NOAA Final Report

I. Title: How many fish does it take to keep the alien algae out?
Author: Danielle Jayewardene, P.I. Charles Birkeland
Organization: University of Hawaii at Manoa
Grant #: 654 539
Date: January 31, 2006

II. Abstract

The dominance of coral reefs by invasive algae is considered one of the major threats to Hawaii's coral reef ecosystems. Projects have been supported to develop methods of removing invasive algae, but due to algae returning through microscopic remnants, removal programs may need to be replicated endlessly. There have been many studies that have shown that algae are controlled by herbivory. When grazing fishes are abundant on a reef, for example in Marine Protected Areas (MPAs), intense grazing sets back algal succession, and turf or a low biomass of algae is maintained on the reef. Even the more toxic and distasteful algae are grazed before they grow large enough for their defensive chemicals and morphological structures to become effective. If alien algae are imported into this system, they cannot gain a high biomass due to constant cropping. When the grazing population is depleted, grazing intensity becomes low and succession to dominance of macroalgae is facilitated. Based on these scenarios, we could predict that a protected reef within an MPA promotes high grazing intensity, and thus creates a resistance to the spread of alien algae. However, would the same abundant, but later established grazing population be able to crop down an established high algal biomass? Is there a point when the biomass of algae simply overwhelms the ability of grazing fishes to crop down the algae even when grazing fishes are abundant. Maybe the grazing efficiency of populations of herbivorous fishes protected by MPAs is determined by whether they were established before or after the invasion of algae. Further, is cropping efficiency dependent on the size of the fish? If there is an abundance of small herbivorous fishes, do these graze down algae as efficiently as fewer, but larger fishes? These are the pertinent management questions our project aims to address.

III. Executive summary

The goal of this project has been to determine the level of grazing pressure needed to crop down a standing biomass of algae on the reef. Specific objectives involved a) determining whether there are differences in cropping ability by larger herbivorous fishes compared to smaller herbivorous fishes, and b) whether there is a threshold level of algal biomass above which even an increased number of herbivorous fishes simply cannot crop down.

These objectives were tested by cultivating replicates of algal plots on different reefs and monitoring how efficiently these simulated algal communities were grazed down by the herbivorous fishes resident to these sites. This was achieved by setting out fish exclusion cages over non-live substrate for a period of months to allow for the uninhibited growth of algae within, and subsequently removing the cages and exposing the algal plots to grazing by the fishes. Grazing pressure was determined by monitoring how efficiently the plots were cropped down by the fishes at the different sites and between different treatments within the sites.

Guidance and advice was provided by the project's Principle Investigator Dr. Charles Birkeland of the Hawaii Cooperative Fisheries Research Unit (HCFRU). Graduate student Danielle Jayewardene of the Zoology department, University of Hawaii, performed the field work involved in the project.

A significant and unexpected problem that emerged in our study was the general lack of algal growth within our experimental plots despite the lengthy period the cages were set out for. The limited biomass of algae did not allow us to properly test the level of grazing pressure needed to crop down a standing biomass of algae, and/or whether there is a threshold level of algal biomass above which even an increased number of herbivorous fishes simply cannot crop down algae. We were however able to address one of our objectives and determine that there is a difference in cropping ability by larger herbivorous fishes compared to smaller herbivorous fishes. Where larger fishes, predominantly parrotfishe, are present, they are able to reduce up to 7 times more algal cover in plots within 3 days compared to only the smaller herbivorous fishes. Repeated experiments are planned to further support these findings. We also found that the grazing urchins *Tripneustes gratilla,* may play an important role in grazing down algae in both the absence and presence of herbivorous fishes.

Overall, we were presented with some important problems during the progress of the project. As mentioned, the most important challenge was our inability to obtain a high biomass of algal community within our experimental plots. A second problem was the loss off parts of our data to ocean swells. However, our discovery that larger parrotfishes are more efficient at cropping down a standing biomass of algae, supports the notion that Marine Protected Areas (with their promotion of increased size and abundance of fishes) are an important management strategy for keeping grazing efficiency high on a reef in turn promoting a coral dominated reef ecosystem.

IV. Purpose

Problems and impediments

Initially we planned to test our research question by running controlled grazing experiments in sea water supplied microcosm tanks at the Hawaii Institute of Marine Biology (HIMB). We planned to manipulate the numbers of parrotfish *Scarus psittacus* (grazers) and surgeonfish *Acanthurus triostegus* (browsers) subjected to different size classes of two types of alien algae, *Gracilaria salicornia* and *Acanthophora spicifera*. We planned to determine the size of the less preferred algae *G. salicornia* at which it would become recognizable and would be avoided by the grazing fish.

However, since writing our proposal in February 2004, we have modified our methods applied to determining our question. We have taken into account critique and suggestions offered not only by the HCRI-RP evaluation committee, but also by researchers holding experience running experiments in microcosm tanks (e.g. Paul Jokiel). A running critique has been that our suggested experiments in microcosm tanks do not necessarily translate to the natural interactions occurring on reefs. Secondly, we have learnt that it is challenging to maintain fish in tanks for periods of time. Due to these two factors, we have decided to run our experiments in the field. While this involved extensive modification of our methodology, our research question remained the same.

