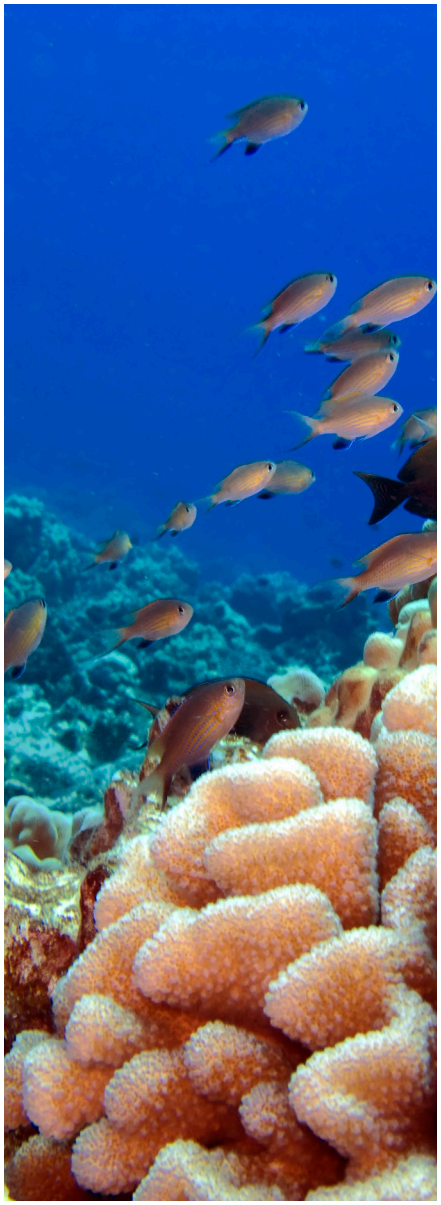
LOOKING BACK

Hawaii Coral Reef Initiative Outcomes

2002—2014



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INTRODUCTION

As Hawaii's unique and fragile reef ecosystems respond to changing environmental stressors, the Hawaii Coral Reef Initiative's research has made tremendous gains in the quest to identify those stressors and understand reefs' mechanisms of change. Our peer-reviewed projects have made a number of scientific accomplishments in the fields of population dynamics, ecological assessments, environmental monitoring, and genetics.

This increased knowledge has improved managers' capability and competence in making decisions to protect the nearshore ecosystems. Constructing databases of critical monitoring information and creating improved methods for data management have added to management capacity. Unique training and collaborative opportunities have both educated scientists and managers and created opportunities for positive relationships between them. Our projects have succeeded socially, as well, by raising public awareness and creating citizen scientists actively involved as stewards of Hawaii's reefs.

RESEARCH FOCI

Each year, the Hawaii Coral Reef Initiative's Management Committee identified priorities to guide its solicitation for research. Funded projects can be divided into these core strands:

- ALGAE
- SEAGRASSES
- POPULATION GENETICS AND DYNAMICS
- NON-NATIVE AND INVASIVE SPECIES
- ECOLOGICAL ASSESSMENTS AND MONITORING
- HUMAN IMPACTS
- MARINE DISEASE
- COMMUNITY
- RETROSPECTIVE

ALGAE

A primary producer of organic matter, algae in Hawaii fill an important role in the coastal reef ecosystem, providing food and habitat for marine life. Because of the isolated location of the Hawaiian Islands, many native species of algae occur nowhere else in the world. Native algae are also culturally significant as a traditional food source (limu) that still is commonly consumed today. Crustose coralline algae are critical reef builders, secreting limestone that helps cement the reef and provide substrata for settling coral larvae.

Having been introduced from a foreign location either accidentally or purposefully, invasive algae take over reefs by filling a niche normally occupied by a native species and then displacing the native species, creating an imbalance in an otherwise healthy ecosystem. Several species of algae in Hawaii match this description and Hawaii Coral Reef Initiative-funded research has found effective ways to control or reduce their spread.

