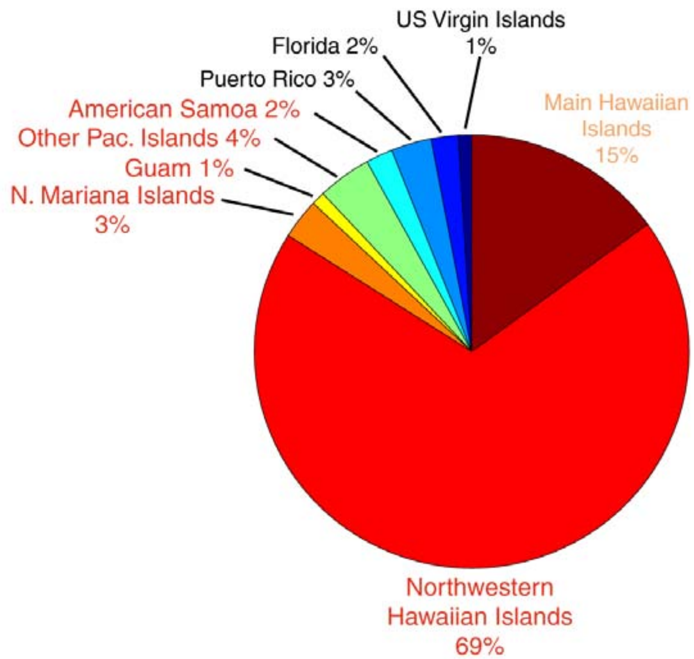

Fig. 3. Percentage of U.S. coral reefs by area (Miller and Crosby, 1998).

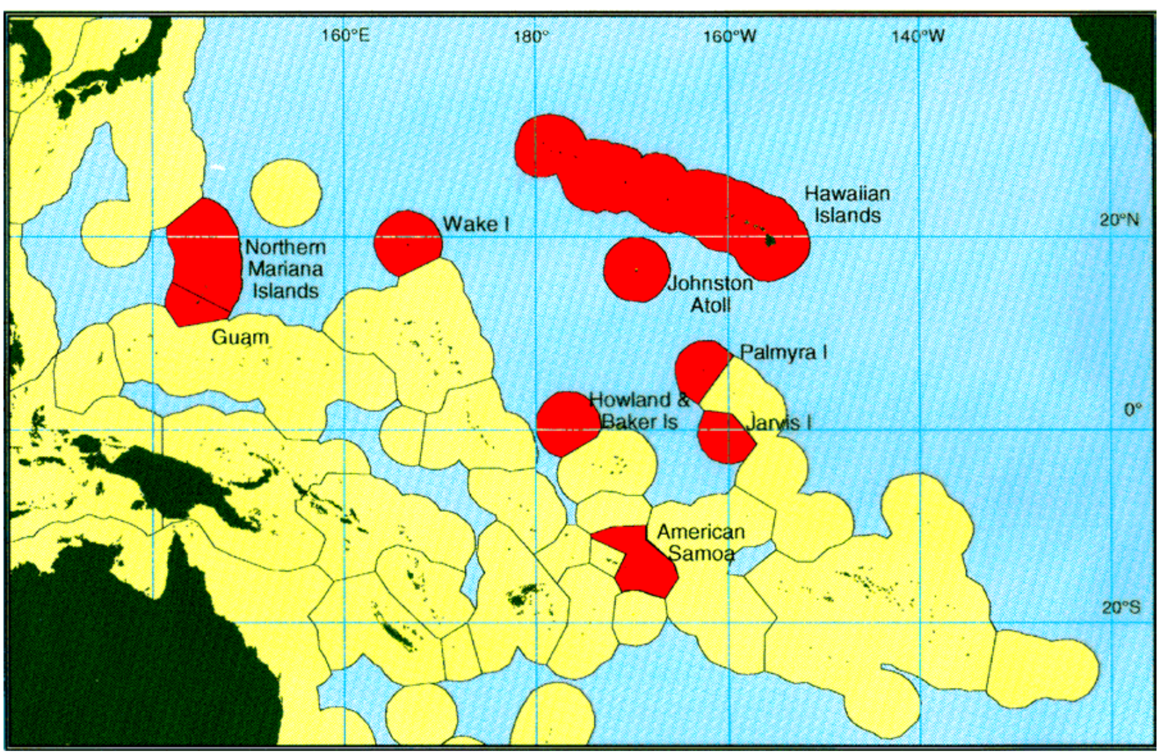

Fig. 4. U.S. Pacific Islands and associated EEZs.

This ecosystem-based program was designed to complement historic and ongoing research conducted for over three decades at the HL. Research has focused on a wide range of species within the central and western Pacific Ocean, ranging from commercial and recreational fish and crustaceans to protected species, such as the endangered Hawaiian monk seal and threatened Hawaiian green sea turtle. The CREI has been designed to examine the broader coral reef ecosystem in a comprehensive manner by simultaneously studying the corals, fish, algae, and other invertebrates, as well as the interactions between and among species and trophic levels and their relationships to the variable oceanographic and benthic habitats.

Since being established in 2001, the CREI has rapidly augmented several existing HL staff by recruiting a scientific staff with expertise in coral reef ecology, reef fish biology, phycology, oceanography, benthic habitat mapping, GIS spatial modeling, engineering, acoustics, remote sensing, programming, and data management. While building a stronger core staff, CREI investigators also established long-term collaborations with colleagues at NOAA's NOS, NESDIS, and Office of Oceanic and Atmospheric Research (OAR), USFWS, the National Park Service, the State of Hawaii's Division of Aquatic Resources, the Territorial governments of American Samoa, Guam, and CNMI, Hawaii Institute of Marine Biology (HIMB), the School of Ocean and Earth Science and Technology (SOEST), the UH Departments of Zoology, Botany and Oceanography, the University of California, Santa Cruz, the University of Guam, Eastern Carolina University, Bishop Museum, and Oceanic Institute. Concurrent with this rapid growth of the program, the CREI team has conducted baseline ecological assessments of fish, corals, algae and other invertebrates, benthic habitat mapping, oceanographic surveys, and established an array of monitoring stations in the NWHI, the U.S. Line and Phoenix Islands of the central Equatorial Pacific, and the Territory of American Samoa. The CREI team has also conducted extensive marine debris removal activities over the past year, removing about 140 tons of derelict fishing gear and other marine debris from the coral reefs and beaches of the NWHI (as of July 2002) bringing the overall total for the multi-agency debris removal team to about 200 tons since HL initiated these efforts in 1996. This report outlines each of the programs of the CREI, discusses some of the recent activities and scientific findings, and summarizes future directions and plans.

ECOLOGICAL ASSESSMENT AND MONITORING

Background

In order to effectively manage marine resources, it is essential to know what resources exist (assessment), where they are located (mapping), and how they change over time (monitoring). To effectively manage these resources at the ecosystem level, it is also essential to observe each of the major components of the ecosystem. These include the fish, corals, other invertebrates, and algae.

Unfortunately, little data exist to accurately describe the health of most of the coral reef ecosystems in the U.S. Pacific Islands. Therefore, one of the principal initial activities of the CREI is to work closely with our partners to document baseline conditions to assess the health of coral reef ecosystems, including both resources of potential economic importance and functionally important components of the ecosystem. A related goal is to permit monitoring of possible future changes due to both anthropogenic and natural impacts. To distinguish between natural and anthropogenic variability of the ecosystem, it is important to have sufficient observations spatially and temporally of the biotic and abiotic components of the ecosystem.

Given the vastness and remoteness of the U.S. coral reef ecosystems, one of the tremendous challenges facing this program is to adequately observe these components at sufficient spatial and temporal resolution to describe and understand the natural variability. Since early 2000, scientists on CREI cruises have initiated baseline ecological assessments of the NWHI, U.S. Line and Phoenix Islands, and American Samoa through detailed comparative surveys and estimates of species composition, density and/or abundance of fish, corals, algae, and other invertebrates at selected sites. This section briefly describes the ecological assessments of the biological components, including reef fish, corals, other invertebrates, and algae. The following sections on benthic habitat mapping and characterization and oceanography describe CREI activities to assess and monitor the abiotic components of the ecosystem.

Goals and Objectives

The primary scientific goals of the CREI ecological assessment and monitoring program are to:

- Document baseline conditions of the health of coral reef living resources (fish, coral, other invertebrates, and algae) in the U.S. Pacific Islands.
- Refine species inventory lists of these resources for the island areas.
- Monitor these reef resources over time to quantify possible natural or anthropogenic impacts.
- Document natural temporal and spatial variability in the reef resource community.
- Improve our understanding of the ecosystem linkages between and among species, trophic levels, and surrounding environmental conditions.

