I. **Project Title:** Integrated Ecosystem Management: Maui
Principle Investigator: Dr. Celia Smith
Project Staff: Meghan Dailer, Darla White, Robin Knox, and Iuri Herzfeld
Organization: University of Hawaii, Manoa
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II. Executive Summary

The State of Hawaii Division of Aquatic Resources has rule changing underway to establish an Herbivore Fisheries Management Area (HFMA) in front of Kahekili Beach Park in West Maui. Reef community structure within the proposed Kahekili HFMA has been surveyed annually by DAR and partners since 1994. Coral cover has been declining since 1999, whereas the abundance of algae has sharply increased, especially the abundance of the invasive algae *Acanthophora spicifera* (DAR, unpublished data). Surveys by DAR in December 2006 demonstrated that herbivorous fish biomass at Kahekili is comparable to that of fish communities at other West Maui reefs that are open to fishing. All open fishing locations average around 40% of the total fish biomass observed in the Honolua Bay MLCD, which is the nearest reef closed to fishing. Based on this severe but far from catastrophic reduction in fish biomass due to fishing, we assume that herbivorous fish stocks at Kahekili would increase should the fishing of key herbivores become regulated. Finally, preliminary discussions between DAR staff and a wide range of resource users, including local fisherman, have shown that all these groups recognize the problems of increased abundance of (invasive) algae and declining reef conditions in West Maui and generally support the establishment of an HFMA at Kahekili through the protection of key herbivores. The Hawaii DAR has submitted a draft rule to the State Attorney Generals (AG) office which is currently under review to establish the Kahekili HFMA. If approved by the AG the rule will be presented at public hearings and then subjected to reviews under Hawaii Administrative Rule processes. Once the Kahekili HFMA is established, it will be a high profile project, and the effectiveness of the project will have a significant impact on DAR's future approach to managing reefs; and possibly even more importantly, successful implementation and performance of the HFMA would give DAR much greater credibility, and therefore greater scope to initiate future proactive management programs. DAR has recognized that the integrated management of the ecosystem involves more than fisheries management. DAR has stated that if steps are not taken to return to conditions under which coral can thrive, that it is nearly certain that additional reefs will reach a state of total system collapse, such as that seen at Ma'alaea. According to "Status of Maui's Coral Reefs" (DAR, HCRI 2008) "Recovery of herbivore stocks may be part of the solution at some locations, but without other steps to reduce land-based impacts there is unlikely to be substantial recovery across the island's reefs."

III. Purpose:

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

This project is concerned with the decadal documentation that increased algal abundance results in the decline of original framework building species such as corals and crustose coralline algae on reefs along the coast of Northwest Maui. This project focuses on the potential causative role of invasive algae in driving such decline to gain insight in the dynamics that cause algae to become abundant and developing practical approaches to restore the environmental conditions under which corals once thrived. This mission corresponds with that of the State of Hawaii's Division of Aquatic Resources (DAR) that in partnership with researchers from the University of Hawaii, local environmental NGOs, and the local community, now prioritizes projects studying the spread and impact of blooms of invasive algae on reef communities along Maui's Northwest coast. In attempts to reverse reef decline in the Kahekili area the Hawaii DAR is in the process of establishing an Herbivore Fisheries Management Area (HFMA) where the taking of key herbivorous fish will be prohibited.

Practical approaches to restoration of environmental conditions under which coral once thrived include the reduction of land-based pollutant loads that have increased sedimentation and nutrient availability in near shore waters. The federal Clean Water Act establishes programs for the management of land-based pollutants from point and non-point sources, as well as the management of water quality to support aquatic life uses (such as coral reef conservation). These programs are implemented by the Environmental Protection Agency (EPA), and the Hawaii Department of Health (DOH). The specific goals of Clean Water Act programs include a national goal of "water quality which provides for the protection and propagation of fish, shellfish, and wildlife, and recreation in and on the water." Specific relevant goals for the state of Hawaii include conservation of coral reefs and maintaining waters that are free from undesirable aquatic life. These Clean Water Act and state water quality programmatic goals clearly align with those of DAR and HCRI with regard to restoring environmental conditions under which coral can thrive.

An integrated, proactive approach to managing coral reef ecosystems is to reduce land-based impacts through enhanced implementation of these existing pollution control and water quality management programs. Implementation is enhanced by greater interagency communication, improved data sharing, education of scientists and government officials, and building local technical capacity. Dissemination of project information to those responsible for pollution control and land use decisions is key to establishing improved implementation of programs designed to maintain and restore the conditions under which coral reefs thrive.