Objectives of the project

The objective of this project has been to determine the level of grazing pressure needed by herbivorous fishes to crop down a standing algal biomass on the reef. We wanted to determine whether there are differences in cropping ability by larger herbivorous fishes, e.g. parrotfishes, compared to smaller herbivorous fishes, and whether there is a threshold level of algal biomass above which even an increased number of herbivorous fishes simply cannot crop down.

V. Approach

Methods

Instead of manipulating the biomass levels of *fish* exposed to macro-algal communities to test grazing intensity in the field, *algae* were manipulated. This was done by cultivating high biomass algal communities in-situ on selected reefs and subsequently exposing these communities to the resident herbivorous fishes at these sites. This was conducted by setting out fish exclusion cages, preventing the herbivorous fishes from grazing the algae within, allowing the uninhibited growth and succession of algae in the protected plots. Once the algal plots reached a high biomass level, the mesh on the cages was removed and the algae within the cages exposed to the grazing fishes. Grazing intensity was determined by monitoring the efficiency in which the fishes cropped down the algal plots.

In order to compare cropping efficiencies by different herbivorous fish communities, experimental cages were set out on different reefs with ranging abundances of herbivorous fishes. Two sites were known to have a high biomass of herbivorous fishes including a significant proportion of large parrotfishes, (Ke'ei and Hanauma Bay), and three sites known to have a low biomass of herbivorous fishes with few large parrotfishes (Wawaloli, Portlock and Ko'olina),(Figure 1).

To test for threshold levels of algal biomass above which even a high intensity of grazing may not result in cropping down of the algae, the grazing fish communities at these sites were exposed to experimental plots with a lower biomass level of algae, compared to ones with a higher biomass level of algae. These different biomass levels were simulated in the plots by leaving half the experimental cages out for a shorter time than the others, thus exposing the algal plots to the grazing community at an earlier algal successional stage.

To test the different cropping effects that large herbivorous fish compared to small herbivorous fish have on the simulated algal communities, we excluded only the large herbivorous fishes (most likely the larger parrotfishes) from cropping down a random selection of the opened plots. This was done by replacing the small mesh on the cages used to exclude all fishes with large mesh which would exclusively exclude the larger sized fishes.

16 cages were set out per site. At each site, the cages were placed randomly within a grid set around permanent fish transects run by WHAP and CRAMP at 10m depth (Figure 2). 8 plots where high biomass levels were simulated were out for 8 months while 8 plots intended to simulate a lower biomass were out for 5 months. The second set of cages were set out 3 months after the first set to allow all experimental plots, whether high or low biomass, to be released to grazing simultaneously. This eliminated potential differences in cropping ability resulting from temporal differences in grazing.

Exclusion cages were constructed from weather resistant clothes line and a fine polypropylene aqua mesh. Mesh used to exclude all herbivores was ½ inch across in size, while mesh used to exclude only the larger fishes was 4 inches across in size. The plot area protected by each cage was approximately 900 cm^2. The mesh did not manipulate water motion or light levels (pers.com Linda Preskitt). The cages were attached directly to the natural benthic substrate (non-live) using cable ties. A skirt of mesh surrounding the bottom of each cage prevented fishes from entering through gaps under the rim of the cage.

Monitoring of all algal plots when released to grazing was conducted daily for up to 9 days. The actual biomass grazed upon was to be determined by taking small random samples of algae from within each of the replicate plots when the cages were opened, then at the end of the monitoring period. Digital images from above and from an angle of each of the plots were also taken on a daily basis.

In order to appropriately compare relative algal cropping rates between sites, the background level of algae at each site was determined by analyzing 150 benthic photoquadrats per site.

Project management

Principle Investigator Dr. Charles Birkeland of the Hawaii Cooperative Fisheries Research Unit (HCFRU) oversaw the progress of the project, providing assistance and advice. Graduate student of the Zoology department, University of Hawaii, Danielle Jayewardene performed the work involved in the project. Work was field-based, requiring the use of SCUBA and thus dive buddies for Danielle. Dive buddies were voluntary, and included Jeremy Claisse, Sarah McTee, Sam Kahng, Lance Smith, Amanda Myers, Megan Bushnell, Brett Schumacher, Delisse Ortiz and Kosta Stamoulis.

The Hawaii Coral Reef Initiative Research Program (HCRI-RP) provided the grant providing the majority of funds for the project. The Hawaii Cooperative Fisheries Unit (HCFRU) provided supporting funds and resources. The West Hawaii Aquarium Project (WHAP) provided additional support by means of the use of the DAR boat on the Kona coast of Hawaii, academic advice, and data including the herbivorous fish biomass data referred to in this report.

IV. Findings

Actual accomplishments and findings

The abundance of algae found at each of the sites is illustrated in Figure 3. Macroalgae is found only at Hanauma Bay, while filamentous algae (turf) is found at all sites ranging in cover from 22%- 81%. The algal cover at Ke'ei is less than that of the cover at the other sites. Thus algae cultivated within experimental plots may have stood out more at Ke'ei compared the other sites, allowing grazing to be focused more intensely on the plots at Ke'ei. Thus cropping rate tested by plots at this site may not only have been an effect of the actual grazing pressure by herbivorous fishes, but also influenced by the lower availability of background algae at the site in general.

