HCRI Project Final Report Format

I. Project Title: KAHEKILI ECOSYSTEM RECOVERY AREA -Science Planning and Support

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Project Staff:
Organization: Hawaii Cooperative Fishery Research Unit
Grant Number: NA07NOS4000193
Date: Jan 31st 2009

II. Executive Summary

Hawaii Division of Aquatic Resource (HDAR) is currently working to establish a 'Herbivore Fisheries Management Area' (HFMA) [n.b. previously titled as Kahekili Ecosystem Recovery Area] encompassing reef areas adjacent to Kahekili Beach park in West Maui. The goal of the proposed HFMA is to increase the reef's capacity to resist a phase shift from coral to macroalgal domination by prohibiting the take of herbivorous fish and sea-urchins.

The aims of this project were to provide survey design, analytical, and other scientific support to staff of Hawaii DAR to: (1) assist with the design and implementation of a statistically- and scientifically-valid baseline of pre-HFMA establishment conditions on the Kahekili reef; and (2) utilize new and existing data generated by HDAR and partners, from survey programs in Maui and elsewhere, to draw broader conclusions about the relationships between local herbivore stocks and benthic algal communities (particularly in terms of reefs' vulnerability to macroalgal overgrowth).

Project staff, together with staff of HDAR and UH Botany (several of whom were working on a parallel HCRI-RP project based at the proposed Kahekili HFMA) together designed and implemented baseline surveys. Using that approach, Fish and benthos were surveyed at 155 sites within the HFMA.

Survey sites were grouped into six broad habitat categories, and herbivore biomass in a range of functional groups was calculated per habitat category.

Data derived from NOAA-DAR cruises of remote and inaccessible locations around the Main Hawaii Islands (MHI) showed clear negative associations between reef herbivore biomass and local human population density, consistent with greater fishing impacts at more populous location.

Among shallow water survey data available to DAR, there was wide variability in local herbivore biomass, and very clear negative relationships between herbivore biomass and macroalgal cover. Analysis indicated clear negative relationships between macroalgal cover and parrotfish biomass, but nor relationships between macroalgal cover and biomass of other herbivorous groups.

III. Purpose

A. Detailed description of the resource management problem(s) to be addressed.

Hawaii Division of Aquatic Resource (HDAR) is presently exploring the possibility of establishing a Herbivore Fisheries Management Areas (HFMA) in front of Kahekili Beach Park in West Maui. The reef in the proposed HFMA, while still in relatively good condition, has been intermittently overgrown by the invasive alga *Acanthophora spicifera* in recent years. *A. spicifera* is highly palatable alga, and the specific goal of the HFMA is to restrict take of herbivorous fishes and sea-urchins to thereby restore the reef's capacity to prevent invasive algal blooms from occurring– and, by doing that, ultimately to halt the insipient slide from coral- to algal-domination. Draft regulations have been written and HDAR has begun the formal process of establishing the HFMA at Kahekili. This project provides analytical and survey design support to HDAR and partner's efforts to establish the HFMA and generate meaningful data against which eventual effectiveness of the HFMA can be assessed.

While the main spatial focus is on the proposed Kahekili HFMA, the problem of coral to algal phase shifts is a concern for many Hawaii reef areas, particularly around heavily populated parts of the state, and so this project also supported wider scale collaborative projects in the state relating to herbivory and macroalgal domination of local reefs.

B. Detailed description of the question(s) asked to answer the resource management problem(s)

The core longer-term question is whether restricting the take of herbivores in the Kahekili HFMA leads to (i) rises in herbivore stocks; and (ii) whether any increases in herbivore stocks lead to greater capacity of the reef to resist macroalgal blooms. The timescale of protected area implementation and of (expected) ecological recovery are very much longer than the duration of this project, but a key objective of this project was to establish a scientifically meaningful and robust pre-closure herbivore and benthic community baselines.

In terms of the broader topic of what is driving coral to algal phase shifts on Hawaiian reefs, key questions include: (1) whether there is any evidence that herbivore stocks are depleted around the populated parts of the state which have become overgrown by macroalgae in recent years; (2) whether there is evidence that locations with large herbivore stocks are less prone to macroalgal overgrowth; and (3) if there are inverse relationships between herbivore stocks and macroalgal abundance, which group(s) of herbivores are particularly important in terms of providing resilience to algal overgrowth?