B and C. Detailed description of the question(s) asked to answer the resource management problem(s) and overarching goal(s) of the project

1: Does the closure of the Kahekili to the taking of key-herbivores result in increases of their biomass through time compared to control areas?
2: If herbivore populations recover, is that increased biomass associated with a decline in the distribution and abundance of invasive algae?
3: If the cover of invasive algae declines, does such decline result in increases in coral cover relative to control areas?
4: Does the temporal variation in algal abundance relate to abiotic factors (sedimentation and nutrient availability) and do such factors represent constant or episodic driving forces of algal abundance?
5: How fast do the most abundant algae in the proposed HFMA location occupy and out-compete corals for space and how persistent is their presence once space is occupied or conquered?
6: What herbivores remove the most abundant and invasive algae and are such rates species or size specific?
7: Do corals effectively increase local herbivory rates by preempting space available for algal colonization and growth?
8. Are there microbial indicators of reef health that can be related to land-based sources of pollutants?
9. What are the sources of land-based pollutants (nutrients, sediments/suspended solids, pathogenic organisms) that contribute to undesirable algal blooms and coral reef ecosystem decline?
10. What are pollutant source loading rates (mass/time) and how are they spatially distributed (watershed-based analysis)?
11. Is there a spatial correlation between pollutant sources, watershed-based pollutant loads and coral decline and algal blooms in down-gradient coastal areas?

IV. Approach:

Kahekili FMRA Baseline (addressing Questions 1 - 3)

Completed by: Mark Vermeij (CAMABI), Ivor Williams (DAR), Meghan Dailer (UH Botany), Darla White (UH Botany), Russell Sparks (DAR), John Mitchell (DAR), and Kristy Wong (DAR)

Surveys were conducted in January and August 2008 to establish a baseline of herbivorous fish, sea urchin, and benthic composition for the Kahekili HEA. In January and August a total of 89 and 69, respectively, 25m transects (Figure 1) were surveyed for herbivore populations and benthic composition. In January the sites were distributed with replicate sites within 3 depth ranges as follows: 1.5-3m (n= 30; shallow fore reef), 4-8m (n= 40; mid-depth fore reef) and 8.5 -10m (n= 19; deep fore reef). Herbivorous fish and sea urchins were surveyed by pairs of divers swimming side-by-side down transect lines. Divers recorded the number and size (in 5cm size intervals, e.g. 0-5cm; 5-10cm, etc…) of all herbivorous fishes and sea urchins were counted by species. During each survey, all herbivorous fishes >10cm total length (TL) were counted swimming within or directly above a 5m-wide belt on the outward swim, and all herbivorous fishes

<10cm TL and grazing urchins within a 2m wide belt on the return swim. Benthic surveys were comprised of 17 random photoquads (0.5m x 1.0m) per 25m transect (1,513 and 1,173 total photoquads in January and August respectively).

The photoquads from the January survey were analyzed with PhotoGrid software with 50 random points per picture which were identified by substrata (i.e. turf, limestone, sand, coral rubble, and basalt) or systematically (i.e. *genus species* for coral, algae, and sea urchins); the data are currently presented as percent of functional group (turf algae, algae, other, urchins, invertebrates, sand, crustose coralline algae (CCA) and coral) per site in Figure 2. The benthic composition of the August survey is currently being analyzed and once completed the benthic composition and herbivore abundance from both baseline surveys will be analyzed with Statisitca software for the following correlations: the presence of (1) coral (by species), (2) coral rubble, and (3) turf algae; with (A) total herbivore (fish and sea urchins) biomass (B) herbivorous fish biomass alone and (C) number of sea urchins.

Temporal variation in algal abundance potentially due to abiotic factors (addressing Question 4)
To be completed by: Iuri Herzfeld (UH Botany), Meghan Dailer (UH Botany), and Darla White (UH Botany)

Water column nutrients overlying the reef and interstitial water in the sediments will be sampled at three of the six locations where DAR conducts fish and benthic surveys every 3-4 months. Standard sediment traps (n= 6) and continuous temperature loggers (n= 1) will also be installed at these locations. The overlap of DAR sites with these measurements ensures that local characteristics of the biotic community can be related to these potentially important structuring factors, even within the proposed FMA (or control areas). Both nutrients and sedimentation are sampled at frequent (e.g. 2 week) intervals to account for the possibility that short-lived structuring events such as nutrient pulses or intensive sedimentation events are more important than gradual or constant environmental factors in structuring the reef community on West Maui reefs.

Small Scale Spatial Interactions (addressing Question 5)
Completed by: Mark Vermeij (CAMABI) and Meghan Dailer (UH Botany)

To determine how fast the most abundant algae in the proposed FMRA location occupy and out-compete corals for space and how persistent their presence is small scale (30 x 30cm) interactions between (1) coral and turf algae, (2) coral and crustose coralline (CCA) and (3) coral and algae were marked with numbered zipties and photographed every 4 weeks for 5 months. 245 interactions were initially designated a number for monitoring, approximately 20 have been lost to large swell events. We plan to analyze these interactions with Adobe Photoshop to calculate the percent cover change of the specific interaction (i.e. percent of coral or CCA lost to turf or macroalgae). Data will be analyzed with Statistica software for significant changes in composition. Examples of these small scale interactions are presented in Figure 3.