Figure 4 shows the biomass of herbivorous fishes at 3 of the study sites. Data for Ke'ei and Wawaloli are supplied by the West Hawaii Aquarium Project (WHAP) and data for Hanauma Bay by the Hawaii Coral Reef Assessment and Monitoring Program (CRAMP). At Ke'ei, a partially managed site, the biomass of herbivorous fishes is 44 g/m^2. As much as 41% of this biomass is made up of Scaridae (parrotfishes). At Wawaloli, an unmanaged site, the biomass of 17$g/m^2$of herbivorous fishes is lower than at Ke'ei. The actual number and proportion of parrotfishes (9%) at this site is much lower. At Hanauma Bay, an established no take area, the graph indicates that the biomass of herbivorous fishes is much higher than even Ke'ei at 104 g/m^2. Yet the biomass of parrotfishes is comparable to Ke'ei with the proportion of parrotfishes to surgeonfishes within the site being lower (24%). It is necessary to mention that the data from this site was gathered in year 2000, and since the coral community on this particular patch reef (10m depth CRAMP site, Fig. 8) has been changed following a storm in November 2003. Thus the fish biomass data may not accurately reflect the actual lower biomass of fishes present at this patch reef currently. This is of relevance when interpreting the grazing results at Hanauma Bay.

Grazing results for experimental plots at each of the sites are illustrated in Figures 5a-c. At Ke'ei (Fig. 5a) there is a distinct cropping difference between the plots that were open to grazing by both small and large herbivorous fishes compared to plots open only to the smaller herbivorous fishes. As seen in Figure 6, over the period of 3 days the open plots were grazed down approx. 7 times more efficiently (48% total algal cover change) compared to the plots cropped only by the smaller fishes (7% total algal cover change). Rasps by parrotfishes in the open algal plots (Fig. 5a and Fig. 7) indicate that it is the larger parrotfishes that are primarily responsible for this increased cropping efficiency at Ke'ei.

At Wawaloli (Fig. 3b) there was not that great a difference in the grazing down of algal plots between treatments. This was expected due to the lack of large parrotfishes at the site. Over the period of 3 days there was a 12% algal cover change in the open plots compared to 3% algal cover change in the plots open to smaller fishes only (Fig. 6). The general lack of rasps within the plots as found at Ke'ei supports the statement that larger parrotfishes are not an important factor at this site. Interestingly, despite the lower biomass of herbivorous fishes at Wawaloli, the algae were grazed down relatively efficiently. We believe this was not an effect so much of the smaller herbivorous fishes, but mainly by the numerous *Tripneustes gratilla* (collector urchins) present at the site.

At Hanauma Bay (Fig. 3c) we expected similar results as at Keei between treatments due to the abundance of large parrotfishes. However, while there were rasps in plots by parrotfishes, there was no great difference in how efficiently the plots were cropped down whether open to all fishes or only the small fishes. Algal cover in the plots grazed by all fishes changed by 11% and in the plots grazed by only small fishes by -1% (Fig. 4). This might be explained by the fact that while there is indeed high biomass of herbivorous fishes (incl. large parrotfishes) at the Hanauma Bay nature preserve in general, these larger parrotfishes aren't necessarily present at the patch reef where we conducted our study. As mentioned previously, in November 2003 a storm came through and damaged much of the coral at this exposed patch in the Bay, thus degrading the habitat available for herbivorous fishes. Further, compared to the other study sites, there was a very low biomass of algae in the plots to start with. This might be due to the high cover of crustose coralline algae (CCA) on the rubble on which the cages were placed (Fig. 3), severely limiting the growth of algae.

Problems

At the early stages of the project four reefs each holding either a high or low biomass of herbivorous fishes were chosen as our study sites. These were Ke'ei and Hanauma Bay (representing a high fish biomass) and Wawaloli Beach and Portlock (representing a low fish biomass). A few months into the study, a fifth study site Ko'olina was added to the study to replace the Portlock study site, as the experimental cages at this site were washed away by summer swells. Unfortunately, winter swells at Ko'olina have subsequently prevented us from getting out to this reef to monitor the experimental plots set out in June 2005. We hope the cages have withstood the swells and plan to get out to this site as soon as the winter swells subside in March 2006. Thus data in this report has been collected from a total of 3, not 4 study sites as initially planned.

A second more important problem that we experienced was the overall lack of algae growing in the cages. For all 3 study sites, the algal biomass that grew within the fish exclusion cages during the 5-8 months they were out was unexpectedly low and predominantly in a filamentous form. Macroalgal growth was not simulated within the cages. While the filamentous turf community was of a higher biomass inside the plots compared to outside, it too was surprisingly low. This general lack of algae made it difficult for us to accurately answer our overall project question of how many fish it takes to keep alien algae.

Further, no difference in algal biomass was found between the cages that were set out 3 months prior to the second set of experimental cages. Thus we could not test for one of our project objectives; whether there is a threshold level of algal biomass above which even an increased number of herbivorous fishes simply cannot crop down the algae. Also due to the low biomass of algae within the experimental plots, we were unable to take standard algal biomass samples from within the plots to determine the change in biomass from when the plots were exposed to grazing to the end of the monitoring period. The level of error for each sample would outweigh the difference in biomass between samples. Instead we determined grazing pressure by analyzing the percent cover change in algae over time from the images that we took daily of each plot. We determined percent cover using a point count method provided by the image analysis program Photogrid.