Biocontrols involve using a biological method of controlling an invasive species, in this case vertebrate and invertebrate herbivores that graze on algae. Discovering the preferences and feeding styles of herbivores helps managers deploy the optimal biocontrols for mitigating invasive algae.

The spread, mortality, and composition of native and invasive algal species is important in determining the most effective measures of conservation management. The cultural significance of limu, native species that have become invasive, and mitigating the impact of invasive species all coalesce into a clear focus for managers' attention. Hawaii Coral Reef Initiative research has added significant understanding to the components of algal population dynamics, aiding in creation of best management practices.

Studying the taxonomy of algae species provides important data on genetic differences that assists managers in identifying algal species. It also contributes to the overall understanding of differences between native and invasive species that may present a means of protecting the former while controlling the latter. In-depth genetic analysis allows for a more complete record of reef species, which in turn allows managers to be more aware of any changes in species abundance, loss, or arrival of new species over time. The Hawaii Coral Reef Initiative research on this topic includes most of the major groups of algae, including crustose coralline algae and green algae.

TAXONOMY OF COMMON CRUSTOSE CORALLINE ALGAE FROM THE HAWAIIAN ISLANDS

Collections of crustose coralline algae in Hawaii dating to 1778 had only been partially identified, and none of them have been critically described with definitive genetic identification. The catalog with the published records is now compiled and organized. A total of 73 species from 16 genera were previously recognized for the Hawaiian Islands. However, after detailed analysis only one-third of all of the previously-used generic and specific used names were valid names. Knowing what "common" species exist will make it easier to recognize if a species becomes missing or diseased.

CORALLINALES			
Dermatolithon	1	Lithothamnion	11
Goniolithon	6	Mastophora	5
Hydrolithon	8	Melobesia	1
Lithophyllum	15	Mesophyllum	8
Lithoporella	1	Neogoniolithon	6
Tenarea	1	Paragoniolithon	1
Titanoderma	1	Pneophyllum	1
Sporolithon	2	Porolithon	5

MINIMIZING THE RISK OF INVASIVE ALGAE TO KONA CORAL REEFS

With the help of Hawaii Coral Reef Initiative projects, resource managers have a broad understanding of the species of algae being introduced in the Hawaiian waters. The most likely pathways of unwanted introduction are aquaculture and deliberate illegal transport. Gracilaria salicornia is being grown in Kona and is one of the species deliberately being transplanted that may negatively impact Kona reefs. The onshore aquaculture facility growing the alga received site visits and interviews, which has resulted in an approved biosecurity management plan.

This plan may prove to be a foundational operations protocol for any aquatics facility that cultures non-native species. Upon analysis, gaps in the policies of the

state's Departments of Land and Natural Resources and Agriculture showed that invasive species management is not cohesive and obstructed by conflicts of interest. To address this, recommendations for amendments to each agency's rules and regulations provide for heightened scrutiny of species proposed for aquaculture and more stringent permit requirements, while giving these agencies the authority to assist with management responsibilities for all imported species.

CHARACTERIZING GREEN ALGAL BIODIVERSITY OF HAWAIIAN REEF AND ESTUARINE COMMUNITIES

Green algal groups do not possess clear taxonomic resolution, so genetic analysis to accurate estimate their species diversity in the Hawaiian Islands is useful to managers in their identification and monitoring of invasive strains within a species.

The taxonomic work completed modified a pre-existing red algal DNA sequence diversity assessment procedure to rapidly characterize green algae of coral reefs and estuaries throughout Hawaii. This improved process eliminates the confusion or impossibility of using only morphological traits to identify an alga. Curated specimens from the Bishop Museum supplemented the 250 field collections used in the DNA sequencing. The heavily-populated sequence diversity framework from this study provides a baseline of Hawaiian green algae and a tool for rapid assessments to distinguish native and alien genotypes. Two new microsatellite markers emerged from the study to aid in identification.

INVASIVE SEAWEED POPULATION GENETICS AND REPRODUCTION

While significant asexual reproduction allows the invasive alga Acanthophora spicifera to spread rapidly in a habitat, it is also frequently seen in a sexually reproducing state. Sexual reproduction likely produces higher genetic diversity and therefore higher adaptability and fitness.