Herbivorous Fish Surveys (addressing Question 6)
Partially completed and ongoing: by Darla White (UH Botany) and Volunteers

In order to determine which herbivores remove the most and invasive algae, and if the rates are species or size specific, a team of volunteers from the local community led by Darla White have been collecting herbivore grazing rate data on fishes from three families: *Acanthuridae*, *Scaridae*, and *Kyphosidae*. The observations are based on bites per minute on macroalgae, turf algae, invasive algae (and if so, what kind), live coral, sand, and other (including crustose coralline algae, detritus, etc). Fish species, size, substrate type, depth, and behavior were recorded to address our questions.

Surveys were subject to ocean conditions and good water visibility. Multiple presentations and training events have been given in both South and West Maui and at Maui Community College (MCC) in an effort to recruit more volunteers. Training and recruitment has been needed every two to three months.

Assessment of local herbivory rates in differing areas of coral cover (addressing Question 7)
To be completed by: Meghan Dailer and Darla White

An array of macroalgae representing different species (n=10 per species) will be collected, weighed and attached to an anchored PVC frame deployed at locations harboring different combinations of herbivore biomass and coral cover. Algal samples will be left exposed and available to local herbivores for four days after which they will be recovered and weighed again. Their reduced biomass is indicative of herbivore intensity which, under similar herbivore community composition, is expected to increase with increasing coral cover. Should this expectation be confirmed, high coral cover (as well as those factors that contribute to it) would provide a route (in addition to restoring herbivore communities) to oppose local increases in algal biomass.

Microbial survey (addresses question 8)
(To be completed by Robin Knox, Meghan Dailer, Darla White and collaborators (TBD))
Conduct an initial survey of marine microbial populations in near shore waters using microbial source tracking techniques such as such as quantitative polymerase chain reaction and standard microbial assays for indicators of sources and pathogens. The survey will look at indicators currently used in water pollution control programs (Enterococcus) and those proposed for future use in Hawaii (Clostridium perfringens). The survey will also look for the pathogenic organisms that maybe correlated to the indicator species.

Wastewater inventory (addressing questions 9-11 for point sources of pollutants) (To be completed by Robin Knox and Darla White)

An inventory of land-based wastewater sources on the island of Maui that are sources of nutrients contributing to algal blooms and coral reef ecosystems decline will be developed from readily available existing sources of information including that maintained by EPA, DOH, and County of Maui. The inventory will include known information about sources of wastewater including cesspools, individual wastewater treatment systems, publicly-owned treatment works, industrial wastewater treatment, contaminated stormwater; and other wastewaters disposed of via surface water discharge, reuse or injection wells. The inventory will include location, effluent flow rate, level of treatment, and method of disposal. Wastewater source locations will be mapped for spatial comparison to locations of algal blooms or coral reef decline. Based on spatial analysis, gross wastewater nitrogen loading estimates will be developed for selected watersheds of interest.

V. Kahekili FMRA Baseline Results to date (see below for results from additional studies):

The completed January and August baseline surveys are mapped in Figure 1. The benthic composition of all January surveys is presented in Figure 2. The datum obtained for the completed abovementioned questions are currently being prepared and analyzed. An interesting observation from the small spatial scale interaction study is presented in Figure 3, which shows the loss of crustose coralline algae (CCA) to turf and subsequent coral tissue loss. Many examples of this were observed during the study which strongly implies that the ability of turf algae to overgrow both CCA and corals is largely underestimated and a strong factor in coral decline at Kahekili in the proposed HEA location.

Kahekili FMRA Herbivore Grazing Survey Results to date

Over the course of the past year, Darla White held eight training workshops for the herbivore grazing survey, and three public talks on the importance of herbivores on the reef. In 2008, a total of 47 herbivore grazing surveys were held with the participation of more than 70 community members (Figure 4). The total volunteer time of the 47 surveys was 950 hours. The analyses of the herbivore grazing surveys are not completed at this time and the results will be included in the final report.

Microbial Survey Progress to date

A literature review has been commenced to identify target organisms and methods. We are currently working on arrangements with Hawaii Institute of Marine Biology and Maui Community College for analytical and laboratory capacity**.** A sampling and analysis protocol is under development.

Wastewater Inventory Results to date

Additional studies (see below) identified sewage sources as a factor in nutrient enrichment contributing to algal blooms. In November 2008, data queries were initiated to identify the number, location, flow rate, and treatment level of wastewater sources on Maui. Preliminary data has been mapped but not independently verified (Figures 5 to 8). Wastewater flow and total nitrogen data from the three county of Maui wells have been received and are being analyzed to develop total nitrogen loading estimates for those sources.

VI. Dissemination of Project Results:

Results will be published in a peer reviewed scientific journal, presented at governmental (Maui County Council), community (NOAA Sanctuary lecture series), community council (Maui Nui Marine Resource Council), and University (Maui Community College, University of Hawaii, Manoa) based venues, and published in local newspapers including the Maui News and Lahaina News.