C. Overarching goal(s) of the project

(1) Provide basis for judging effectiveness of herbivore protection as means of reversing coral to algal phase shifts at Kahekili and on Hawaiian reefs more widely.
(2) Provide scientifically valid information on relationships between herbivore stocks and algal communities on Hawaiian reefs more generally (particularly around Maui Island), sufficient to

justify wider protection of key grazing organisms (e.g. through stricter bag or size limits).

D. Hypothesis (if application) and objectives to answer each question.

(1) Objective: Design, and implement baseline surveys of fish and benthic populations in the proposed Kahekili HFMA. No suitable hypothesis for this project.

(2) Objectives: Collate and analyze data on herbivore stocks and benthic cover from surveys in Maui and elsewhere in the Main Hawaiian Islands (MHI). Collate and analyze information on the status of herbivore stocks around the MHI, and determine the extent to which herbivores are or are not depleted close to human population centers.

IV. Approach

Detailed description of the work performed for each objective from III(C), including (but not limited to):

A. list individuals and organizations actually performing the work
B. material list
C. construction instructions for anything used to accomplish the III(C) objectives
D. deployment steps
E. data collection procedures
F. data analysis techniques
G. photos from research during each stage (construction, in situ, lab)
H. contact information for companies used to purchase items unique to your project (if applicable)

(Objective 1)

Baseline surveys of the proposed Kahekili HFMA were conducted in January 2008 and August 2008 by a combination of project staff (Ivor Williams), staff of HDAR (Russell Sparks, John Mitchell, Kristy Wong), staff of University of Hawaii Department of Botany (UH: Mark Vermeij, Meghan Dailer, Darla White) working on a parallel project (also funded through HCRI-RP).