Microsatellite analyses reveal significant population structure within a dozen populations from the main Hawaiian Islands. Substantial testing refined seven reliable microsatellite markers for final genetic analysis. This method provides a genetic fingerprint that allows for identification of any clones, or genetically identical individuals that resulted from asexual reproduction. A number of clone genotypes appeared in the results, especially in sterile populations that rely entirely on vegetative reproduction.

The high degree of genetic structure in this invasive alga may also be applied to native limu species, which would allow them to be evaluated with similar tools.

Range and dispersal of any algal population has management implications, including conservation of native species. Populations with low genetic diversity may not withstand control measures as well as those with high genetic variation, making them the first choice for mitigation. Genetic diversity may be an indicator of the age of a population, with newer populations possessing lower diversity. Populations that occur in the intertidal zone are accessible and produce more reproductive structures than subtidal populations, making them another potential target for removal efforts. The microsatellite information garnered reveals a substantial amount of knowledge regarding the reproductive strategies of the most invasive algae in Hawaiian waters, helping managers to target populations that would easily be brought under control.

OF URCHINS AND PARROTFISH-SOURCES AND SINKS OF KEYSTONE HERBIVORES

To design effective marine protected areas, management needs information on the dispersal of larval keystone species between the Hawaiian Islands. Collecting high resolution genetic data to determine the connectedness or isolation of populations and islands will provide this information.

Two keystone herbivores, Scarus rubaviolaceus (ember parrotfish), and Tripneustes gratilla (collector urchin) are ideal candidates for a description of population structure. Both disperse widely throughout the main and northwestern Hawaiian Islands and Johnston Atoll. This connectivity implies a need to manage reef systems across the state as a collective network, since local populations can act as sources for more distant populations. The lack of genetic structure also indicates moving urchins between islands for biocontrol measures should not be problematic for algal-dominated sites. Parrotfish homogeneity indicates that the subspecies is a significant unit, which could impact the diversity of the species on global scale if not properly managed.

HOW MANY FISH DOES IT TAKE TO KEEP THE ALIEN ALGAE OUT?

Since microscopic remains of invasive algae can regrow after a clean-up event, herbivory may be a more powerful tool in the management of invasive algae. Marine protected areas allow for a high abundance of herbivores that graze on both native and invasive algae, keeping the algal cover low enough that it does not begin to take over the reef ecosystem. An objective of the study is to test for a correlation of body size with grazing efficiency. Investigators measured grazing around Oahu at Keehi Lagoon and Hanauma

Bay, known for their high biomass of herbivorous fishes. They also measured grazing at Wawaloli, Portlock and Ko Olina, known for low biomass of grazing fishes.

Grazing measurements at sites around Oahu (Keehi, Hanauma Bay, Wawaloli, Portlock, Ko Olina) indicated that while they may have had lower fish biomass, areas with concentrations of larger herbivorous fishes, such as parrotfish (uhu), had more effective algae cropping than areas of higher biomass of smaller fishes. In areas containing larger sized herbivorous fishes, specifically large parrotfishes, the standing biomass of algae was more effectively cropped than in areas containing large populations of small herbivores. This may be due to differences feeding style. Grazing pressure influences a number of management concerns, including reef diversity, nutrient concentration, succession, erosion, and productivity. The grazing efficiency of parrotfishes supports the idea that marine protected areas are an important management tool in supporting a coral-dominated reef ecosystem.

NATIVE GRAZING SEA URCHINS

Invasive macroalgae pose a threat to corals in shallow parts of Kaneohe Bay by competing for space and blocking sunlight from reaching the corals. These coral depend on algae living inside their bodies for supplemental nutrition, which they obtain through photosynthesis. In a balanced ecosystem, grazing herbivores would control macroalgal biomass. Investigators tested the preference of a native species, the collector urchin (Tripneustes gratilla), for macroalgae in hopes of employing it as a biocontrol mechanism for the invasive algae.