VII. Additional Studies

Examining $\delta^{15}N$ values of intertidal macroalgae on Maui to identify locations and potential sources of nutrient enrichment

Meghan Dailer (UH Botany), Celia M. Smith (UH Botany), Jennifer E. Smith (USD, Scripps Institute), and Donna Brown (MCC) *Supported By EPSCoR* and HCRI.

Since nitrogen is often limiting in marine environments, macroalgae will utilize nitrogen from additional sources such as land based fertilizers and sewage effluent when available. These sources of additional nitrogen entering the ocean are often difficult to detect with basic water quality assessment tools (ambient nutrient and salinity measurements) because the ocean is a dynamic environment where currents, wave action and general mixing events dilute potentially elevated nutrient levels. However, natural stable isotopes of nitrogen (^{15}N:^{14}N, expressed as $\delta^{15}N$) have been used to detect anthropogenic nitrogen loading because nitrogen sources have distinct $\delta^{15}N$ signatures (Umezawa et al. 2002, Lin et al. 2007, and Gartner et al. 2002). For example, sewage derived wastewater $\delta^{15}N$ signatures range from 11to 25‰, and can be as high as 38‰ (Savage and Elmgren 2004). The $\delta^{15}N$ values of macroalgae growing directly in front of sewage outfalls are often highly enriched with values ranging from 9 to 15‰ (Lin et al. 2007, Gartner et al. 2002, and Costanzo et al. 2001). Because macroalgae continuously utilize new nitrogen from their environment their $\delta^{15}N$ values are an integration of all nitrogen sources available to them. It has been suggested that since these sources are integrated over time, the $\delta^{15}N$ values of macroalgae are more useful in detecting anthropogenic sources of enrichment than monitoring nitrogen levels in the water column (Umezawa et al. 2002, Gartner et al. 2002).

In the summer of 2007, a survey of intertidal macroalgal $\delta^{15}N$ values from all accessible coastlines on Maui (130 sites, over 600 samples) was conducted to locate areas and potential sources of anthropogenic enrichment. This survey shows that average macroalgal $\delta^{15}N$ values generally reflect the areas exposure to anthropogenic impact (Figure 9). Low impact areas (i.e. Olowalu, La Perouse, Nahiku and Haleakala National Park) ranged from 0 to 3‰ (blue circles) while developed areas such as Waiehu, Kahului, Kihei, Wailea, and Kaanapali have enriched values ranging from 6 to11‰ (yellow circles). The elevated $\delta^{15}N$ values in the 6 to 11‰ range are above background levels and potential sources of enrichment in these areas include but are not limited to runoff from the use of fertilizers and/or reclaimed water for irrigation and leakage from septic tanks and cesspools and merits further investigation. Heavy $\delta^{15}N$ signatures (≥18‰ orange and red circles) correspond to areas with a sewage injection a well (i.e. Kahului, Kihei and North Kaanapali) which shows that the injected reclaimed water is percolating into the near shore marine environment.

Fine scale mapping of injection well plumes in Kahekili and Kihei using a multi-parameter approach Meghan Dailer (UH Botany), Darla White (UH Botany), Celia Smith (UH Botany) and Chip Hunt (USGS)

Because the previous study was able to successfully detect areas of anthropogenic concern due to the presence of elevated $\delta^{15}N$ values, an additional study was conducted in early May 2008 in collaboration with the US Geological Survey to map the injection well plumes in Kahekili and Kihei with the following parameters: (1) $\delta^{15}N$ in macroalgae, (2) temperature, (3) salinity, (4) turbidity, (5) dissolved oxygen (6) pH, (7) chlorophyll a (8) fluorescence (9) conductivity (10) $\delta^{15}N$ of water column samples, (11) nutrient concentrations of water column samples (12) waste indicator compounds of water column samples and (13) pharmaceuticals. All sampling occurred in the intertidal along approximately 2km of coastline spanning the waste water treatment plants in both Kahekili (Figure 10) and Kihei (Figure 11).

Macroalgae were collected in triplicate from 30 sites in Kahekili and Kihei (Figures 10 and 11). The abovementioned parameters 2 through 7 were determined using instrumental trolling via wading transects with a Hydrolab. Florescence and conductivity were determined with 20 water column samples from each injection well plume area. Ambient water $\delta^{15}N$ values and nutrient concentrations were determined with 10 water column samples from each area, 4 of which were also used to detect pharmaceuticals and 1 of which was used to detect waste indicator compounds (i.e. soaps, fragrances, and mosquito repellants). A previous study by S. Dollar (1998) of the nuisance algal blooms along Kihei and West Maui captured multispectral aerial imagery highlighting the *Hypnea* and *Ulva* signals in the near shore areas. The first of these images were scanned and georeferenced in a GIS for spatial visualization of the blooms in relation to land based features. The existing imagery for Kihei was completed (Figures 12 to 14), and the remaining imagery for West Maui will be completed in the coming months.