Assessments of Reef Fish

Initial characterizations of reef fishes of the U.S. Pacific Islands range from true baselines at currently unexploited locales like Jarvis Island to new "baselines" at historically exploited locales such as the MHI and the main islands of American Samoa and Guam. Objectives are to systematically characterize reef fish assemblages and the abundances of component reef fish stocks at each of the reefs and reef systems. Characterization of spatial patterns using baseline abundance data is an important short-term (1-2 year) analysis goal. These abundance baselines will be used to specify monitoring designs aimed at detecting temporal changes in numerical or biomass density at representative stations. Monitoring for temporal changes is a longer-term (> 5 yr) goal, to assess the magnitude and importance of temporal changes in reef fish assemblages and component stocks which might result from anthropogenic causes (e.g., fishing, ecotourism, pollution, coastal development) or from natural disturbances (e.g., habitat loss from hurricanes or warming/bleaching events). Species inventories (lacking in remote areas) will complement this work and help to describe patterns of biodiversity.

Methods

Several complementary underwater survey methods are employed: 1) 50-m^2 belt transects (2-m wide, 25-m long) for small (<20-cm), site-attached fishes (e.g., ornamentals); 2) 100-m^2 belt transects (4-m wide, 25-m long) for medium-sized (20-50-cm), more vagile fishes (e.g., groupers); 3) 300-m^2 Stationary Point Counts (SPCs) whose density and size distribution data complement the latter; and 4) ~3-km long towed diver/video surveys focused on sharks, jacks, and other apex predators (> 50-cm long). Fish tallies are binned by Total Length (TL) class on all surveys. All survey types include replicate sampling within station areas and within major habitats (forereef, backreef, lagoonal patch reef). Transects are located within randomly selected areas of reef, typically in shallow water (5-20-m), but occasionally to 30-m. From 1-3 annual surveys are proving necessary to complete adequate baseline assessments because of the inaccessibility and the expansiveness of some reefs. Possible within-year (e.g., seasonal) variations are controlled by conducting the surveys at the same time of year in the respective regions.

Complementary Rapid Ecological Assessment (REA) data are being collected to assemble reef- and archipelago-specific fish species inventories based on transect and additional “roving diver” census-swims. The present focus is on fishes of the U.S. Line and Phoenix Islands; these inventories are being prepared primarily from lists of species compiled on fish transects during cruises in 2000, 2001, and 2002.

Data Analysis and Results

Some initial findings of interest, by region, that have resulted from the analyses of fish data to date include:

NWHI:

- Both numerical and biomass densities become more precisely estimable after taxa are pooled into functional groups such as trophic levels (e.g., primary and secondary consumers, apex predators) and foraging guilds (e.g., detritivores, herbivores, benthic invertebrate-feeders).
- Because sharks are too infrequently encountered on diver-swum transects, direct diver counts of sharks, intercepted on ~3-km long towed diver surveys, allow densities of these large apex predators to be estimated and compared (e.g., on the 2000 cruise, some reefs like Necker

Island had demonstrably higher densities of reef sharks than elsewhere in the NWHI).

- An overwhelming biomass-dominance of piscivorous apex predators (primarily large jacks [ulua, kahala] and reef sharks [mano]) was found throughout the entire NWHI chain, in stark contrast to the present depleted status of apex predators on reefs in the MHI (Figs. 5a and 5b). The very high biomass of apex predator fishes at NWHI reefs is perhaps unique in the world and a reflection of extended periods of low fishing pressure.

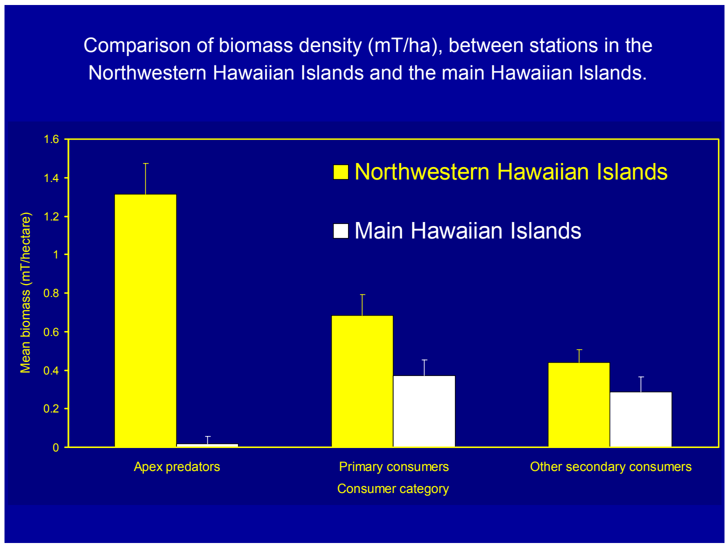

Fig. 5a. Comparison of fish biomass density (MT/ha) between the NWHI and the MHI.

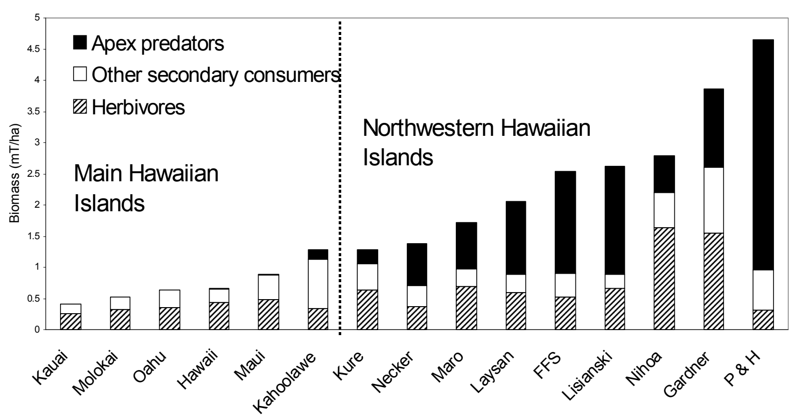

Fig. 5b. Distribution of fish biomass density (mT/ha) among islands throughout the Hawaiian Archipelago.

- The frequency of occurrence of two species of large uluas was historically higher at FFS versus Midway Atoll since observations began in 1992 at FFS and in 1993 at Midway. Figure 6 shows the relative presence-absence of (A) giant trevally (*Caranx ignobilis*) and (B) omilu (*C. melampygus*) at FFS and Midway stations during 1992 (FFS) or 1993 (Midway) through 1995-2000 pooled. The stacked histograms indicate species subtotals "Before" 1996 versus "After" 1996 at each site; Panel C plots percent presence at stations on each survey. However, the relative disparity between these Midway and FFS increased during the period from 1996 to 2000**,** when ecotourism activities, which included an intensive catch-and-release recreational fishery for ulua, were conducted at Midway. Table 3 presents summary statistics for a 3x2 (species x site x survey period) G-test comparison of relative frequency occurrence of two species of jacks (white ulua, *Caranx ignobilis*; omilu, *C. melampygus*) at the two sites (FFS and Midway), during two survey periods – "before" a recreational catch-and-release (C&R) fishing program was begun (prior to and during 1996) versus "after" (in 1997 and subsequent years) the establishment of a C&R fishing program. Occurrence was scored based on presence-absence at each of the 9 historical monitoring stations during each of the 7 survey years at FFS (63 station-surveys) and at Midway (62 station-surveys). Note the significant* Site x Survey period interaction term indicates the difference in relative frequency occurrence at FFS and Midway between "Before" and "After" survey periods.

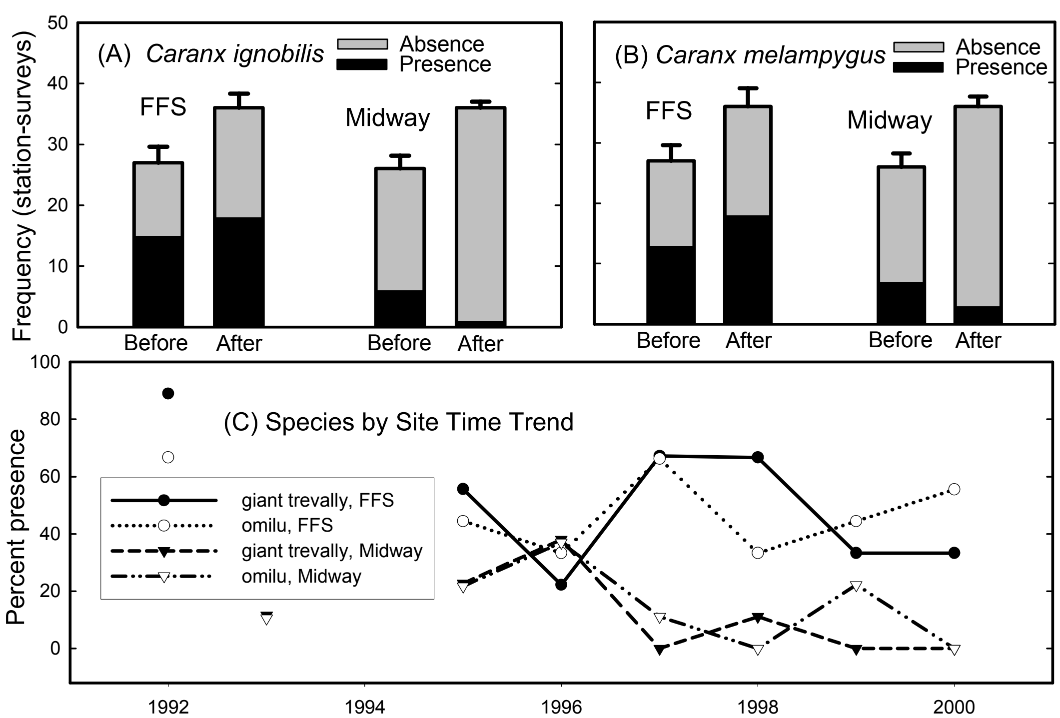

Fig. 6. Frequency occurrence of jacks.