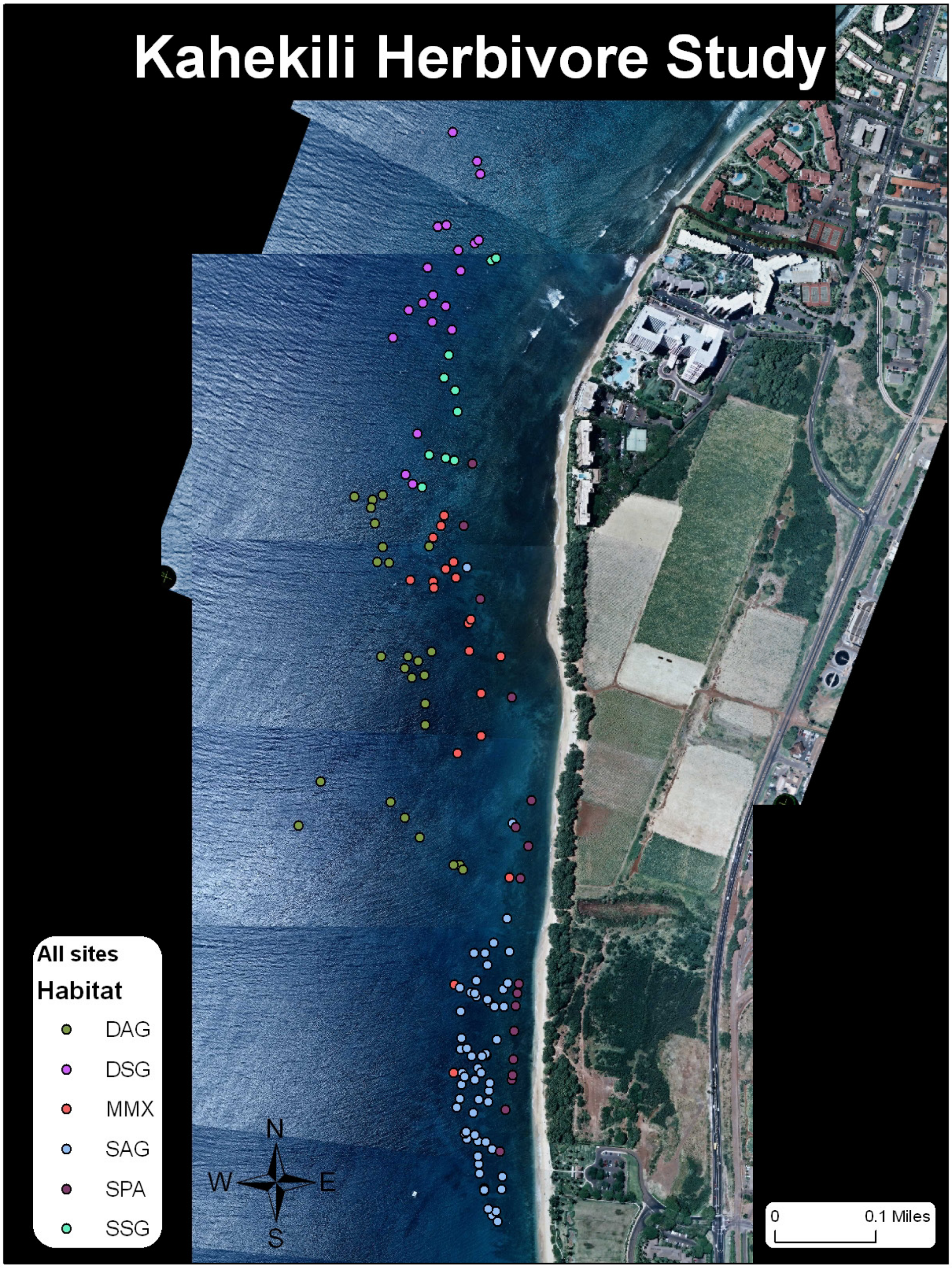

Figure 1. Location of Kahekili Baseline Surveys. January and August 2008 surveys combined.

Surveys were haphazardly located on hardbottom areas within the proposed Kahekili ERA boundaries with the aim of broadly covering the full extent of the area and with adequate replication within different habitat zones (Figure 1). Surveys were conducted from a small boat. Survey teams comprising two divers each were haphazardly dropped over hardbottom areas throughout the proposed HFMA. The divers would then swim straight down to the nearest suitable habitat (hardbottom large enough to lay a survey transect in); one of the survey divers tied of the starting point of the survey transect and the other recorded the transect start location using a GPS in a waterproof bag attached to a float. As much as possible, surveys were always run parallel to the shoreline running approximately northwards, and in all cases a transect bearing was taken by one divers. In total 155 surveys were conducted throughout the proposed HFMA (Figure 1).

Reef habitats vary considerably within the Kaheklili HFMA, and hence survey habitats were grouped into 6 broad categories (Table 1) corresponding with evidently distinct ecological zones within the HFMA. It seems almost certain that fish and algal populations will be inherently very different in different habitats, and hence real understanding of any future change within the HFMA will be much more meaningful if analyzed within habitat classes.

Table 1. Habitat types within the Kahekili ERA.

Habitat	N	Depth Range (ft)	Characteristics
Deep Aggregate Reef	28	23 - 50	Some patches and sand, but substrate largely dominated by corals. Consequently, reef has moderate or high complexity.
Shallow Aggregate Reef	59	5 - 23	As above (but shallower-largely corresponding with depth range of fringing reef in front of Kahekili Beach Park)
Shallow Spur and Groove	10	10 – 13	Spur and groove (confined to northern edge of proposed HFMA). Shallow spur and groove begin to develop at around 10 ft deep, but do not develop substantial physical relief until 15ft deep or lower. Shallow spur-and-groove areas were also clearly more sedimented than deeper spur-and-groove
Mid-Deep Spur and Groove	20	17 – 40	Spur and groove habitat – by around 15ft, physical structure is well established and by deeper portions of this habitat, spurs are up to about 15ft off the bottom
Shallow Pavement	19	4 – 8	Largely flat, low relief and low coral cover areas dominated by limestone pavement and loose sediment
Mixed Mid-Depth	19	10 – 25	Mixed medium depth and deeper habitat. Coral cover low and coral distribution patchy, abundant loose sediment and sand patches are common

Survey transects were of 25m length. One of the divers conducted fish surveys using methods closely based on those used by NOAA-CRED throughout the state of Hawaii (so data would be comparable with larger-scale data sets): species, number and size (in 5cm slots) was recorded for all fishes larger 15 cm total length (TL) within a 4-m wide belt centered on the diver as they laid out the 25 m transect tape. The diver would then turn around and resurvey the transect line, recording species, number and size of all fishes smaller than 15 cm TL in a 2m wide belt centered on the transect line.

The other survey diver followed the fish survey diver, and conducted a photo quadrat survey of the benthos under the transect line, and then recorded all sea-urchins with a 1m-wide belt, during a return swim down the transect line.

Fish surveys were conducted by project staff and by staff of HDAR, but benthic surveys were largely performed by UH staff working on a parallel project with its own reporting requirements. This project report will therefore only cover details of fish survey methods and data processing.