The Kahekili area has provided a number of interesting observations during the surveys. The shallow fore reef area (approximately 5 to 30 feet offshore) harbors algae blooms (primarily *Ulva fasciata*) in the summers, when the large north swells are no longer persistent and the south swells are fewer and farther between

(Figure 10). This area also frequently has bubbles flowing from the benthos and warmer-than-ambient-water fresh water seeps (Figure 10). The two seeps labeled in Figure 10 are consistently present and are surrounded by rocks and coral rubble with black precipitates. The black precipitate is currently being analyzed, but is most likely iron oxide which arises from anoxic conditions in the groundwater. We are still awaiting laboratory analysis of the samples collected from this study.

Investigating the physiological response of *Hypnea musciformis* to additions of reagent grade Nitrogen and Phosphorous Meghan Dailer and Celia Smith (UH Botany)

A nutrient enrichment experiment was conducted to explore the effects of Nitrogen (N) and Phosphorus (P) independently and in combination on the growth and photosynthetic properties of *Hypnea musciformis.* In this experiment, separate samples (n=9, per treatment) of *H. musciformis* were grown in an outdoor aquarium system in individual aerated 1.0L beakers under one of the following nutrient treatments for seven days: (1) No Addition, (2) Mid Phosphorus (MP: 0.5µMPO_4), (3) Mid Nitrogen (MN: 40.0µMNH_4), (4) MNMP (40.0µMNH_4 and 0.5µMPO_4)(5) High Phosphorus (HP: 1.0µMPO_4), (6) High Nitrogen (HN: 80.0µMNH_4), and (7) HNHP (80.0µM$NH_{4,}$ 1.0µMPO_4). On Days 0 and 7 samples were weighed (wet weight) and assessed for (1) photosynthetic status, Relative Maximum Electron Transport Rate ($RETR_{MAX}$) and (2) Photosynthetic Saturation Irradiance (E_K) with a Pulse Amplitude Modulated (PAM) fluorometer (Diving PAM, Waltz). The water in each 1.0L beaker was changed every day of the experiment to maintain the desired nutrient concentrations.

The response of *Hypnea musciformis* on Day 7 to the abovementioned treatments is visually displayed in Figure 15 where the coloration of plants given any combination of N is clearly distinct from those lacking N addition. In fact this change in color from dark purple to tan is nearly complete by Day 4. The fact that *H. musciformis* maintains phycobilin pigmentation (dark purple color) only when given nitrogen allows for the potential to use this plant as an indicator species of elevated nitrogen levels. Surprisingly, there were no significant differences of growth between the No Addition treatment and any other treatment. The highest sustained $RETR_{MAX}$ and E_K values were observed in the MNMP and HNHP treatments on Day 7. The E_K values of samples in the MNMP and HNHP treatments were significantly higher than all other treatments on Day 7.

This study documented how rapidly *H. musciformis* responded to elevated combined N and P conditions with increases in pigmentation leading to increased photosynthetic capabilities. These findings confirmed the expected requirement of both N and P to sustain increases in photosynthesis. The surprising lack of significant differences among growth rates between the No Addition and other treatments initiated many additional nutrient enrichment experiments with N, P, and Iron (Fe) in every combination as well as different light treatments. None of those experiments produced the growth rates observed in the field supporting nuisance algae blooms.

Investigating the response of *Hypnea musciformis*, *Ulva fasciata*, *Acanthophora spicifera*, and *Dictyota acutiloba* to secondarily-treated sewage effluent Meghan Dailer and Celia Smith (UH Botany)

The abovementioned Maui coastline survey of intertidal macroalgae successfully detected elevated $\delta^{15}N$ values of samples that were likely influenced by sewage effluent percolating into the near shore marine environment in certain areas. Yet we were unable to reproduce observed growth rates of plants in the field while conducting laboratory reagent grade nutrient enrichment experiments. For this reason, we pursued the response of bloom species and non-bloom species to secondarily treated sewage effluent. *Hypnea musciformis* (invasive, bloom forming), *Ulva fasciata* (native, bloom forming), *Acanthophora spicifera* (invasive, bloom forming), and *Dictyota acutiloba* (native, common across all of Hawaii but not bloom forming).