Tripneustes gratilla ate all six varieties of macroalgae in shallow reef areas. This species is an ideal organism to control the growth of macroalgae, as it does not damage the coral reef substrate. Tripneustes gratilla fed on roughly seven grams of algae per day, which equates to about the same rate of an average herbivorous fish. This research found that the urchin prefers invasive species to native ones. Another factor in the urchin's favor is its high juvenile growth rate and low adult mortality. Because they feed on fleshy algae, they not only pose less of a threat to the reef structure, they also interfere less with newly settled coral larvae. Live coral can act as a barrier to the movement of the urchins, so one urchin per square meter should be placed to effectively reduce the amount of algae in areas where they are abundant.

Since the reproductive methods and life history of the collector urchin are representative of other reef invertebrates, it may be a useful model for reef herbivores. With long-range larval dispersal, individuals in a subpopulation may have been born nearby or immigrated from afar. Approaching the collector urchin population structure as a metapopulation (many subpopulations connected by dispersing larvae) will yield the best information for reef management, as it will allow them to identify the source of larval recruits in other subpopulations. This will promote the growth of the species.

DNA sequence and microsatellite loci data reveal that there is a lack of genetic diversity among the four major Hawaiian Islands. Only four common haplotypes were found that occur at similar frequencies among Tripneustes gratilla. Gene flow seems to be high at the scale of the main Hawaiian Islands as well as beyond to French Frigate Shoals and Johnston Atoll. Local populations are likely be enhanced by reproduction in distant sources. Since Tripneustes gratilla are dispersing across large scales, closely spaced protected areas will not likely have local effects on increasing urchin recruitment. In other words, urchins among the main Hawaiian Islands don't show substantial genetic differences, so moving urchins between islands shouldn't have negative effects on established urchin communities.
Two additional species, Echinothrix calamaris and Echinothrix diadema, referred to as wana in Hawaii, present models that have genetic differences but ecological and morphological similarities. Investigators have not studied them to the same level of detail that Tripneustes gratilla has received.

Despite their outward similarities, DNA analysis reveals that Echinothrix calamaris and Echinothrix diadema are distinct species and the analysis also yielded a key to identify them. Studies of their habitat indicate that Echinothrix diadema prefers shallow water areas, but Echinothrix calamaris and Tripneustes gratilla prefer middle depths. Both Echinothrix species feed at rates similar to that of Tripneustes gratilla and do not show evidence of any food partitioning between species. This may make them additional keystone species worth managers' attention as additional biocontrols for invasive algae.

PROVIDING MANAGERS WITH CRITICAL TOOLS FOR ASSESSING REEF ALGAE

This project identified algae at under-collected sites around ten islands while assessing the usefulness of Halimeda incrassata to indicate whole ecosystem health. It also contributed significantly to resource managers' education on the topic. Scientists collected 100 samples across 90 sites from the main and northwestern Hawaiian Islands, ranging from reef areas to the intertidal zone. They identified 27 species new to science and 45 new to Hawaii. With this data, managers had information that could assist them in further decision-making regarding the presence of the non-native species. Since the collection sites covered a large range, researchers were able to determine candidate species to serve as ecosystem health indicators. Researchers documented various growth rates due to seasonality, depth, presence of fertilizing nutrients, and amount of light. Abundant in Hawaiian waters and possessing rapid growth, Halimeda incrassata appeared to be the most suitable.

ALGAE

This information would enable resource managers to use the increase of the species to better determine the extent and impact of land-based sources of pollutants and any changes over time. The project provided workshops on turf algae, crustose coralline algae, and macroalgae for managers. These sessions consisted of day-long presentations, discussions, field trips, and lab work which resulted in better overall knowledge of algae in Hawaii's nearshore waters.

EFFECTS OF INVASIVE ALGAE ON LARVAL TRANSPORT INTO CORAL REEFS

Prior research impacts of algal mats on water flow between the reef substrate and the water column show that the interrupted flow can impact larval settlement. Studies on larval settlement show that certain species settle in response to chemical cues carried in water from the reef, while others do not use those cues.