(Objective 2)
Two sources of data have been utilized to broadly assess status of herbivores on Hawaiian reefs, and on links between herbivore stocks and benthic algal communities: (1) Main Hawaiian Islands Reef Assessment Program (MHI-RAMP), which involved staff of NOAA Coral Reef Ecosystem Division in Hawaii (NOAA-CRED) and Hawaii DAR. For that program, 128 surveys were conducted around mostly previously un-surveyed parts of the MHI between Feb 2005 and Aug 2006; and (2) Hawaii DAR's ongoing survey programs, including: (i) laynet-ban assessment program, which monitors target fish and visually estimated benthic composition at locations around Maui Island; (ii) DAR's ongoing coral-reef monitoring program around Maui and Lanai; and (iii) Hawaii DAR's shallow target fish surveys of the Big Island.

NOAA-CRED survey methods are detailed on the NOAA PIFSC web page (http://www.nmfs.hawaii.edu/cred/eco_assess.php), but essentially involve three 25m-transects per site. Transects were surveyed by fish and benthic teams – fishes >20cm TL being surveyed on 4m-wide transects by each of 2 divers per transect (divers swimming in parallel) and fishes < 20cm TL in 2-m wide belts during return swims on the same transects.

Among DAR shallow water (<15ft deep) sites, comparable data was available from 14 locations in Maui County (laynet and shallow water resource fish survey locations), and 3 locations in Oahu – each of which were multiply surveyed by DAR staff over 2007 and 2008 (the period used for analysis). In addition, a total of 72 shallow water resource fish swims were conducted in West Hawaii. Herbivorous fish were surveyed similarly at all locations: by means of timed swims, in which all fishes > 15cm TL were counted within a visually estimated 5m-wide belt. For each survey, GPS was used to determine distance swum, and survey area was calculated as total distance swum * belt width.

There are considerable differences in habitat among islands. For example, Oahu shallow water sites were surveyed in both 'reef-crest' (3m deep, high energy environments) and 'backreef' zones (generally flat and 1-2m deep). West Hawaii shallow sites were mostly either boulder habitats or were abutting high relief rocky areas. In contrast, Maui shallow sites are typically gently sloping moderate relief hard bottom habitats. Therefore, although Oahu and Big Island data are shown on graphs (figure 3), statistical analysis and generation of trends was restricted to Maui county sites only. In addition, because each of the 72 Big Island sites was only surveyed once, because sites were not groped into natural spatial locations, and because Big Island data is only included for purposes of comparison with the core data from Maui, all 72 Big Island surveys were pooled into a single value for that island.

V. Results

A. Findings for <u>each</u> III(C) objective.
B. Answers to III(B) <u>each</u> resource management question(s).
C. Site specific results for <u>each</u> location (Can place in an appendix as electronic file).

(Objective 1)