All species were separately subjected to a series dilution experiment to determine their response to sewage effluent in terms of growth, photosynthetic status, $\delta^{15}N$ values, and nutrient uptake rates. In addition, we planned to determine if the tissue composition (C:N:P) of the plants are representative of the surrounding available nutrient concentrations, and what micro-nutrients (Zinc, Iron, Molybdenum, Manganese, Magnesium, and Copper) limit photosynthesis and growth in these species. Samples were subjected to the following 7 treatments (n = 6 per treatment): (1) No Addition, (2) 25ml L^{-1}, (3) 50ml L^{-1}, (4) 75ml L^{-1}, (5) 100ml L^{-1}, (6) 150ml L^{-1}, and (7) 200ml L^{-1} of sewage effluent. Treatments for each sample were created every day with (1) water from Olowalu (area of low anthropogenic impact), (2) the corresponding sewage effluent addition (obtained from the Lahaina Wastewater Treatment Plant) and (3) the appropriate addition of natural sea salt to return the salinity to oceanic levels (32 ‰, confirmed with a Mettler Toledo Seven Multi meter (calibrated with Mettler Toledo conductivity standards). Trials lasted for 9 days with the following sampling and measuring design. On Days 0 and 9 samples were first measured with Pulse Amplitude Modulated (PAM) fluorometry for photosynthetic parameters (1) Relative Electron Transport ($RETR_{MAX}$), (2) Photosynthetic Saturation Irradiance (E_K), and (3) Photosynthetic Efficiency (Alpha) then weighed. Samples were prepared in triplicate per treatment for $\delta^{15}N$ and tissue nutrient analysis on Days 0 and Day 9. To determine that the sewage effluent additions remained consistent during the study samples for water chemistry analysis were collected in triplicate per treatment on Days 0 and 8 for analysis of the following macro and micro nutrients: Total Organic Carbon (TOC), Total Nitrogen (TN), Total Phosphorous (TP), Nitrate (NO3), Iron (Fe), Molybdenum (Mo), Manganese (Mn), and Copper (Cu). Nutrient uptake rates were determined in triplicate per treatment over a 24 hour time period by collecting water samples on Days 8 and 9 from the same samples at the same time.

Summary of Results
Samples of *Hypnea musciformis*, *Acanthophora spicifera* and *Ulva fasciata* visibly change with distinct increases in pigment in only six days (Figures 16-19). Highly significant differences in the Relative Growth Rates (RGR) (Figure 20) between Days 0 and 9 were found between the No Addition and all treatments above 25 and 50 ml L^{-1} for *H. musciformis* and *U. fasciata*, respectively, while no significant difference was found among any treatment for *A. spicifera* or *D. acutiloba.* In addition, the RGRs of *H. musciformis* and *U. fasciata* from the 50 ml through the 200 ml L^{-1} additions were significantly higher than those of *A. spicifera* and *D. acutiloba*. This shows that in terms of growth, *H. musciformis* and *U. fasciata* similarly respond to excess nutrients more positively and faster than *A. spicifera* and *D. acutiloba.*

The Nitrogen content (in milligrams per gram) of *Hypnea musciformis* samples in response to the following conditions: to in situ Waipuilani Beach Park bloom status, Acclimation to water from Olowalu for 7 Days, No Addition of sewage effluent and additions of sewage effluent from 25 to 200ml L^{-1} is presented in Figure 21. This shows that *H. musciformis* responds or acclimates to low nutrient water by significantly losing Nitrogen content. *H. musciformis* then responds to excess Nitrogen by increasing in phycobilin pigmentation (turns a dark purple color) subsequently increasing Nitrogen content. No significant difference was found between treatments above 75 ml L^{-1} and the Waipuilani Beach Park bloom status.

The $\delta^{15}N$ values of *Hypnea musciformis* samples in response to the following conditions: to in situ Waipuilani Beach Park bloom status, Acclimation to water from Olowalu for 7 Days, No Addition of sewage effluent and additions of sewage effluent from 25 to 200ml L^{-1} is presented in Figure 22. No significant difference was found between the Waipuilani Beach Park bloom status, Acclimated samples and the No Addition treatment. A significant increase in $\delta^{15}N$ values occurred when samples were subjected to as little as 50ml L^{-1} of sewage effluent and these values were significantly lower than those found in the additions of 100 to 200ml L^{-1}. This shows that when *H. musciformis* acquires new Nitrogen from the surrounding environment the $\delta^{15}N$ is representative of the source of the new Nitrogen.

The nutrient concentrations on Day 8 and accompanying nutrient removal on Day 9 by *Hypnea musciformis* are presented in Figures 23 to 26. On Day 8, significant increases in concentrations occurred with higher additions of sewage effluent with the following nutrients: Total Nitrogen (TN), Nitrate (NO_3), Ammonium (NH_4), Total Phosphorous (TP), Manganese (Mn), and Iron (Fe). In 24 hours 1.3g of *Hypnea* in the 200ml L^{-1} Treatment used the following levels of macro and micro nutrients: 39.61 µM TN, 38.3µM NO_3 , 7.8 µM NH_4, 2.57µM TP, 8.92 ppb Mn, 2.00 ppb Fe, 7.9 ppb Zn, and 7.3 ppb Mo. In 24 hours 100% of the following nutrients were removed: Ammonium, Total Phosphorous, Iron (in exception of the 100ml treatment), Zinc, and Molybdenum (with the exception of the No

Addition treatment). This shows that in only 24 hours *H. musciformis* is capable of greatly reducing the available nutrients in the water and merits reconsideration of standard water column nutrient testing in bloom areas.