Finally, we found that the site we set out our experimental plots at within Hanauma Bay probably did not accurately represent areas within the Bay that are frequented by the large parrotfishes. The patch we used was a site that was formerly used as a long term monitoring site by HCRI-RP funded CRAMP, the reason for choosing to work at this site. However, the data gathered by CRAMP was from 2000, and it has come to our attention that since this patch has been hit hard by storms changing the reef dynamics of this patch reef in particular. Thus the biomass of herbivorous fishes is probably lower in this area than once was.

Additional work

In order to further support our findings that larger parrotfishes are more efficient at cropping down algae in our experimental plots, we plan to re-run our experiments in Hanauma Bay. This time we plan to set out cages at a shallower site of the reef that we have observed to be frequented by very large parrotfishes (Fig. 8). We expect to obtain similar results as we did at Ke'ei where the plots open to grazing by all sizes of fishes were cropped down more efficiently than the plots open to cropping by only the small sized fishes.

We are also in the process of determining the overall community grazing pressure exerted by the resident herbivorous fishes specific to each of our study sites. In the field, 60 individuals of each of the 5 most commonly found herbivorous fishes (*C. sordidus, A. olivaceous, N. litturatus, A. nigrofuscus and Z. flavescens*) were followed to determine the average number of bites taken per 5 minute periods. Individuals were followed at 2 different sites and over 3 different time periods during the day. The average bite rate per species has been calculated (Fig. 9) and will be multiplied by the abundance of each species found at each of the sites to determine the site specific grazing pressure exerted by each species. Further, total grazing pressure for the entire herbivorous fish community characteristic of each site is calculated by totaling the grazing pressures for all the species found at each site.

VII. Evaluation

Attaining project goals & objectives

The overall goal of our project has been to understand the grazing intensity by herbivorous fishes needed to keep algae from dominating a coral reef. Due to the significant problem encountered during our work of algae not reaching a high biomass in our experimental plots, we were not directly able to answer this question. The plots were all grazed down so no threshold could be determined. The lack of algae was perhaps due to growth being nutrient limited, the cages causing changes to the light or water motion with the plots negatively affecting algal growth, and/or grazing urchins getting into the cages and maintaining the algal biomass at a low level. Also due to the lack of high biomass of algae in the plots, we were not able to address the question as to whether there is a threshold above which algal biomass cannot be cropped down even by an abundance of herbivorous fishes.

We did however obtain interesting results that address one of our project objectives; whether cropping efficiency is dependent on the size of the grazing fish. Our results indicate that larger herbivorous fishes, more specifically large parrotfishes, are key grazers in the reef ecosystem. These large parrotfishes are more efficient at cropping down a standing biomass of algae by means of rasping algae off non-live calcium carbonate substrate compared to even an abundance of small fishes that take smaller non-rasping bites.

Our findings add important evidence to the argument that MPAs, which are empirically proven to promote the size and abundance of large herbivorous fishes (Halpern 2003), may control the dominance of algae, and thus promote a healthy ecosystem. This statement is based on herbivores often being keystone species in facilitating coral settlement and growth by grazing down algae (McClanahan, 1997). This is shown by the reduction in grazing pressure often triggering shifts in community structure, causing coral and crustose coralline algae to be overgrown and excluded by faster growing erect algae. The community structure is subsequently changed from a high diversity coral based ecosystem to a macroalgae dominated system, with decreased genetic-, species- and functional-diversity (Hixon and Brostoff 1981, Moberg and Folke 1999). Grazing pressure not only influences species composition, but also affects the level of productivity, bioerosion, nutrient concentration, succession and a range of other ecological processes (McClanahan 1997, Moberg and Folke 1999, Babcock et al. 1999).

Dissemination of results

Progress and final results of the project have been presented at four HCRI-RP meetings, both on Oahu and in Hawaii. These meetings bring together an audience of fellow scientists from different departments at the University of Hawaii, as well as Federal and State employees from organizations such as DLNR, DAR, NOAA, USFWS, TNC. Since final results for this project were not gathered until a month ago (December 2005) we have waited to present our final findings at other venues until now. We plan for example to share our findings with the general public at the Thursday evening educational gatherings that the Hanauma Bay nature preserve holds. Also, Dr. Charles Birkeland who speaks at a range of meetings and venues will incorporate this data into his workshops and presentations. The results further directly constitute Danielle Jayewardene's PhD dissertation and thus will be presented on numerous occasions throughout her carrier as well as be published in peer reviewed scientific journals. Finally, a colorful pamphlet for outreach purposes will be printed highlighting the important role of large parrotfishes as key grazers in the coral reef ecosystem.

VIII Signature of Principle Investigator ___________________________________

CHARLES BIRKELAND

Bibliography

Babcock R.C., Kelly S., Shears N.T, Walker J.W. and Willis T.J. 1999 *Changes in community structure in temperate marine reserves*, Marine Ecology Progress Series, vol. 189 p. 125-134

Belliveau S.A. and Paul V.J. 2002 *Effects of herbivory and nutrients on the early colonization of crustose coralline and fleshy algae*, Marine Ecology Progress Series, vol. 232 p. 105-114

Birkeland C., Nelson S. G., Wilkins S. and Gates, P. 1985. *Effects of grazing by herbivorous fishes on coral reef community metabolism*. Fifth international Coral Reef Congress, Tahiti. 4:47-51

CRAMP *website http://cramp.wcc.hawaii.edu/* as visited in December 2004

Halpern, B. (2003). *"The Impact of Marine Reserves: Do Reserves Work and Does Reserve Size Matter?"* Ecological Applications, (13): 1.