Table 3. Frequency occurrence of jacks.

Maximum-Likelihood Analysis-of-Variance Table

Source	df	Chi-square	Probability
Specis (ulua, omilu)	1	0.01	0.91
Site (FFS, Midway = MW	1	22.51	<0.0001
Survey period (Before-After)	1	2.20	0.14
Site x Survey period	1	5.24	0.022*
Likelihood ratio (= Error)	3	1.25	0.74

Species: omilu=white ulua
(41/125)=(40/125)

Site: FFS>MW
(32/63)>(9/62)

Site x Survey period: FFS, Before=FFS, After>MW, Before>MW, After
white ulua: (15/27)=(18/36)>(6/26)>(1/36)
omilu: (13/27)=(18/36)>(7/26)>(3/36)

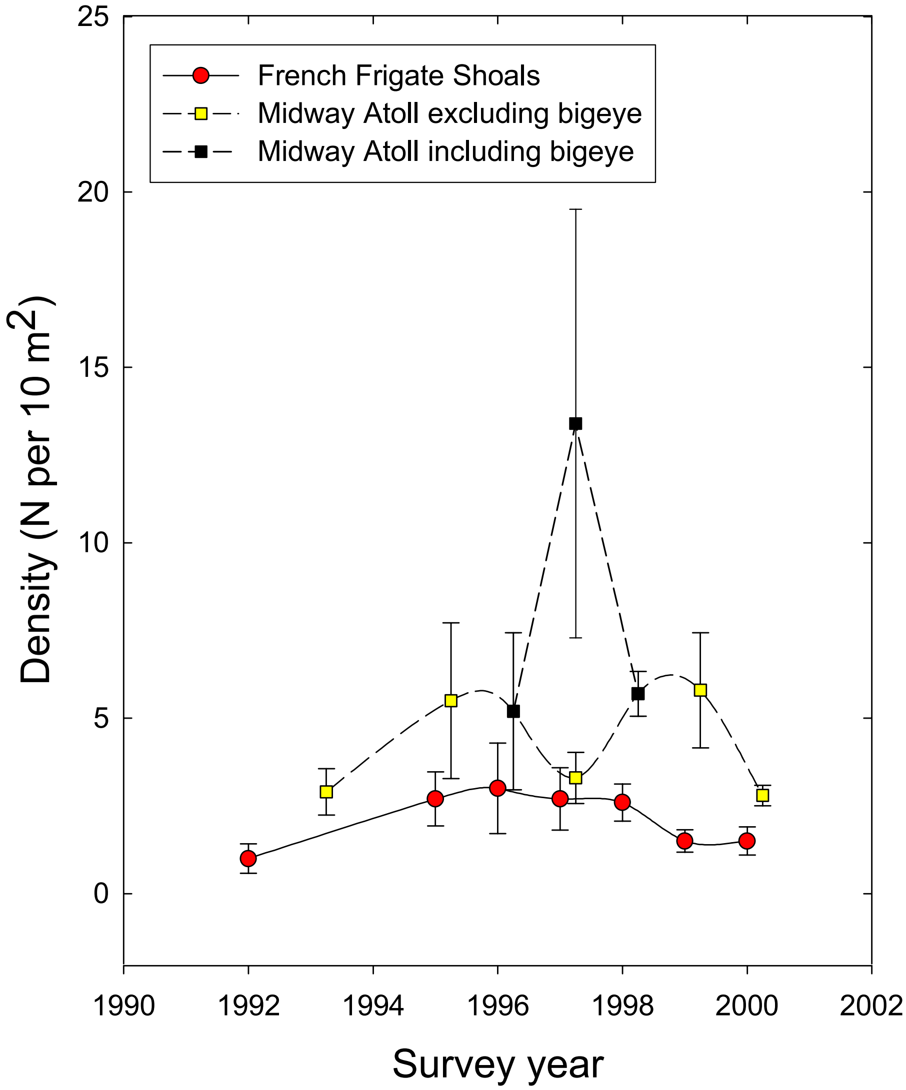

Fig. 7. Time-series plots of numerical densities of young-of-year (yoy) fishes for all taxa (either including or excluding Hawaiian bigeye, Priacanthus meeki) at FFS and Midway Atoll. Spline curves are fit to survey-year means; vertical lines indicate +/- 1 se.

- At FFS and Midway, recruitment pulses were out-of-phase with one another (Fig. 7), which demonstrates the need for reef-specific assessment and monitoring within archipelagos.

- NWHI fish data have important implications for the design and siting of reserves, including no-take MPAs within the NWHI Coral Reef Ecosystem Reserve. Greater absolute and relative numbers of yoy recruits were found at wave-sheltered habitats within atoll lagoons (versus wave-exposed fore reefs at these atolls and at fringing reefs) (Fig. 8). which attests to the importance of sheltered habitats as juvenile nursery grounds, in turn important to the sustained replenishment of populations at atolls and other reefs in the NWHI, and coral reef ecosystems elsewhere.

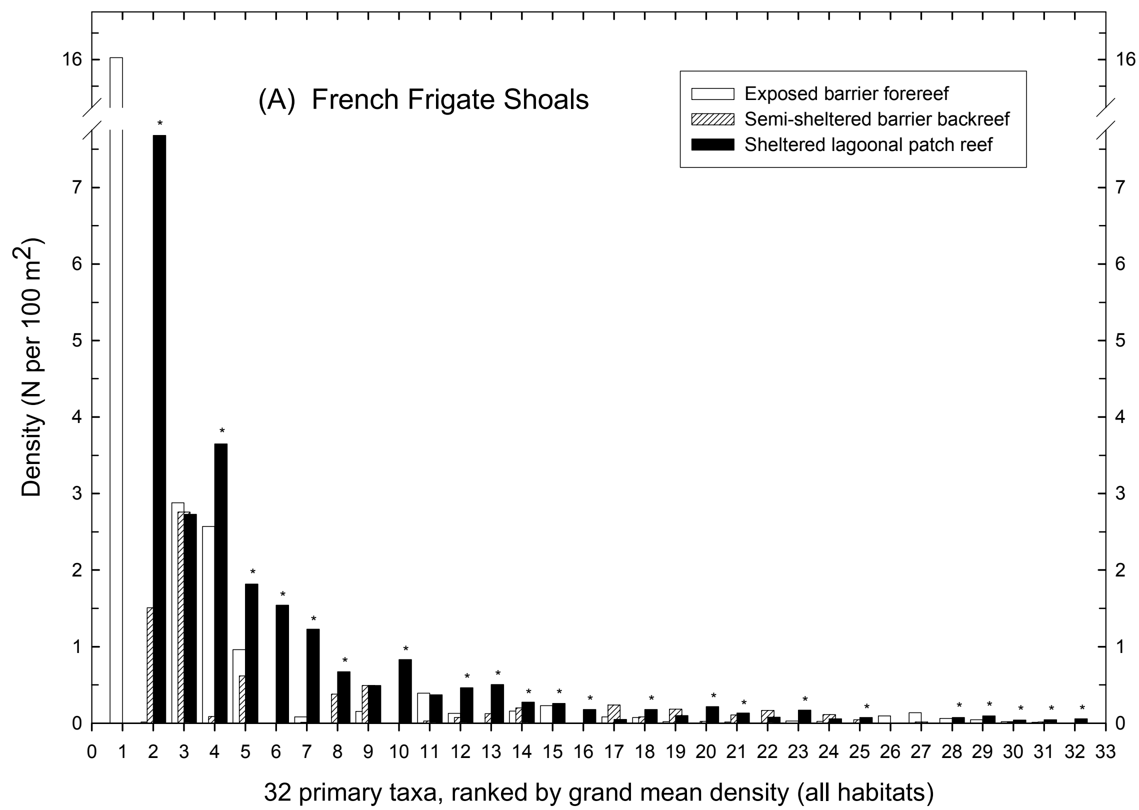

Fig. 8. Bar histograms of the mean densities of yoy for each of 32 primary taxa (defined as either the most abundant or common and frequently encountered) at FFS on yearly diver surveys during 1992/93-2000, inclusive. Taxa are numbered from 1 to n, ordered by decreasing overall yoy density, and partitioned by subhabitat. The 22 taxa with nominally highest yoy densities at wave-sheltered patch reefs are indicated by asterisks. Disproportionate numbers of yoy on patch reefs were even more pronounced at Midway Atoll, where yoy densities were higher for 30 out of 35 primary taxa.

- Results strengthen support of the concept that Hawaii has the highest level of endemism known for marine fishes (23.1%). Estimated values based on fish densities range from 27% for numbers at FFS to 57% for biomass at Midway (Fig. 9). Endemic species dominate reef fish abundance in the NWHI. Preliminary analyses suggest that the proportion of endemic species is higher in the NWHI than in the MHI, and perhaps increases with latitude and with decreasing representation of Indo-Pacific species that have greater tropical affinities.