Investigators also sought to understand settlement processes to test the possibility of seeding and restoration of coral. When investigators released larval mimics, those in clean reefs and those in dead reefs encrusted with coralline algae settled deep within the reefs. In contrast, the mimics released in reefs overgrown by algae could not settle deep within the reef due to the algal mats on top of the corals.

The reefs with holes in the algae allow water movement just as well as those reefs that are clear of any algae. When punching 4.8-centimenter holes into the mats, the researchers found that most of the complete mats collapsed over time. Pocilopora damicornis was able to attach on the reef, and required a force of nearly 15 Pascals to dislodge. Once metamorphosis had taken place, the Hawaiian coral is nearly impossible to remove.

PREVENTING THE INTRODUCTION AND SPREAD OF NUTRIENT DRIVEN INVASIVE ALGAL BLOOMS AND CORAL REEF DEGRADATION IN WEST HAWAII

One of the key factors in the spread of invasive algal species is level of nitrogen in the water. Higher nitrogen will usually encourage rapid algal growth, as it is a critical nutrient for algae. Nitrogen in the water may come from human sources, like runoff carrying fertilizer to the ocean. A stable amount of coral cover and substantial protected coastline with populations of grazing herbivores in west Hawaii may be sufficient to prevent this increased growth of algae, even if a combination of alien species and nitrogen input exists there. By a partnership with the state's Department of Land and Natural Resources' Division of Aquatic Resources, bioassays alien algae surveys helped to construct an integrated nitrogen concentration assessment from the surface to the benthos in specific monitoring

locations. Highest baseline nitrogen values occurred at Kawaihae Harbor, Waikoloa Beach Marriot Resort and Spa, Honokohau harbor mouth, and around Kailua-Kona.

A visual survey of hulls in Kawaihae and Honokohau harbors revealed less than 25% cover of nuisance species from the Ulva and Cladophora genera. Bioassay results from Ulva fasciata (limu palahalaha) tissue indicate that surface water contained higher nitrogen than lower depths overall. Nitrogen concentration was not related to herbivore biomass or abundance, coral cover, turf algae cover, or macroalgae cover in this study.

The bioassay method developed in this study allows for a reliable and resilient means of predicting nitrogen concentration of interest to agencies conducting water quality assessments. Subsequent Hawaii Coral Reef Initiative-funded projects employed a similar method.

ASSESSING SUCCESS WITH THE KAHEKILI HERBIVORE MANAGEMENT REGION

Using a decade of research showing a decline in coral cover and a spike in the population of the invasive red alga, Acanthophora specifera, as a basis, the state's Department of Land and Natural Resources' Division of Aquatic Resources established an herbivore fisheries management area in front of Kahekili Beach Park on Maui to regulate fishing of keystone herbivores in 2009.

Analysis of Ulva fasciata bioassays for nitrogen assessments revealed that bioeroders, like the boring sea urchin (Echinometra mathaei), and percent of turf algae correlated positively with nitrogen concentration. Coral cover declined with increasing nitrogen concentration, indicating a vulnerability from wastewater, with decreased coral cover leaving more space for turf algae to colonize. Crustose coralline algae cover remained highest at sites with lowest nitrogen values. The most likely source of nitrogen is plumes of freshwater from wastewater discharge. As indicated by other studies, concentration of nitrogen was highest near the surface, where the greatest proportion of recreation occurs.

A number of management outcomes resulted from this information. The Environmental Protection Agency requested nitrogen bioassays to identify sewage sources and revised its draft underground injection control permit to limit the current discharge of nitrogen and bacteria while reducing future amounts, as well. Maui County's mayor set a goal for improved wastewater reuse. The Environmental Protection Agency required Maui County to apply for a Clean Water Act Section 401 Certification to meet state water quality standards, as well as issued a Section 308 Order for Information to Maui County, requiring more stringent testing of effluent.