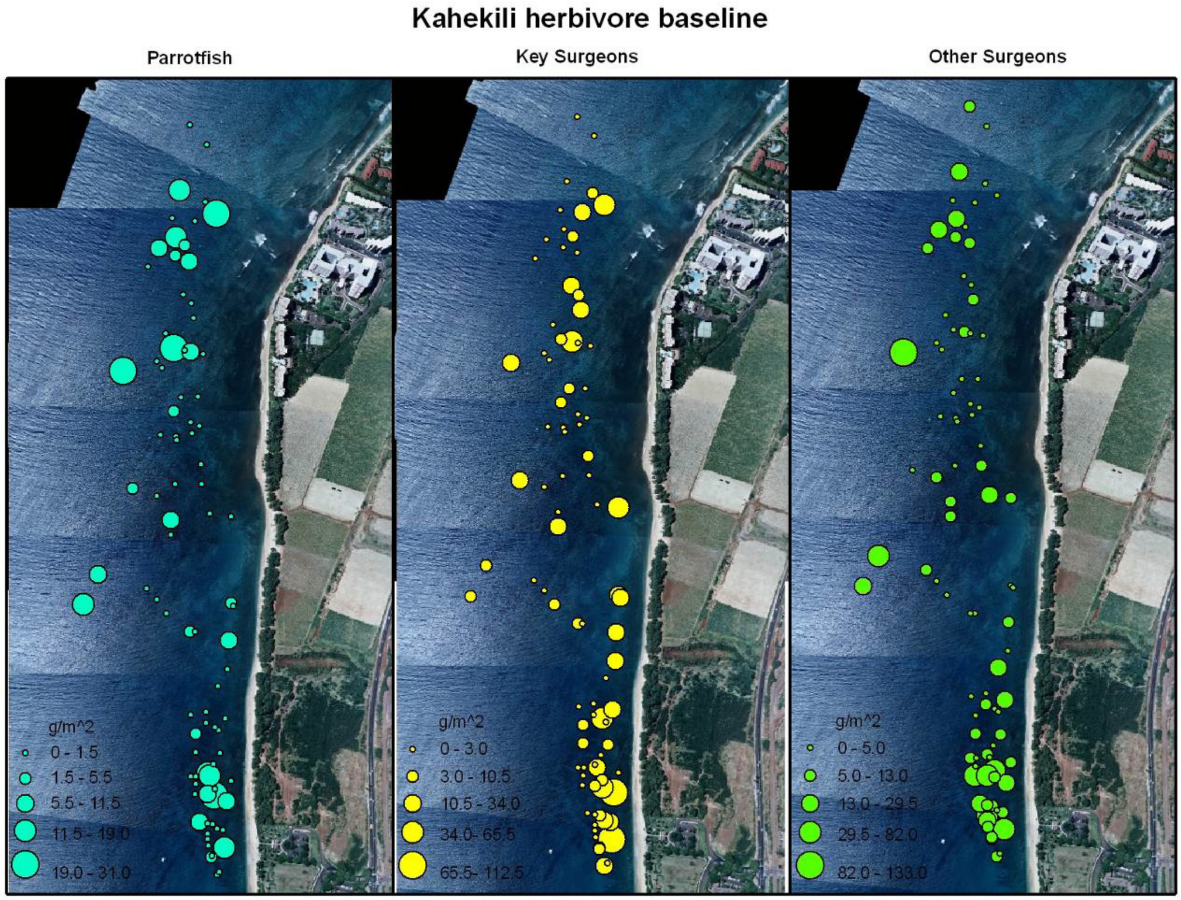

Figure 2. Herbivore Biomass at Kahekili Baseline Surveys (based on January surveys only)

Herbivore biomass estimates per site from January surveys are shown in Figure 2. 'Key surgeonfish' were those that are known to feed largely on benthic algae: *Acanthurus achilles; A. triostegus; A. guttatus; A. leucopareius; A. nigrofuscus; Zebrasoma flavescens; Naso lituratus.* 'Other surgeonfish' are those that do sometimes feed on algal substrate, but are detritivores or largely planktivores as adults: *Ctenochaetus* spp.; *Naso breviorostris;* and medium-large surgeonfish which predominantly feed on diatoms over compacted sand: *Acanthurus blochii; A. dussumieri; A. olivaceous;* and *A. nigroris*. Surgeonfish which are nearly entirely planktivorous as adults, e.g. *Acanthurus thompsoni* and *Naso hexacanthus*, were considered 'planktivorous surgeons' and were not included in the analysis here (those were rare at Kahekili, and are presumably unlikely, anyway, to influence benthic algal communities).

Table 2. Herbivorous Fish Biomass by habitat type within the Kahekili ERA.

		(Mean ±SD)			
Habitat	**N**	**Parrotfish (g m^{-2})**	**Key Surgeons (g m^{-2})**	**Other Surgeons (g m^{-2})**	**Planktivorous Surgeons (g m^{-2})**
Deep Aggregate Reef	28	2.7 ± 4.3	2.4 ± 3.0	3.6 ± 4.6	1.5 ± 5.7
Shallow Aggregate Reef	59	2.1 ± 5.0	9.5 ± 20.3	6.8 ± 13.9	2.2 ± 8.3
Shallow Spur and Groove	10	9.4 ± 12.4	19.4 ± 23.8	15.6 ± 41.5	0 ± 0
Mid-Deep Spur and Groove	20	4.0 ± 5.7	2.0 ± 3.7	6.5 ± 7.1	0 ± 0
Shallow Pavement	19	1.2 ± 2.3	15.3 ± 19.7	6.0 ± 7.0	0.6 ± 2.8
Mixed Mid-Depth	19	0.7 ± 2.1	2.6 ± 4.9	2.8 ± 6.0	0 ± 0

There were clear differences in fish stocks among locations: for example, shallow spur and groove sites had much higher herbivore biomass than deeper spur and groove zones (Table 2). Future comparisons of fish biomass should be made within comparable habitat zones. To facilitate that, this project has generated maps of the Kahekili ERA which identify habitat classifications by survey site (Figure 1).