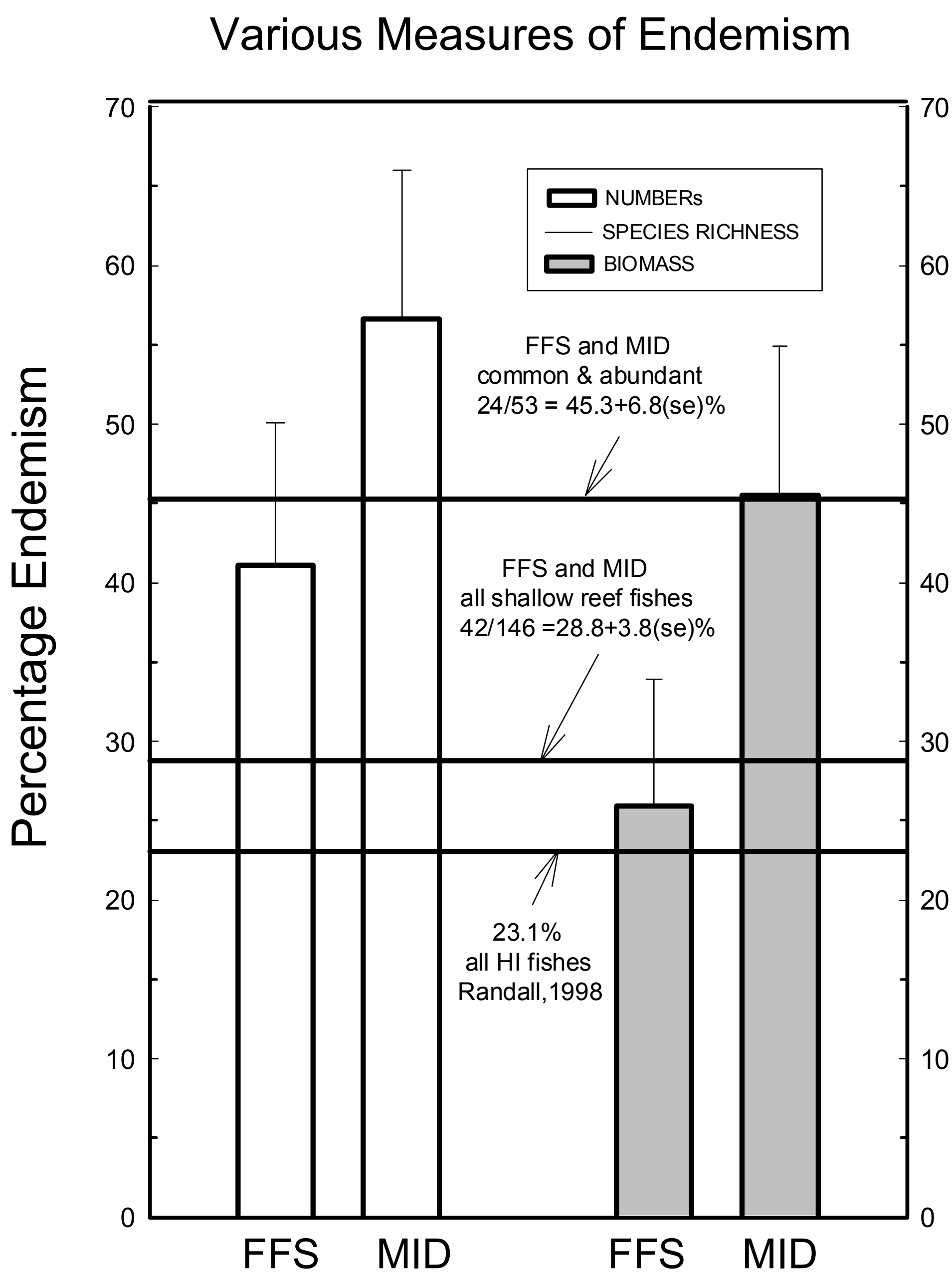

Fig. 9. French Frigate Shoals (FFS) and Midway Atoll (MID). Histograms depict percentage endemism based on numerical and biomass densities estimated on yearly diver surveys (< 15-m depths) during 1992/93-2000, inclusive. Also shown are three reference lines indicating species diversity (richness) for all Hawaiian fishes (Randall, 1998, Zool. Stud., Taiwan 37:227-268), for the shallow reef fishes surveyed at FFS and MID, and for only the most common and abundant fishes surveyed at FFS and MID.

- Size-distribution data corroborate the importance of apex predators in shaping populations of prey fishes, such as parrotfish, that structure coral reef habitats.

American Samoa:

- In American Samoa, the density of large fish on transects was low relative to the NWHI. Densities at Rose Atoll and Swains Island were several-fold higher than at the more populated Tutuila Island and the Manu'a Islands (Fig. 10). The densities of small fish were higher at reefs in American Samoa than in the NWHI.

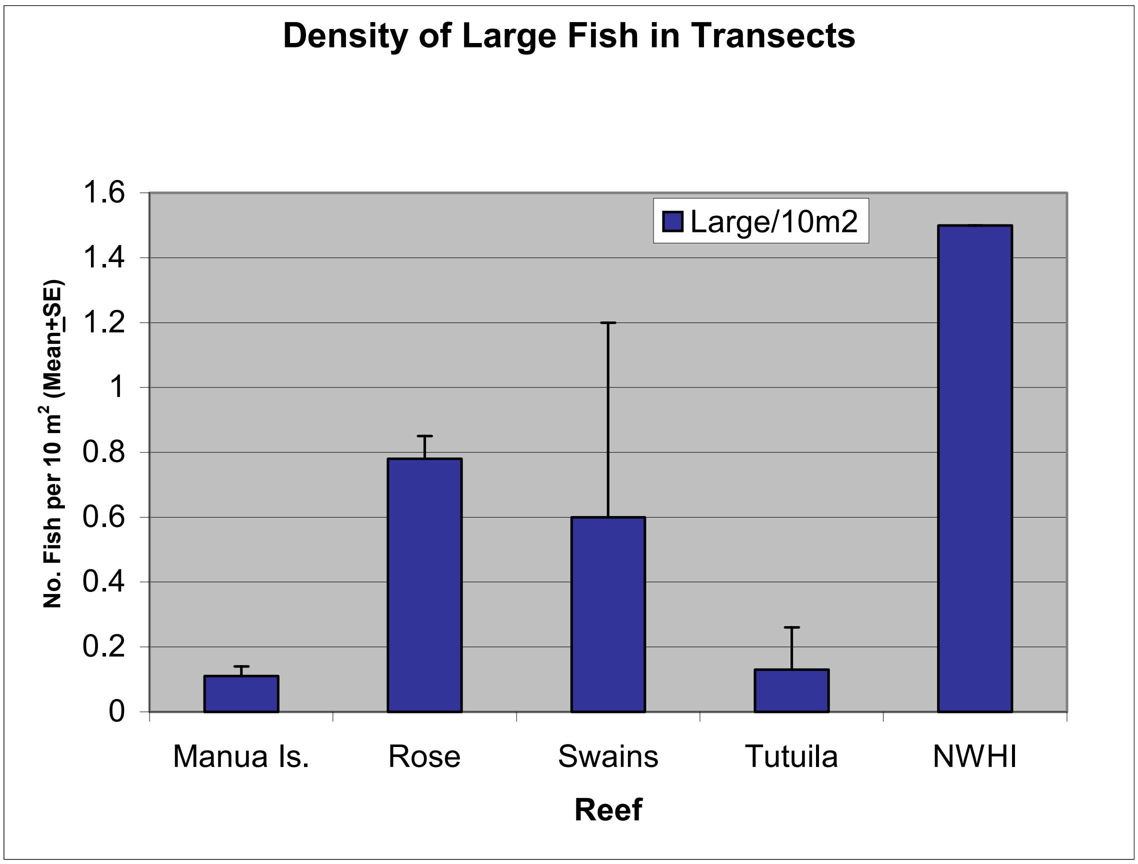

Fig. 10. Density of large fish in American Samoa.

- Grouper abundances were about twice as high on reefs of the Samoan outer islands, where the human population is low, compared to Tutuila where most of the human population resides (Fig. 11).