Hay M.E, Kappel Q.E and Fenical W. 1994. *Synergisms in plant defenses against herbivores: interactions of chemistry, calification and plant quality.* Ecology. 75 (6) p. 1714-1726

Hixon M.A and Brostoff W.N. 1981 *Fish grazing and community structure of Hawaiian Reef Algae.* Proceedings of the fourth international Coral Reef Sysmposium, Manilla. Vol 2, p.507-514.

Jokiel P.L, Brown E.K., Friedlander A, Rodger S.K. and Smith W.R. 2001 *Hawaii Coral Reef Inititive Coral reef Assesment and Monitoring Program (CRAMP)* Final Report 1999-2000

Jones G.P., McCormick M.I., Srinivasan M. and Eagle J.V. 2004 *Coral decline threatens fish biodiversity in marine reserves.* PNAS, Vol 101 p. 8251-8253.

McClanahan T.R. 1997 *Primary succession of coral-reef algae: Differing patterns on fished versus unfished reefs,* Journal of Experimental Marine Biology and Ecology, vol. 218 p. 77-102

McClanahan T.R, Hendrick V., Rodrigues M.J and Polunin N.V.C. 1999 *Varying responses of herbivorous and invertebrate-feeding fishes to macroalgal reduction on a coral reef.* Coral Reefs, Vol 18 p.195-203

Moberg F. and Folke C. 1999. *Ecological goods and services of coral reef ecosystems*, Ecological Economics 29:. 215-233

Smith J.E., Smith C.M. and Hunter C.L. 2001 *An experimental analysis of the effects of herbivory and nutrient enrichment on benthic community dynamics on a Hawaiian reef, Coral Reefs*, vol. 19 p. 332-342
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Williams I.D., Polunin N.V.C. and Hendrick V.J 2001 Limits to grazing by herbivorous fishes and the impact of low coral cover on macroalgal abundance on a coral reef in Belize, Marine Ecology Progress Series, vol. 222 p. 187-196

WHAP website *http://www.coralreefnetwork.com/kona/default.htm*.

Appendix:

Fig. 1: Study sites on Oahu and in west Hawaii.

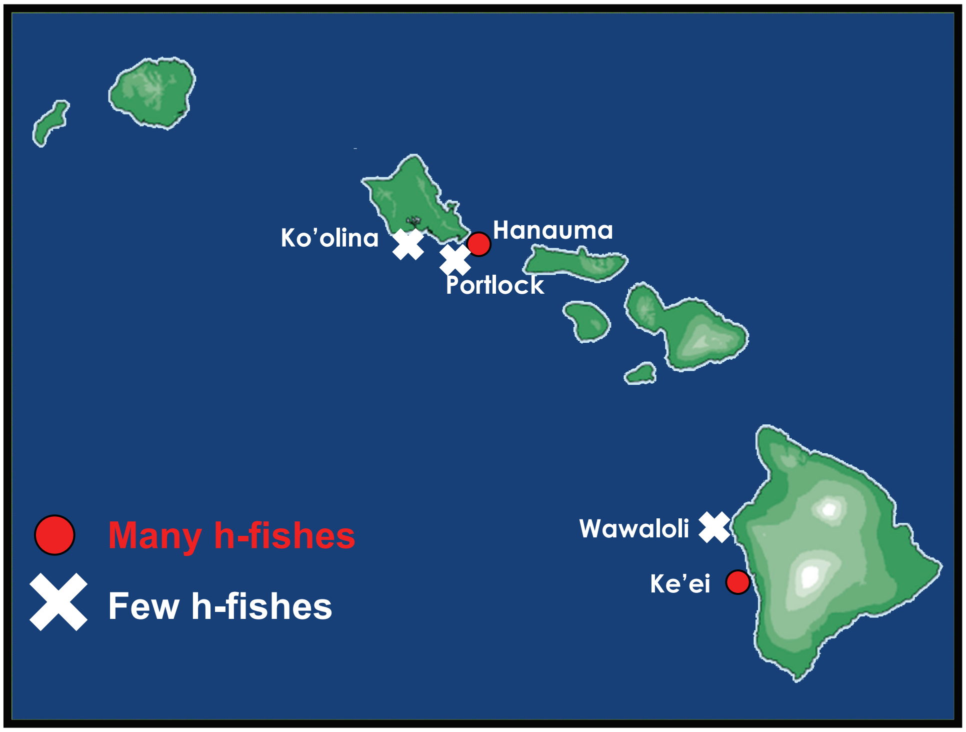

Fig. 2: Random placement of cages/treatments per site.