Overall Summary
Nuisance algal blooms of the red alga *Hypnea musciformis* and the green alga *Ulva fasciata* are problematic in shallow coastal waters around urbanized regions of Maui. The Kahekili area is an area of problematic algal growth and substantial reef decline. Kahekili has the highest macroalgal $\delta^{15}N$ values on Maui, which strongly indicates the presence of sewage effluent in the near shore marine environment. Sewage effluent contains elevated levels of many nutrients, some of which are important for algal growth and photosynthetic needs. From laboratory studies with reagent grade nutrient enrichment, we see that Nitrogen and Phosphorous play important roles in the photosynthetic needs of *Hypnea musciformis*, but are unable to promote excessive growth by themselves. Our sewage effluent addition experiments resulted in growth rates similar to those observed in bloom situations for both *H. musciformis* and *Ulva fasciata*, which were significantly higher with increasing levels of sewage effluent, whereas no significant difference was found between treatment for *Acanthophora spicifera* and *Dictyota acutiloba.* Therefore, in terms of growth, *H. musciformis* and *U. fasciata* similarly respond to excess nutrients more positively and faster than *A. spicifera* and *D. acutiloba*. Additional results from the sewage effluent addition experiments were that (1) *U. fasciata* requires fewer nutrients to increase photosynthetic performance ($RETR_{MAX}$) than what is required for both *H. musciformis* and *A. spicifera*, (2) *U. fasciata* is more sensitive to decreased nutrient conditions in terms of photosynthetic efficiency (Alpha) than all other species tested, (3) all species, except for *D. acutiloba*, positively respond to excess nutrients in terms of building photosynthetic capacity (E_K) and *U. fasciata* is the most responsive, and (4) the native, non-bloom forming reef plant *D. acutiloba* does not enhance photosynthetic properties in the presence of elevated nutrients, and naturally has higher photosynthetic efficiency than bloom forming algae. Substantial decreases in Nitrogen, Phosphorous, Iron, and Molybdenum were found over a 24hr time period in the *H. musciformis* experiment, which displays the ability of this species to utilize substantial levels of these nutrients in a short amount of time. In addition, these experiments present the importance of considering more stringent limits on the total allowable daily loads of algal growth promoting macro and micro nutrients, such as Manganese.

Watershed Assessments Watershed assessments are on going in order to answer the following questions:

1. What are the existing laws, regulations, policies and procedures that govern water quality management and pollution control, and how can implementation of existing programs be enhanced to reduce land-based pollutant loads and restore water quality conditions under which corals can thrive?

2. What physical factors (e.g., groundwater movement, ocean mixing conditions, and runoff rates) contribute to the "critical conditions" under which the pollutant load causes unacceptable impacts to aquatic ecosystems?

Watershed planning
Provide local technical capacity to facilitate watershed planning including identification of nonpoint sources of sediment, nutrients, and bacteria, development of loading estimates, and implementation plan for best management practices for load reductions.

Policy Analysis
The policy analysis will identify existing laws, regulations, policy and procedures at federal, state, and county levels that govern water quality management, and control of point and nonpoint source pollution. The analysis will identify common goals and key procedural or decision-making opportunities where interagency sharing of information and expertise, or integration of management activities can enhance pollutant load reduction. The analysis will also identify areas where project information can be used in management programs, and identify questions that managers need to have answered by project research.

Identify Critical Conditions for Pollution Control Strategies
Successful strategies for controlling pollution need to be targeted toward the critical conditions under which impacts are occurring. Monitoring of physical factors such as wind, waves, currents, temperature and salinity concurrently with biological monitoring at Kahekili will develop understanding of conditions under which it is most critical to control pollutant loads.

Watershed Planning Results to date
Robin Knox provided local technical capacity to the following efforts:

West Maui Watershed Planning

- Meeting with Wes Nohara (West Maui Soil and Water Conservation District and John Astilla (Natural Resource Conservation Service to scope proposal for DOH grant funding for watershed planning under Clean Water Act Section 319 (8/28/08)
- Meeting with Board of Directors, West Maui Soil and Water Conservation District to discuss DOHG grant proposal (09/08/08)
- West Maui Watershed Plan Stakeholders meeting (scoping meeting with US Army Corps of Engineers for West Maui Ecological Restoration project) (11/13/08)

Southwest Maui Watershed Planning

- Monthly meetings (July – November 2008) with Central Maui Soil and Water Conservation District and Southwest Maui Watershed Advisory Group to work DOH grant proposal for watershed planning

- Meeting with DOH and Central Maui Soil and Water Conservation District representative to review contract, scope of work, and budget for watershed planning grant (11/13/08)

Policy Analysis Results to date

Policy analysis was driven by a series of opportunities to present project information to regulators and decision makers.

Wastewater disposal policy was analyzed in the context of review of the EPA proposed Underground Injection Control (UIC) permit for the County of Maui Lahaina Wastewater Reclamation Facility injection wells. It was determined that the UIC regulatory program, which is under the Authority of the Safe Drinking Water Act, does not consider impacts to aquatic life uses in receiving water ecosystems, but is instead focused on human health and protection of drinking water supplies. Project research on the role of nutrient enrichment from sewage sources ((see additional studies below), formed the basis of a compelling regulatory argument for imposing water quality-based effluent limits under authority of the Clean Water Act. (See Appendix A- Robin Knox Comments on Lahaina, HI WWRF UIC Permit Number HI50710003).