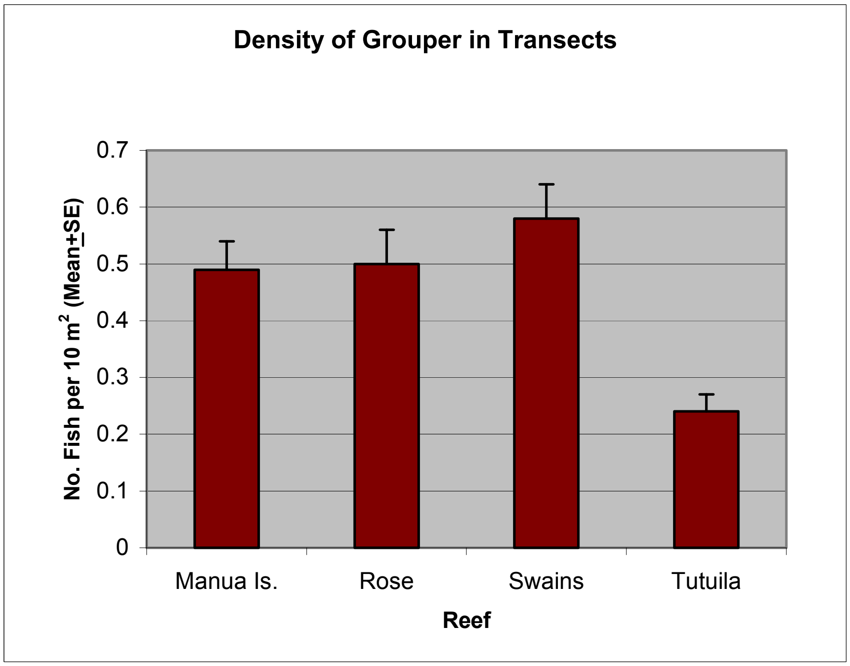

Fig. 11. Density of grouper in American Samoa.

- Herbivorous surgeonfish, parrotfish, and pygmy angelfish were several times more abundant at a site at Rose Atoll impacted by a shipwreck and oil spill a decade ago (where blue-greens and other algae have become more abundant), compared to other sites of similar habitat around the atoll (Fig. 12).

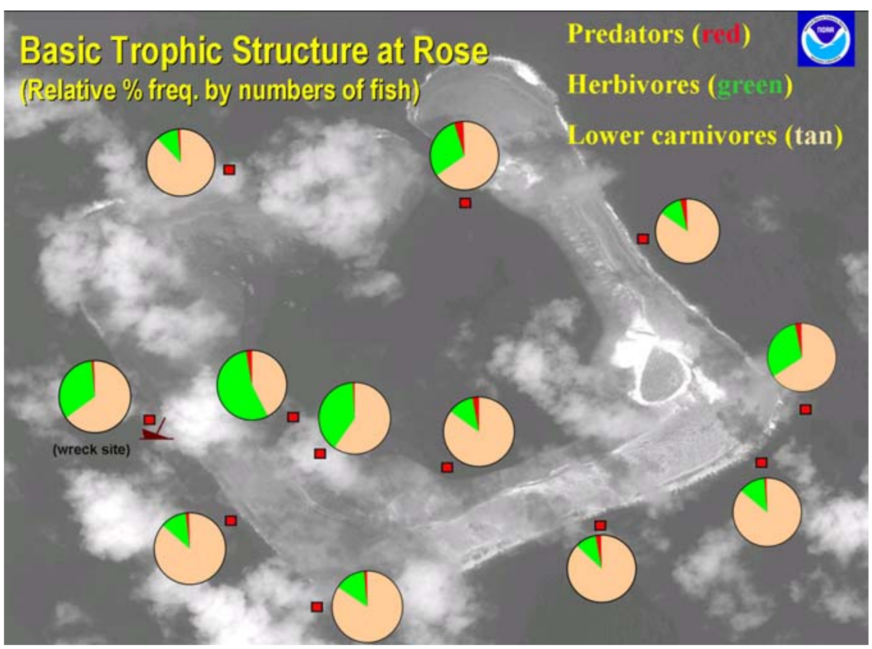

Fig. 12. Basic trophic structure at Rose Atoll.

- Red snapper was less common (by relative percent frequency of occurrence at stations) at Tutuila, but the Maori wrasse, which was relatively rare, did not differ greatly among reefs. The bumphead parrotfish was not seen in American Samoa.

U.S. Line and Phoenix Islands:

- Numerical densities of fishes (particularly small planktivores) were high at these islands. Densities were highest along the west side of the equatorial islands, apparently related to topographically induced upwelling.
- At Howland and Baker Islands, extremely large (2- to 4-fold) differences between islands in the mean densities of pygmy angelfishes and epinepheline groupers are statistically demonstrable despite the small number of stations that are typically surveyed on a single cruise.
- A total of 480 fish species was recorded in the U.S. Line and Phoenix Islands. CREI surveys yielded 164 species (34%) not previously recorded from these islands. For individual islands, new records comprised 60-78% of the species observed at Howland, Baker, and Jarvis Islands, as did 96% of fish species observed at Kingman Atoll, which previously had only been cursorily sampled. New CREI records at Palmyra Atoll, where several earlier expeditions collected, were only 35% of the reef fish fauna.
- The vast majority of fishes at these islands are widespread Indo-Pacific species that occurred at all five islands. Unlike Hawaii, no fish species are known to occur only at these islands. Only three of the five fish species thought to be Line and Phoenix Island endemics were seen, but the five islands include a significant component of south-central Pacific endemic species not found at other U.S. reefs.
- The U.S. Line and Phoenix Islands appear to be at the junction of two biogeographic areas, one centered in French Polynesia and a larger one centered in Micronesia. This is exemplified by the contribution of CREI data to a recent revision of the surgeonfish genus *Ctenochaetus*, which demonstrated that the Phoenix Islands, including Howland and Baker, are the only area of co-occurrence for a western-central Pacific species and an otherwise French Polynesian species.
- A collaborative study with ecological geneticists at the University of California, Santa Cruz evaluated species differentiation in one group of Indo-Pacific fishes (the three-spot damselfish *Dascyllus trimaculatus* species complex) that includes the recently described *Dascyllus auripinnis* found in the Line and Phoenix Islands. The distribution of mtDNA genotypes within the group was consistent with geographic separation but incongruent with external characteristics that define some of the nominal species, indicating that more work on the systematics of this group and likely many other central Pacific fishes is needed.
- The occurrence of south-central Pacific Ocean species in the Line and Phoenix Islands is unique among U.S. coral reef ecosystems and adds to the exceptional conservation value that these five islands have for the U.S.

Assessments of Corals

Methods

Two principal methods are used to assess the diversity, relative abundance, and percent cover of scleractinian corals: REAs and towed diver surveys. recruitment plates are used to assess successful settlement, growth, and survival over 1-2 year time periods of benthic organisms with dispersive larvae or other reproductive propagules. Reproductive studies have been initiated to begin assessing the temporal patterns of coral spawning in the U.S. Line and Phoenix Islands and American Samoa.

REAs are video surveys of the substrate conducted along each of the first two 25-m transect lines laid down by the fish team, at a height of about 1-m above the center of each line. These tapes provide a basis for quantitative analysis as well as an archival record of the condition of the reef. A random swim is then conducted in the vicinity of the transect lines to record all species present in the area and to assess their relative abundance using the Dominant, Abundant, Common, Occasional, Rare (DACOR) system. In some areas (e.g., Manu'a Islands, American Samoa), *in-situ* quantitative data on the size of corals present within a 1-m belt centering around the transect lines has been collected; this methodology will increasingly be incorporated into future REA designs.

Towed diver surveys allow ecological assessments over wide spatial areas of the reef habitat (~3-km/dive) to complement fine-scale resolution afforded by the more stationary REA dives. The towboards, which are equipped with digital video equipment, precision temperature and depth recorders, and paired lasers, are used to collect basic habitat information and estimate coral, algal and other bottom cover over broad areas. The paired lasers allow for accurate sizing of corals and fish. The innovative use of computer-assisted quantitative analysis of the video records allows CREI researchers to calculate the percent cover of coral, algae, other macroinvertebrates, and substrate type over broad areas (Fig. 13). In addition to REAs and towboard surveys, CREI partner USFWS have established permanent transects in the NWHI, U.S. Line and Phoenix Islands, and American Samoa as a basis for monitoring future changes over time in sessile benthos at these established sites.

Recruitment is the process by which larvae or other reproductive propagules of organisms leave the plankton in order to settle into another habitat. Recruitment plates (Fig. 14) are a tool by which this process can be quantified for benthic organisms (e.g., corals, algae, bryozoans, sessile bivalves, serpulid worms) over a chosen period of time. Recruitment plates have been set out in conjunction with moored instrument arrays in the NWHI, U.S. Line and Phoenix Islands, and American Samoa. Twelve PVC-arrays, each with 16 ceramic tile plates, have been deployed for time periods of 1-2 years. Fresh recruitment plates will be installed each time the seasoned plates are collected.