(Objective 2)

Main Hawaiian Islands NOAA-DAR Data

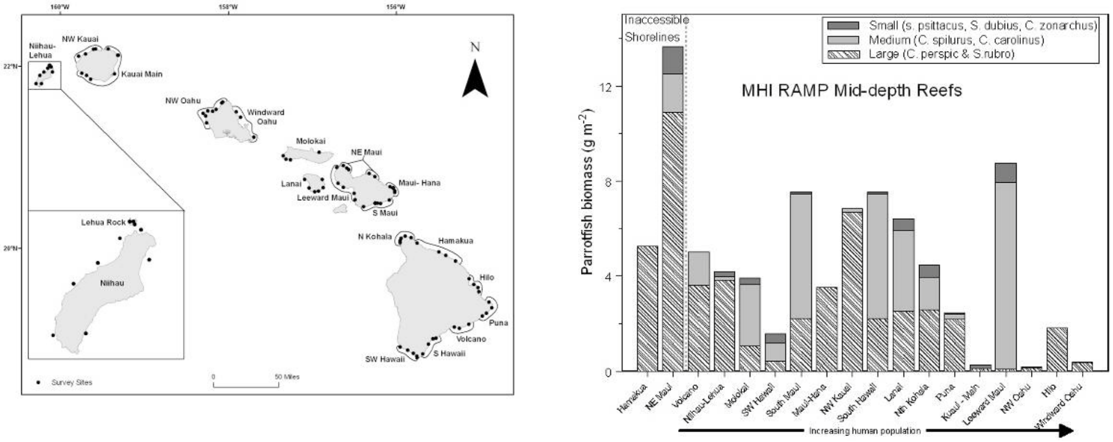

Figure 3. Sites surveyed for MHI-RAMP cruises.

Among the 128 survey sites, grouped into 18 locations, spread widely around the populated Hawaiian Islands (Figure 3), there was a strong negative association between human population density adjacent to survey sites, and biomass of large parrotfishes (spearman's rank correlation of parrotfish biomass and human population among accessible sites: R_s= -0.60, p=0.01).

Hawaii DAR Shallow Water Surveys

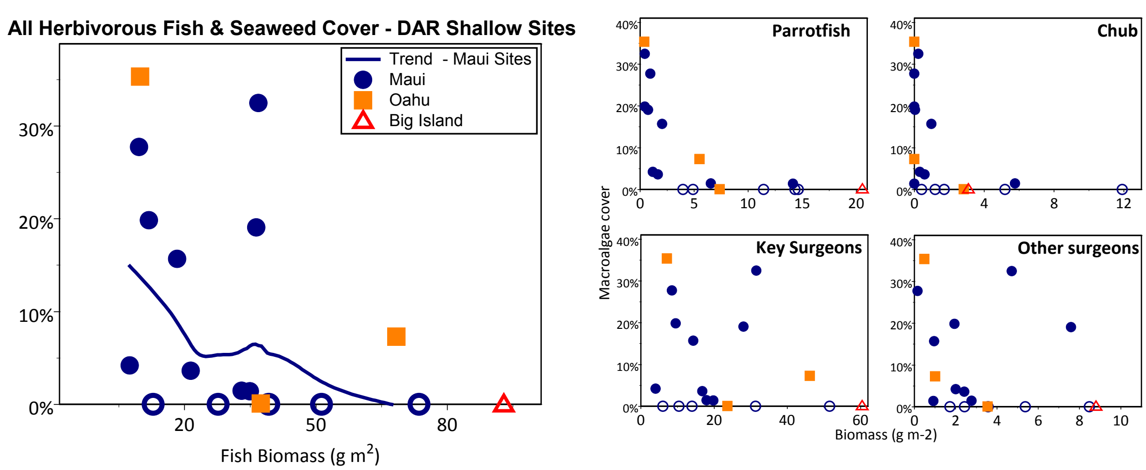

Figure 4. HDAR Shallow-water herbivore stocks and macroalgal cover. Trend line in first graph is a LOESS smoothed curve of data from Maui sites only.

Total herbivore biomass varied from 7.5 gm^{-2} at Kapalua Bay to 92.9 g m^{-2} at Big Island sites, and among those sites, macroalgal cover varied from 0% to over 30% at Aelaoa and Paia on Maui, and at Ala Moana on Oahu. Total herbivore biomass appeared to be weakly negatively correlated with macroalgal cover (Figure 4), but among herbivore functional groups, negative relationships appeared much stronger for parrotfish and chub, than for either group of surgeonfishes (Figure 4). Parrotfish biomass was significantly negatively correlated with seaweed cover (Table 1)

Table 2. Partial correlations between macroalgal cover and herbivore group biomass. Because of substantial differences in habitat type among islands, only Maui sites were included for analysis. Partial correlations control for the impact of other potentially co-varying factors – for example, the correlation between parrotfish biomass and macroalgal cover controls for possible impacts of other herbivorous fishes (chub, both surgeon groups).