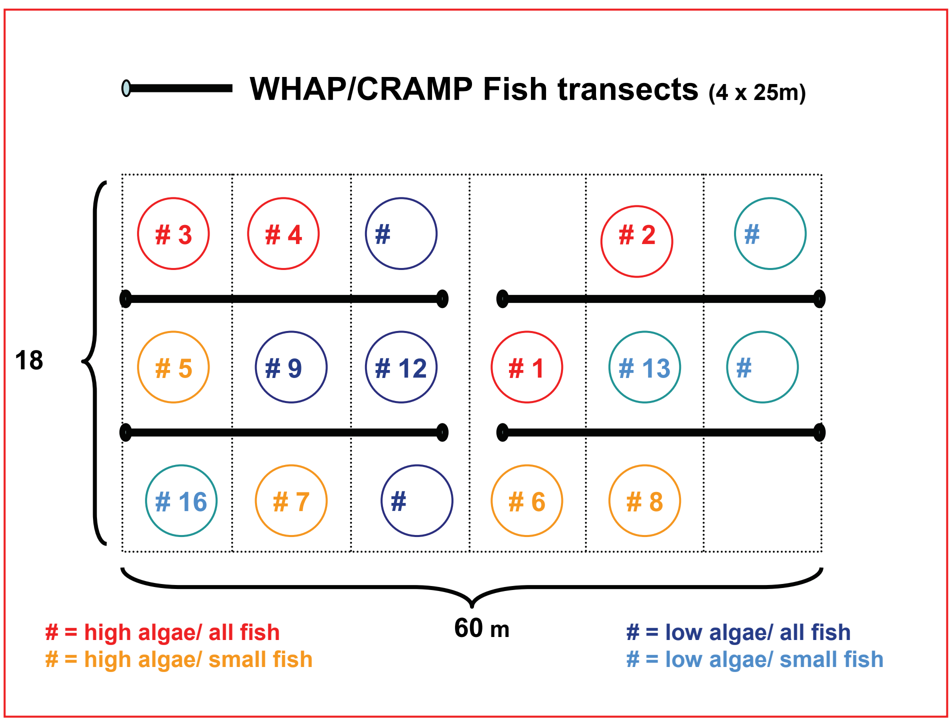

Fig. 3: Percent macroalgal, turf, crustose coralline algal and coral cover at study sites

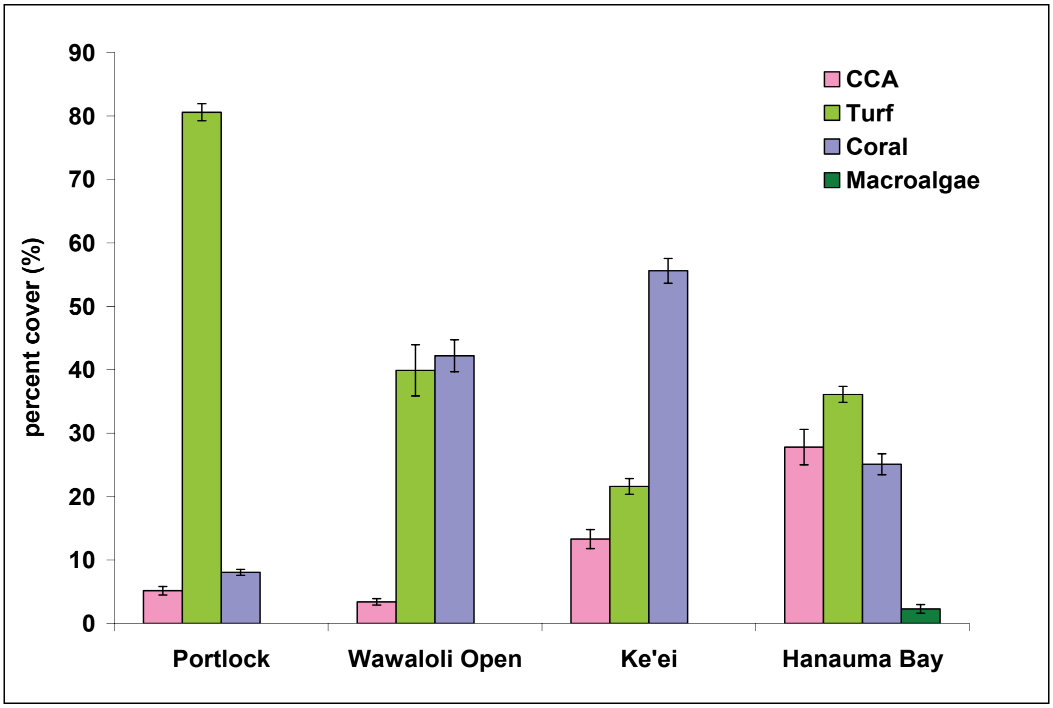

Fig. 4:.Biomass of herbivorous fishes at study sites (*data supplied by WHAP surveys 2003-2004 for Ke'ei and Wawaloli and CRAMP 2000 for Hanauma Bay*).