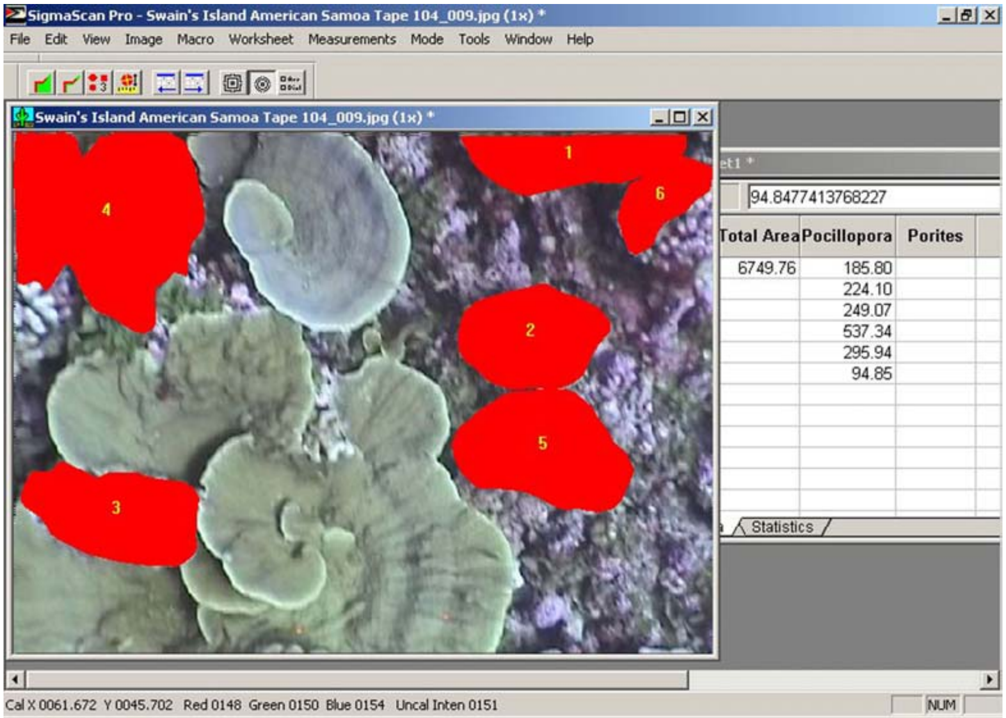

Fig. 13. The computer software SigmaScan™ is used to analyze digital video images of the benthos. In this slide, colonies of *Pocillopora* corals have been overlaid in red, and the area coverage of each colony, in pixels, appears in the spreadsheet to the right.

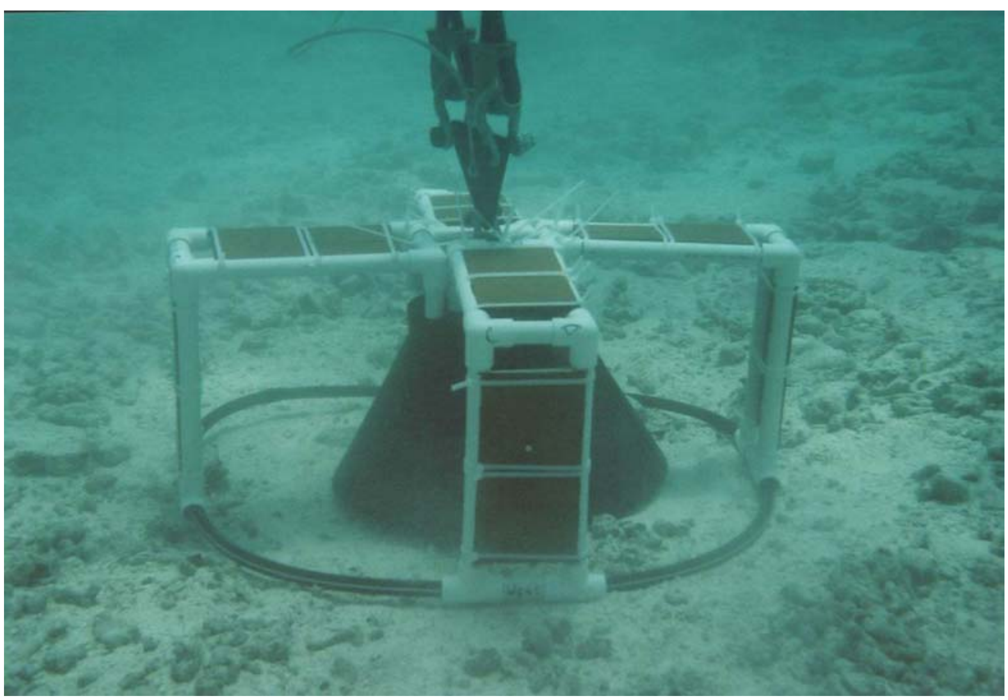

Fig. 14. Recruitment plates attached to a buoy anchor at FFS.

Most scleractinian corals release reproductive propagules (gametes or brooded larvae) during a brief, predictable time period only once per year. Nothing is known of the phenology of coral spawning in the U.S. Line and Phoenix Islands. Limited sampling in American Samoa by a non-CREI investigator has suggested that coral spawning occurs in October and November in this island group. From January to March 2002, small samples of live corals were collected in the U.S. Line and Phoenix Islands and American Samoa, and fixed in 10% formalin. Samples will be decalcified, and preserved tissue examined for presence of developing eggs and testes; the size of developing gonads will be compared with the size of mature gonads cited in published literature in order to infer the time of coral spawning in these regions.

Data Analysis and Results

Several CREI researchers and partners were major contributors to the 46-page collaborative publication entitled *Coral Reef Ecosystems of the Northwestern Hawaiian Islands: Interim Results Emphasizing the 2000 Surveys* (J. Maragos and D. Gulko (eds), 2002). Other results are summarized here:

Table 4 summarizes the geographical and temporal distribution of the 261 REA sites surveyed by CREI.

Table 4. Summary of number of REAs conducted by CREI and partners

Cruise	NWHI	Line Islands	Phoenix Island	Am. Samoa
Line & Phoenix 2000		20	11	
NOWRAMP 2000	65			
Line & Phoenix 2001		19	14	
NOWRAMP 2001	31			
L/P Am. Samoa 2002		28	12	61
Total	**96**	**67**	**37**	**61**

- In 2000-2001, more than 30 new range records and 2-8 new species of scleractinian corals were observed in the NWHI. Additional new records and species are also expected at depths greater than those 0-20-m surveyed in 2000-2001. Before some of these new records and all of the new species can be authenticated and described, additional photographs and voucher specimens need to be collected. Despite the limited opportunities to study and collect corals from these islands over the past century, the suite of known coral species in the NWHI observed in 2000-2001 exceeds that of the MHI.
- Analysis of coral species distribution collected from REA surveys in the NWHI suggests that diversity is higher at most of the atolls than at high or low island sites. Atoll lagoons afford greater protection from wave action

and provide additional types of reef habitats that are absent elsewhere in the Hawaiian Archipelago. Moreover, larger atolls provide more quantity of habitat, perhaps one reason for the greater number of coral species there.

- Two hundred and seventy (270) downward-looking digital videotapes documenting coral reef benthic habitat in the NWHI, U.S. Line and Phoenix Islands, and American Samoa have been collected to date as well as 376 tapes from forward looking videos, REA surveys, and instrument deplayments (Table 5). The resources necessary to quantitatively analyze these tapes have been acquired and a protocol for analysis has been developed. Each 50-minute tape requires 10-16 hours to analyze and summarize.

Table 5. Number of underwater digital videotapes collected and duplicated for quantitative analysis

Cruise	Total #	Towboard Surveys[1]	Other[2]
NOWRAMP 2000	215	191	24
NOWRAMP 2001	61	50	18
Line & Phoenix Islands 2000	65	45	20
Line & Phoenix Islands 2001	76	52	14
Line & Phoenix Islands 2002	70	66	4
American Samoa 2002	143	136	14
NOS/Kona coast Hawaii 2002[3]	16	16	0
Total	**646**	**556**	**94**

[1] *includes both fish surveys and habitat surveys*
[2] *includes free-swimming diver transects, snorkel transects, and documentation of habitats in which instruments have been deployed, and towed camera surveys*
[3]*conducted as an experiment in using towboard tapes to ground-truth mapping efforts*

Thirty-five (35) digital video towboard habitat tapes have been quantitatively analyzed to date. In Tables 6 and 7 and Figure 15 components were quantified using SigmaScan™ analysis of still frames grabbed at 30-second intervals from towed diver habitat digital videotapes, n = number of tapes analyzed. Quantitative analysis has focused on the reef habitats surveyed around Nihoa and Necker Islands and Kure Atoll in the NWHI and Rose Atoll in American Samoa. A brief synopsis of salient features follows:

Kure Atoll: The outer barrier at Kure is primarily characterized by carbonate pavement on which little macrobiota could be discerned from the digital videotapes (Table 6). Less than 10% of the benthos is composed of live coral, which is almost exclusively dominated by the genera *Pocillopora, Porites*, and *Montipora*. Algae, including the three functional classes of macroalgae, turf algae, and coralline algae, account for less than 3% of benthic coverage; it should be noted, however, that algae, particularly turf, is difficult to discern on videotapes and is probably underrepresented in these analyses. By comparison, *in-situ* observations by towboard divers of algal cover average 18.7%, a statistic that suggests the degree of underestimation yielded by the limitations of videotape analysis. Sea urchins, though contributing less than 1% of the benthic coverage, are numerous. Thirty-nine (39) crown-of-thorns starfish were seen in 11 tapes from 2000. The towed diver observations found the highest concentrations of crown-of-thorns in the NWHI at Kure and Pearl and Hermes Atolls. While absolute abundances were low, their presence among very low live coral abundance suggests they could pose a potential threat and should be carefully monitored. Sand channels frequently transect the sparsely colonized outer barrier substrate, accounting for nearly a quarter of the benthos. In contrast to the outer barrier reef, the central lagoon and its patch reefs are primarily composed of sand, with slightly more than a third of the substrate consisting of carbonate pavement on which no live coverage could be discerned. Live coral is confined to lagoonal patch reefs, and contributes less than 2% to the benthic coverage along transects surveyed. Rubble (~6%) and algae (~6%) are somewhat more prevalent components on wave-sheltered patch reefs than on the more exposed barrier fore reef. No crown-of-thorns was seen on any of the lagoonal patch reef tapes.