	Partial Correlation	
Herbivore group	R	p
Parrotfish	-0.70	0.01
Chub	-0.32	0.13
Key surgeons	0.39	0.96
Other surgeons	-0.11	0.82

Therefore, the only statistically significant relationship between macroalgae and biomass of a herbivorous fish group was for parrotfishes: and, controlling for the effects, there was not relationship between biomass of other groups and macroalgal cover. While these results are only correlations, it is notable that every survey location with parrotfish biomass below ~ 3 g m^{-2} had abundant macroalgae, whereas every site with biomass of parrotfish > ~5 g m^{-2} had negligible amounts macroalgal cover (figures 4 and 5). In contrast, there were several sites with large stocks of benthic-algae feeding surgeonfishes but which still had abundant macroalgae (figure 4). In addition, nearly all remote, lightly populated or protected sites had high parrotfish biomass (e.g. Big Island and Lanai sites, plus MLCDs and NARs – all of which prohibit take of herbivorous fishes, figure 5).

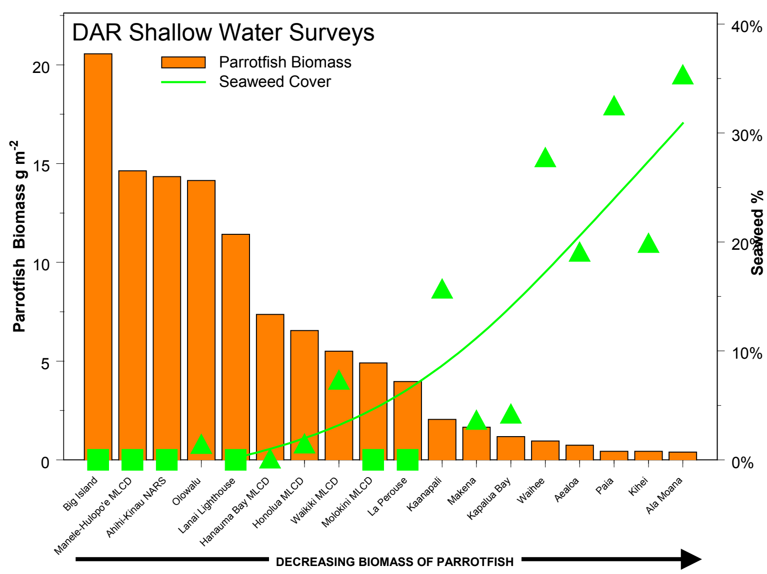

Figure 5. HDAR Parrotfish and Macroalgal cover –all HDAR shallow-water sites included.

VI. Dissemination of Project results:

Explain, in detail, how the projects results have been, and will be, disseminated.

A. New fundamental or applied knowledge
B. Scientific publications
C. Patents
D. New methods and technology
E. New or advanced tools (e.g. models, biomarkers)
F. Workshops
G. Presentations
H. Outreach activities/products (e.g. website, newsletter articles)
I. Partnerships established with agencies or organizations

Results from this project have been presented to HDAR staff at an internal meeting in June 2008 in Honolulu to discuss appropriate bag and size limits for inshore fishes of particular ecological importance, and have been incorporated into presentations given by HDAR staff at public meetings to gather public comment on the same topic (at Maui, January 17th, and at Kona on February 3rd 2009). Herbivorous fishes, because of their role in providing resilience to macroalgal overgrowth, are clearly an important group, and hence data shown in Figure 4 (strong negative association between herbivore biomass and macroalgal cover) and Figure 5 (evidence of significant depletion of key herbivores around locations with higher local human populations) are highly relevant.

Results from this project were also incorporated into a presentation given by Russell Sparks of Maui DAR at the Harmful Algal Bloom Workshop in Honolulu on December 9th.

In addition, the analysis of the MHI-wide NOAA-HDAR surveys formed the basis of a presentation given by the PI (Williams) at the Hawaii Conservation Alliance July 2008 meeting in Honolulu (presentation titled "Assessing anthropogenic impacts on Hawaiian reef fish assemblages along regional-scale human population gradients"). Large-scale data on relationships between herbivores and seaweed cover were also included in a public presentation organized by the Nature Conservancy of Hawaii entitled "What's up down under" by Dr Bill Walsh of Hawaii DAR and the PI (Williams).