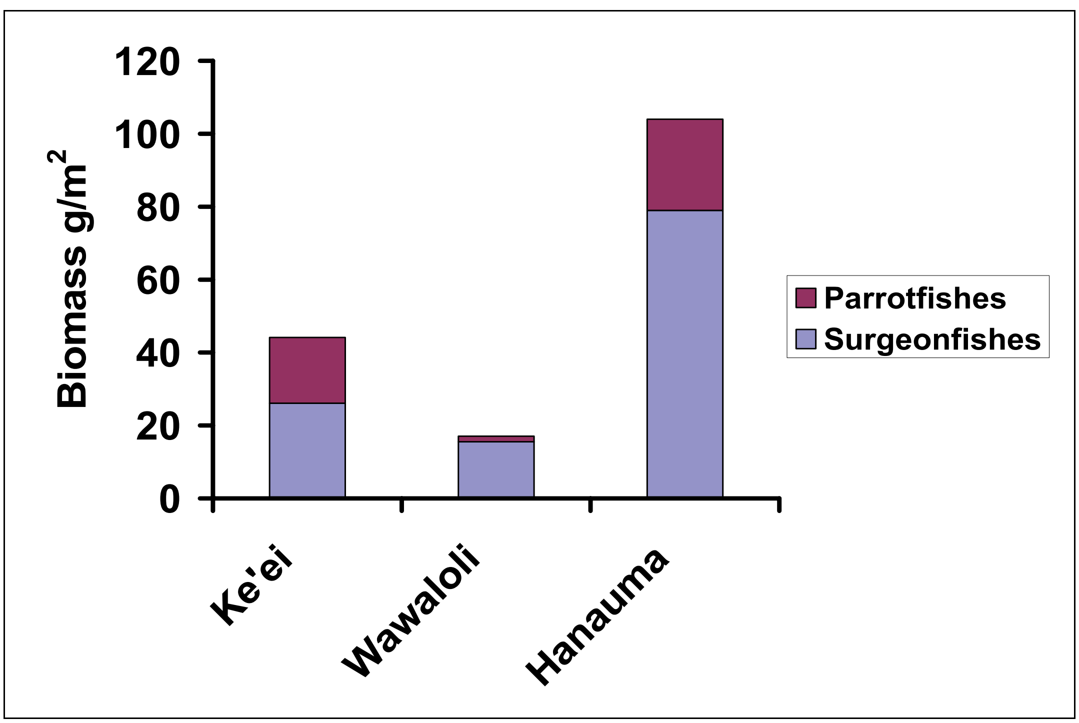

Fig. 5 a-c: Percent cover change of algae over monitoring period, at a) Ke'ei b) Wawaloli and c) Hanauma Bay.

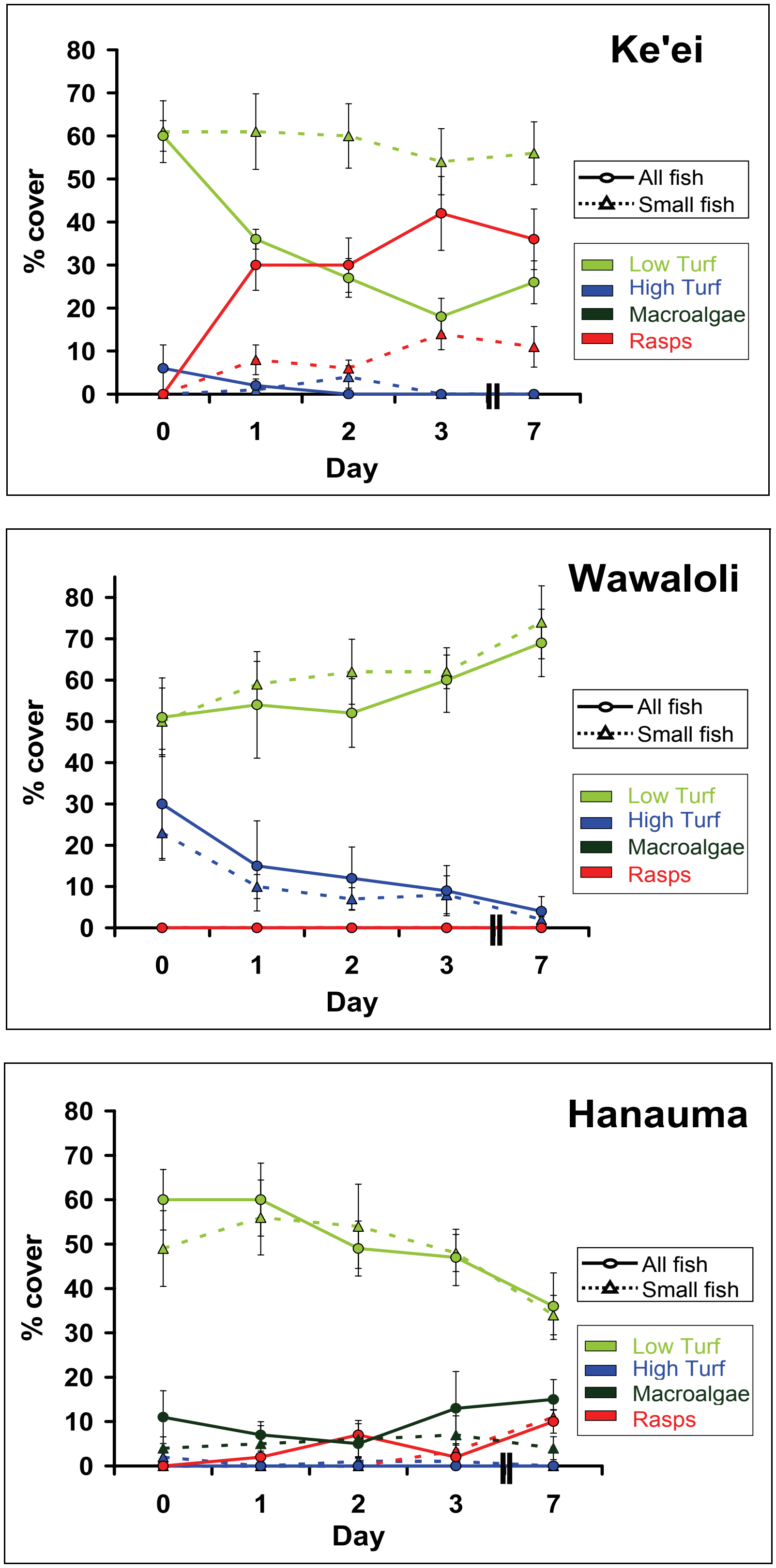

Fig. 6: Total percent cover change of algae (macroalgae, high biomass turf and low biomass turf) over 3 day monitoring period at 3 study sites.