Table 6. Summary of Benthic Components at Kure Atoll, NWHI

Benthic component	Outer Barrier (n=11)	Lagoon (n=3)	Inner barrier (n=1)
Pocillopora	4.26	0.47	0.84
Porites	5.38	0.94	0.14
Montipora	0.10	0.00	0.00
Other live coral	0.01	0.00	0.00
Unencrusted coral	0.06	0.00	0.00
Macroalgae	0.16	4.43	3.78
Turf algae	0.93	0.26	3.05
Coralline algae	1.72	1.04	0.06
Fish	0.02	0.07	0.00
Other invertebrates	0.60	0.11	0.17
Rubble	0.69	6.05	11.82
Sand	21.94	51.70	53.86
Pavement	63.96	34.93	26.27

Rose vs. Kure Atoll: A comparison of towed diver habitat digital videotapes analyzed to date from Rose Atoll in American Samoa with those from Kure Atoll reveals substantial differences (Table 7). There is virtually no barren carbonate pavement on the outer barrier at Rose Atoll (Fig. 15**)**.

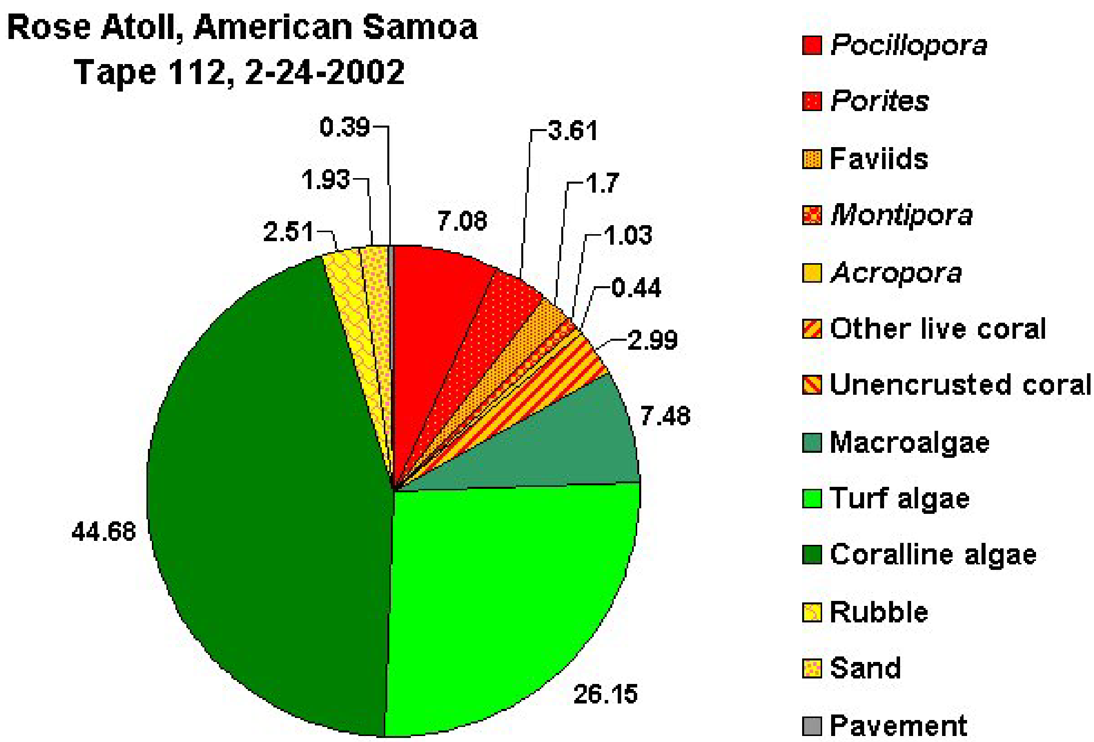

Fig. 15. A pie chart readily displays the breakdown of benthic components. This pie chart illustrates the relative abundances of bottom organisms and substrates along the shallow (~30 feet) northwest side of the outer barrier reef at Rose Atoll.

Coralline algae, which accounts for more than 53% of the benthic coverage, covers whatever substrate that is not colonized by live coral or macro/turf algae. Macroalgae and turf algae contribute close to 25% of the benthic cover; hence, algae comprise nearly 78% of the bottom cover. Live coral represents 20% of the benthos, dominated by the genus *Pocillopora*. Although the coral genus *Acropora* dominates many shallow tropical reefs, it is poorly represented at Rose Atoll. No crown-of-thorns starfish were seen in the video footage, and other macroinvertebrates were absent as well. Unlike the outer barrier at Kure Atoll that is cleaved by sand channels, the outer barrier at Rose is largely contiguous, with sand as a rare component. The inner perimeter of the lagoon is dominated by rubble (72%) with sand as a lesser component (24%). Few live organisms were documented in this dynamic, shifting environment. Along the lagoon floor transects surveyed, the benthos was largely sand (83%) with few solid carbonate surfaces available for colonization by sessile organisms. Although it could not be quantified by the analytical methodology, much of this sand appeared to be stabilized by a thin mat of filamentous algae and/or cyanobacteria. It should also be noted that the lagoon at Rose Atoll is studded with a number of pinnacle-like patch reefs that rise from the lagoon floor to the surface and which, due to their sharply vertical nature, could not be surveyed by the towboards and are hence not included in this quantitative analysis.

Table 7. Summary of Benthic Components at Rose Atoll, American Samoa

Benthic component	Outer Barrier (n=9)	Lagoon perimeter (n=2)	Lagoon floor (n=2)
Pocillopora	9.13	0.00	0.00
Porites	3.89	0.00	0.00
Faviids	0.91	0.09	0.88
Montipora	0.80	0.00	0.00
Acropora	0.52	0.00	0.00
Other live coral	5.06	0.00	0.03
Unencrusted coral	0.12	0.00	0.00
Macroalgae	12.63	1.16	4.01
Turf algae	12.15	0.54	4.77
Coralline algae	53.09	0.41	0.05
Fish	0.11	0.01	0.00
Other invertebrates	0.00	0.00	0.08
Rubble	0.69	72.35	1.76
Sand	0.49	23.54	83.08
Pavement	0.41	1.92	5.37

Recruitment: Recruitment plates deployed in the NWHI (FFS, Maro, Lisianski, Pearl & Hermes, Midway, Kure) in September-October 2001 will be collected in September-October 2002 and fresh plates installed. Recruitment plates deployed in the U.S. Line and Phoenix Islands (Baker, Jarvis, Palmyra Atoll, Kingman Reef) and in American Samoa (Rose Atoll, Swain's Island) between January and March 2002 will be collected in 2004 and fresh plates installed.

Reproduction: Approximately 270 coral samples from 22 species have been collected from the U.S. Line and Phoenix Islands and American Samoa. Developing eggs were noted with the naked eye in a number of species and specimens collected at Rose, Palmyra, and Kingman Atolls. In the month before spawning, eggs of many species are known to become brightly colored; the presence of colored eggs is an accepted indicator that spawning will occur within several weeks. At Rose Atoll, most samples of *Acropora digitifera* collected on February 26 had dark orange eggs that were easily visible to the naked eye, generating the prediction that spawning would occur within several weeks. As results from this important reef-building species are at odds with other observations of coral spawning in October-November in American Samoa, it appears that much remains to be determined concerning coral spawning cycles at Rose Atoll, and within the larger region of American Samoa. The essential laboratory equipment and reagents have been procured to begin processing of formalin-fixed samples using decalcification, microscopic observation, and measurement of developing gonads.

Assessments of Invertebrates Other than Corals

Methods

Quantitative surveys of macroinvertebrates were conducted 1-m to either side of the first two 25-m transect lines laid by the fish REA team. For any species that cannot be identified in the field, a representative specimen is collected for later identification. After the completion of the two transects, a "roving diver" survey is conducted in the general area to collect qualitative data for rare and cryptic organisms and to survey any additional habitats present at the site. At this point, a variety of specialized collections may also be taken: additional collections of organisms unable to be identified *in-situ*; sand/sediment samples for infaunal organisms; and rubble, dead coral, and algal collections for symbiotic organisms or substrate-specific inhabitants. Collected organisms that can be identified onboard the research vessel are returned to the field the next day; species that cannot be identified onboard ship are preserved in ways suitable to the particular taxonomic group and saved for later analysis at the Bishop Museum. The analysis at Bishop Museum involves the use of taxonomic literature to make tentative identifications, and then specimens must be sent to experts throughout the world for confirmation of these identifications. This post-processing sample activity and data management requires a considerable investment of time by the invertebrate zoologist involved in the field collections as well as additional personnel, making for the slow emergence of results.