Water Quality Management Policy was analyzed within the context of Integrated Water Quality Reporting. The Clean Water Act requires DOH to inventory water quality, identify impaired waters where uses are not attained, and prioritize water bodies for actions including reduction of point and nonpoint source pollutant loads. A workgroup convened by DOH and facilitated by Robin Knox, included team member Meghan Dailer, and representatives of the DAR. The purpose of the workgroup was to develop new methods for the state to assess attainment with state water quality standards. Past assessments have relied heavily upon comparison of water column chemistry to numerical criteria. The workgroup proposed a methodology that expands the assessment to include metrics designed to assess attainment of specific uses, such as conservation of coral reefs. The new methodology will allow water quality managers to better incorporate data from sources such as the Coral Reef Assessment and Monitoring Program when assessing attainment of uses and establishing priorities for monitoring and pollution control. The results of the project studies on use of $\delta^{15}N$ values to identify locations and potential sources of nutrient enrichment, and the response of *Hypnea musciformis*, *Ulva fasciata*, *Acanthophora spicifera*, and *Dictyota acutiloba* to secondarily-treated sewage effluent were identified as having potential to be developed as an assessment tool within the proposed methodology. The project report and draft assessment methodology are currently under DOH internal review.

Critical Conditions

Initial discussions of physical factors which influence assimilation and or mixing of pollutants in the environment were included in the EcoHAB Nuisance Algal Bloom Workshop held December 9-10, 2008. The steering committee is currently preparing conclusions and recommended actions based on that workshop. Those recommendations should be reviewed to give further direction to this aspect of the research.

VI. Dissemination of Results from the Additional Studies (both Governmental and Public):

Presentation of Results by Meghan Dailer:

August 2008: Maui Nui Marine Resource Council
November 2008: Maui Nui Marine Resource Council
Maui Community College, Marine Options Program
December 2008: Maui County Council, Water Resources Subcommittee
Maui Algal Blooms Meeting, EcoHAB, University of Hawaii

Press Release following County Council presentation:
Maui News, December 2, 2008 by Harry Eager
http://www.mauinews.com/page/content.detail/id/511895.html

Informational Meetings provided by Meghan Dailer

July 2008

Wendy Wiltse, US Environmental Protection Agency, Pacific Islands Contact Office
David Penn, TMDL Coordinator, State of Hawaii, Department of Health

August 2008

David Taylor (Chief), Steve Parabicoli, Maui County, Wastewater Reclamation Division
John Summers, Administrator, Maui County, Long Range Planning Division

September 2008

Michelle Anderson, County Council Councilwoman, Chair of Water Resources Subcommittee

November 2008

Nancy Rumril, US Environmental Protection Agency, Groundwater Office Region 9

December 2008

Bill Frampton, Developer, Frampton and Ward, LLC
John Summers, Administrator, Maui County, Long Range Planning Division

Public Testimony:

November 6, 2008

Public hearing on the permit for Underground Injection Control of secondarily treated wastewater from the Lahaina Wastewater Treatment Plant.

Press Release following the LWTP UIC Permit Public Hearing
Haleakala Times, November 12, 2008 by Eve Clute
http://www.haleakalatimes.com/2008/11/12/maui_s_message_to_epa_don_t_inject_redirect/

Informational Meetings attended by Robin Knox
July 2008
DLNR Office of Conservation and Coastal Lands re: Beach Nourishment projects (impact to water quality and benthos)
Central Maui SWCD, Southwest Maui Watershed Advisory Group
Maui Nui Marine Resource Council – Clean Water Act Role in Protecting Coral Reefs and Fisheries

August 2008
West Maui SWCD, Natural Resource Conservation Service

September 2008
DOH Integrated Water Quality Workgroup Meeting
DIRE (Don't Inject, Redirect Effluent) a consortium of NGO's including Maui Reef Fund and Maui Tomorrow Foundation who are promoting reuse of wastewater.

November 2008
DOH and Central Maui Soil and Water Conservation District
West Maui Watershed Plan Stakeholders

December 2008
Bill Frampton, Developer, Frampton and Ward, LLC
John Summers, Administrator, and staff Maui County, Long Range Planning
Ian Horswill, Project Coordinator Stables Road Beach Restoration

Public Testimony:
November 6, 2008
Public hearing on the permit for Underground Injection Control of secondarily treated wastewater from the Lahaina Wastewater Treatment Plant.
November 19, 2008
Maui County Council Land Use Committee on the proposed change in zoning for Makena Resort
December 1, 2008
Maui County Council, Water Resources Subcommittee
Maui Algal Blooms meeting, ECoHAB, University of Hawaii