VII. Resource Management Implications

A. Given the results from VI, what are the implications for resource managers?
B. How do these implications and results help to address the resource management problem(s) identified in III(A)?
C. What recommendations for resource managers can be made based on the implications and results?
D. Management outcomes - Societal condition improved due to management action resulting from output; examples:
    i. Improved water quality
    ii. Lower frequency of harmful algal blooms
    iii. Reduced hypoxic zone area
    iv. Improved sustainability of fisheries

A.
Data generated for Objective 1 is primarily useful as a pre-closure baseline against which the effectiveness of the Kahekili Herbivore Fisheries Management Area can be assessed.

Implications for resource managers from Objective 2 include:

- Among herbivorous fish groups, the strongest evidence of grazer control of algal cover was for parrotfishes, which were strongly negatively correlated with macroalgal cover. Results therefore suggest that special protection for parrotfishes may be warranted at locations which are vulnerable to algal blooms, such as the reef at Kahekili. It is, however, important to recognize that correlations do not prove causality, and in this case are prone to confounding by other differences among lcoations. For example, sites with few parrotfish (Ala Moana, Kihei, Paia, figure 5) also tended to be near large human population centers, and hence sites with low parrotfish stocks were potentially also impacted by other anthropogenic factors such as eutrophication.
- Remote, lightly-populated, and protected areas tended to have large populations of key herbivores and negligible algal cover (Figure 5), which corroborates the expectation underlying the establishment of the Kahekili HFMA, namely that herbivores are vulnerable to depletion by fishing, and that that depletion has contributed to algal blooms there.

B. HDAR and partners now have a robust baseline and methodology which can be used to assess effectiveness of the Kahekili HFMA, and provide scientifically robust results to managers and to the public at large.

Relationships between herbivores and macroalgae and, in particular, evidence of the likely importance of parrotfishes, provides scientific support to current efforts by Hawaii DAR to increase regulation of take of that group. That management effort is still at an early stage, but HDAR is already using results from this project in presentations at public meetings on inshore fish regulation.

C. Specific recommendations to managers include:

- Repeat herbivore and benthic surveys described in Objective 1 on an annual basis, and compare results with baseline surveys to assess impact(s) of the establishment of the Kahekili HFMA. Full impacts of closure are likely to take 5 or more years to become apparent.
- Consider specific protection for key herbivores, to include strict bag limits on parrotfishes, and perhaps also chub.
- As reefs with healthy herbivorous fish stocks appear to be much more resilient to algal overgrowth then reefs with few grazing fishes, herbivorous fishes merit special protection. In addition to establishing the Kahekili HFMA, consideration should be given to additional herbivore protection area at locations across the state that are most vulnerable to seaweed blooms, which would include: (ii) on reefs where invasive seaweed are beginning to become established, such as around the outer edge of existing ranges of some of the invasive species; and (ii) where the reef is intermittently overgrown by algal blooms.

- Successful implementation of the Kahekili HFMA, should lead to reduced frequency of algal blooms on the reef there. The existence of a meaningful baseline against which effectiveness can be measured will be key to assessing that and to sustaining and building public and legislative support for continuing herbivore protection at Kahekili, and for extending the approach elsewhere.

- To the extent that results from this study will assist HDAR and partners in their efforts to build support for increased protection of key herbivores statewide, this project can play an important role in improving Hawaii reefs resilience to invasive algal blooms.

VIII. Evaluation

For <u>each</u> III(C) objective:

A. Describe the extent to which the objective was attained, including:
   1. Was the objective attained? How? If not, why?
   2. Were modifications made to objective? If so, explain.
   3. If significant problems developed, resulting in less than satisfactory or negative results, discuss.
   4. Description of need, if any, for additional work.

B. What performance measures are used to evaluate how well the project met the stated objective?

A. Objectives were fully met
B. (For objective 1) – baselines surveys were conducted. Results analyzed and data archived in Hawaii DAR survey database.
(For objective 2). Large scale data sets analyzed. Results passed to Hawaii DAR managers and scientists as tables and figures. Figures and analysis generated by this project utilized by DAR staff in public presentations about the proposed HFMA, and separate meetings about possible changes to size and bag limits for coral reef fishes.