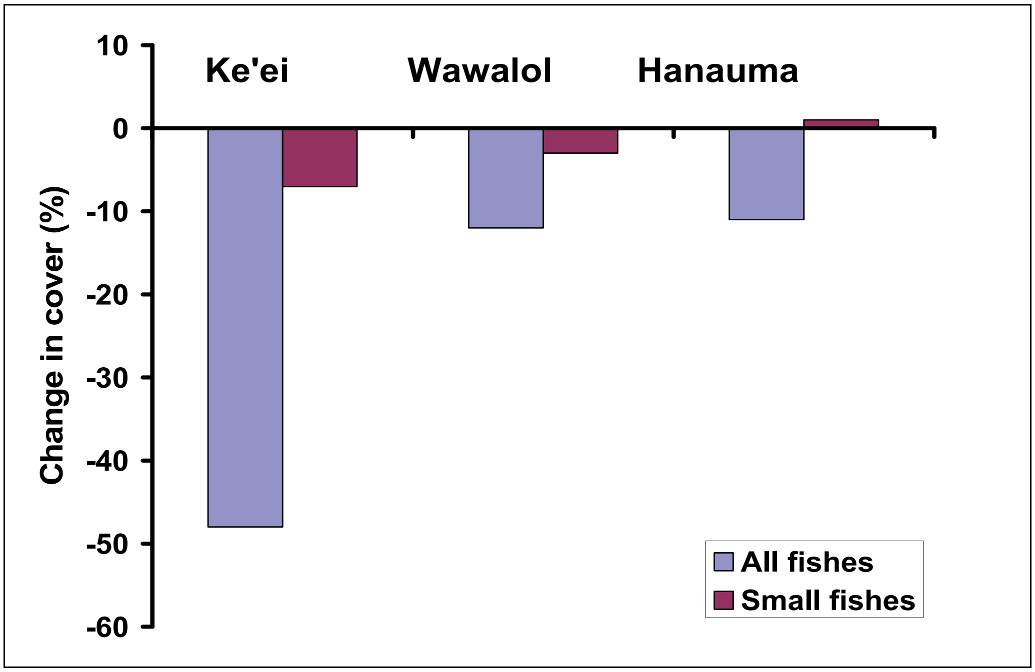

Fig. 7: Example of parrotfish rasps in coral rubble within open experimental plot at Ke'ei.

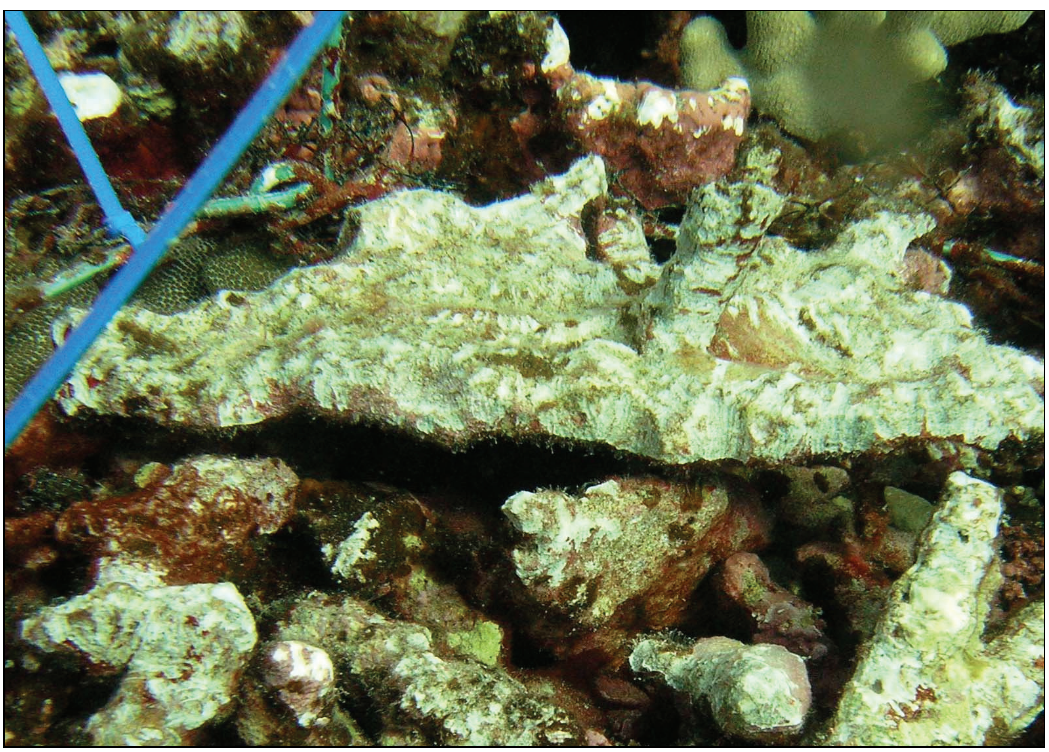

Fig. 8: Study sites at Hanauma Bay MLCD.

Fig. 9: Bite rates for common herbivorous fish species *(data for S. rubroviolaceous and C. perspicillatus has been provided by Ling Ong).*