Data Analysis and Results

Although the process of species identification is slow and involves many steps, some information on the distribution and species composition of invertebrates in the NWHI has already emerged:

- Of invertebrates found settled on marine debris in the NWHI, three species (a sponge, a bryozoan, and an anemone) are potentially non-indigenous. Verification of preliminary species identification is in progress.
- High islands in the NWHI like Nihoa and Necker had distinct assemblages when compared to the atolls, such as FFS and Pearl and Hermes.
- Because the specimens collected from FFS were the first to be identified by CREI collaborative scientists at Bishop Museum, the most is known about invertebrates from this atoll. In the extensive FFS lagoon, a reef composed almost entirely of bivalve clams was found, a feature that has not been found in the MHI.
- The invertebrate assemblage at FFS contains as many as 600 species, more than 250 species (not including marine snails) are new records for FFS. More than 230 additional species of marine snails have been added to existing records, tripling the number of previously known snail species at FFS. Of these, at least three are known to be new records to Hawaii.

Nineteen sponge species were collected at FFS, of which 17 may represent species previously unknown to science.

- More than 250 sponge specimens representing somewhere around 75 species have been collected from the NWHI by CREI partner scientists, of which roughly 80% are new records to Hawaii or undescribed species.

Assessments of Marine Algae

Methods

Surveys of identifiable algae were conducted 1-m to either side of the first two 25-m transect lines. For any species that cannot be identified in the field, a representative specimen is collected for later identification. After the completion of the two transects, a 'roving diver' survey is conducted in the general area to collect qualitative data and additional samples. Because basic species lists of algae are lacking for most of the U.S. Pacific Islands, present algal research by CREI and collaborators at the UH Botany Department has concentrated on compiling species inventories through field observations and collection of samples in the NWHI, U.S. Line and Phoenix Islands, and American Samoa.

Until recent CREI cruises, algae reported from the NWHI were the byproduct of incidental collections from HL lobster surveys provided to the UH Botany Department for analysis. Although such collections provided a first glimpse at algal communities in these remote areas, they offered no information about depth range, habitat type, or abundance of algal species collected. The only records of marine algae from American Samoa were published in 1924 by W.A. Setchell (a temperate water researcher with little expertise in tropical algae). Similarly, prior reports of marine algae from the U.S. Line and Phoenix Islands consist of a few papers with only a small number of species reported. CREI collections are enabling comprehensive species lists of algae from remote islands to be assembled for the first time. Such collections are a vast improvement over previous collections because they allow researchers to relate species to distinct habitat types, depth ranges, and oceanographic conditions.

Data Analysis and Results

Significant effort is needed to identify algal samples. More than half of the species identified are microscopic epiphytes (plants that grow on other plants). Even large, macroscopic algae usually need to be studied at a microscopic level for proper species identification. Sorting through samples from a single site, preparing microscope slides, and identifying species can take weeks. However, the results are rewarding. The number of new algal records from sites sampled and analyzed (to date) in the NWHI and American Samoa is impressive (Table 8).

Table 8. New Algal Records From CREI Cruises

	French Frigate Shoals (NWHI)	American Samoa
Number of sites analyzed to date	22	4
Total number of algal species recorded	126	76
Number of new algal records	114	52

Creating comprehensive species lists for all sites surveyed will take several years. In order to provide CREI with useable data as quickly as possible, large algae that are clearly visible to divers in the field will be identified first. Presence and absence data of macroalgal species will be analyzed using Primer software to determine site similarities, and then correlated to habitat descriptions. This will enable researchers to predict which algal species are associated with specific habitat types. These species can then be used as indicator species to monitor possible ecosystem changes. Once comprehensive species lists for sites are complete, diversity indices for each site will be created. The REA marine algae surveys are complemented by towed diver habitat surveys which allow assessments of general functional components (e.g. macroalgae, turf algae, coralline algae) over wide spatial areas of the reef habitat, as described in the coral assessment section.

Future Plans

Continuation of REA Studies

With the exception of Guam, the CNMI, and the atolls at Johnston and Wake, CREI baseline characterizations of all U.S.-affiliated Pacific coral reef ecosystem resources are well underway. The long-range plan is to survey the NWHI annually and the U.S. territories, commonwealth, and PRIAs every two years. Substantial quantities of interesting data illustrating key processes and patterns, useful for understanding reef ecosystem function as well as for designing a program for future monitoring of temporal changes, have already been obtained from the fish studies. During the upcoming CREI NWHI cruise in September 2002, quantitative collections and assessment of algal abundance will be initiated. Permanent digital photos along the REA belt transects will be used in conjunction with the collections to assess percent cover for common algal species. In conjunction with towed diver habitat surveys, such information will show how algal composition, abundance, and distribution on reefs changes over time.

Once completed, the initial quantitative baseline assessments of reef resources will allow for design of follow-on monitoring to detect changes resulting from natural and anthropogenic impacts. These surveys should focus on “what is do-able" (i.e., what has tractable precision) within "what is meaningful" (i.e., what represents acceptable measures of structural or functional ecosystem change). In so doing, CREI is trying to balance rigor with flexibility to adequately if not optimally evaluate diverse, even unforeseeable, types of impacts. Perhaps more importantly, the CREI ecological assessment studies begin to provide the fundamental biological information necessary for understanding distribution and abundance patterns of fishes and benthic resources, and ultimately the ecosystem processes, upon which future sustainable management and conservation will depend. The CREI has already begun and will continue to prepare oral presentations at scientific workshops and conferences and fishery and other resource management meetings and manuscripts on the more important findings of the ecological assessments for publication in appropriate peer-reviewed literature.

Analysis of Towboard Fish Data

The analysis goals of the towed diver forward-looking video are to sample fishes >20-cm in length over a large spatial scale and to complement the benthic towboard analysis by providing three dimensional benthic habitat classification information. The spatial distribution of fishes, in the context of the observed habitats, will allow CREI researchers to better understand habitat utilization patterns of individual components of the fish assemblage. This can then be related to observed oceanographic conditions. The video analysis for fishes consists of sub sampling 40% of a tape for individuals 20-50-cm TL and viewing 100% of a tape for others >50-cm TL. Habitats are classified by 1-minute segments and the segments are assigned a zone, a dominant habitat type, and an estimated rugosity value.

Development of Acoustic Monitoring Capabilities

In addition to the above-mentioned ecological assessment and monitoring activities, CREI is presently working with partners at Eastern Carolina University, HIMB, and NOAA's Pacific Marine Environmental Laboratory (PMEL) to develop an acoustic monitoring program to alert scientists and resource managers to large changes or potential threats to the health of coral reef ecosystems in remote areas where *in-situ* ecological monitoring can be conducted only at infrequent annual or biannual intervals. The long intervals between ecological assessments of the biotic components makes it difficult or impossible to observe major changes to the ecosystem as they are occurring and in sufficient time to potentially minimize damage through proactive management. Therefore, CREI plans to augment its *in-situ* assessment program by developing acoustic techniques to monitor indices of ecosystem health at these remote locations. The envisioned acoustic monitoring system, designed to detect shorter-term trends, will have satellite telemetry capability and be deployed as a moored buoy or integrated into existing *in-situ* CREI oceanographic monitoring stations (see oceanography section). Telemetry can serve to alert researchers of imminent or occurring changes to the coral reef ecosystem so that additional field observations and data collection efforts can be initiated, if warranted. Changes in the status of a remote coral reef ecosystem resulting from global warming and/or bleaching, hurricanes, storm damage, and other natural or anthropogenic events are of particular interest. Passive acoustic techniques are also proposed to monitor vessel traffic and illegal incursion into MPAs. This information would automatically be forwarded to enforcement agencies, such as NMFS, U.S. Coast Guard (USCG), USFWS and the appropriate state and territorial agencies.

On-going CREI efforts to develop this acoustic monitoring capability include the following:

- Recording ambient acoustic data from varied locales within reef ecosystems.
- Analyzing acoustic data to determine specific measurements that can be correlated to ecosystem health. Such factors might include the presence (or absence) of easily observable species or simple measurements such as the amount of acoustic energy within a given set of frequency ranges.
- Developing long-term monitoring stations that will acquire and analyze acoustic data and telemeter a summary of metrics back to CREI scientists.

To date, CREI has collected data from 26 short-term deployments at acoustic monitoring stations. These data were collected in conjunction with *in-situ* ecological assessments in a variety of reef environments throughout American Samoa and the U.S. Phoenix and Line Islands. CREI collaborators at Eastern Carolina University have conducted preliminary qualitative and spectrographic analyses of these data. Future plans for acoustic monitoring of the coral reef ecosystems of the U.S. Pacific Islands include:

- More thorough spectral analysis of existing data to develop a variety of simple measurements that are candidate metrics.
- Correlate these metrics to the *in-situ* biological data collected.
- Develop a prototype acoustic monitoring buoy that can be easily deployed and recovered.
- Use this buoy to test candidate metrics for correlation with short-term temporal and spatial changes as measured in a variety of reef ecosystems in the MHI.
- Design a long-term, remotely operated acoustic monitoring buoy that can be deployed at remote sites and serve as a desired early warning system.