SEAGRASS

Hawaii hosts two species of seagrass: Halophila hawaiiana and Halophila decipiens. The species grow in sandy, soft-bottomed habitats of the photic zone. These seagrasses are vascular plants, with veins for carrying nutrients throughout their leafy fronds, unlike seaweeds. They are also part of the angiosperm group of plants, which produce flowers and fruits.

As halophiles, they thrive in salty water. Sea grasses help to stabilize sediments, filter water, and recycle nutrients, as well as providing nursery habitat for fish and invertebrates. In Hawaii, adult sea turtles graze on the meadows of short, paddle-shaped blades. The Hawaiian coot eats seagrasses and uses it as a preferred nesting material. The Hawaiian moorhen and the endemic snail species, Smaragdia bryanae also rely on seagrasses as a food source.

Of the two species, Halophila hawaiiana is the sole endemic one, with Halophila decipiens possessing a pan-tropical range. First found in Hawaii in 2000 near the Kahala Mandarin Hotel, Halophila decipiens may compete with the native species. Halophila hawaiiana does not grow around the Big Island, but in other areas may be locally dense. Total area of occupancy for the grass is less than 2000 square kilometers. The International Union for Conservation of Nature's Red List includes Halophila hawaiiana as a vulnerable species. In contrast, it lists Halophila decipiens as a species of least concern.

CONSERVATION AND RESTORATION APPROACHES FOR HAWAIIAN SEAGRASSES DISPLACED BY INVASIVE MACROALGAE

As with other conservation projects, information on natural histories and genetics improve resource mangers' decision-making. For the Hawaiian seagrasses, which have faced increasing encroachment by invasive green algae over the last 20 years, this information is important to their conservation.

An experimental removal of the invasive Avrainvillea almadelpha preceded transplant of Halophila hawaiiana and a native red alga into cleared areas, using traditional Hawaiian limu transplanting practices. Community volunteers assisted in the clearing of experimental plots. Investigators also placed Halophila hawaiiana in an erosional escarpment with stable sediments. Two factors, type of donor material (sea grass fragments and cores) and application of fertilizer, served as manipulated variables in the experiments. After two years, the invasive algae showed only 15% growth, while Halophila hawaiiana rapidly grew to 85% aerial coverage. Therefore, removing the alga is an effective control mechanism for seagrass recovery. The traditionally transplanted seagrass grew new blade pairs within three weeks.

At a site in Waikiki, investigators examined Graciliaria salicornia's impact on what was once a large seagrass meadow in a dredge basin. Dives in different seasons using quadrats set out to quantify the amount of invasive algae. A nearby, pristine meadow served as a control. The impacted site had much higher fruit and flower numbers for the seagrass, while leaf pair densities were not significantly different.

Using nuclear and chloroplast markers, investigators completed genetic screening on three seagrass species, with Ruppia maritima and Halophila hawaiiana showing the most promise for restoration.

POPULATION DYNAMICS

Many of the Hawaii Coral Reef Initiative's projects involve the study of population dynamics. Biological and ecological processes influence the movement, growth, and mortality of populations. In a coral reef ecosystem that has such high diversity, change in one or two populations may not have a large impact, but because so many populations are under new pressures, study of their dynamics and interconnectedness is vital to conservation planning. Documenting recruitment on a large scale helps define target areas for the most effective protected areas, help identifying sensitive sites with low recruitment, or areas with high diversity.

ASSESSMENT OF GENETIC DIVERSITY AND CONNECTIVITY IN FISH REPLENISHMENT AREAS ON THE HAWAIIAN YELLOW TANG

Yellow tang (Zebrasoma flavescens) exhibit a pelagic larval stage, which make them vulnerable to ocean currents, such as the eddy system around the big island. It may be possible that just a few breeding areas source other locations with yellow tang recruits. Ocean currents and larval behavior may also be dispersal mechanisms that restrict gene flow between sub-populations. Ocean currents may also foster genetically different sub-populations in source locations, which has important management implications.

The DNA microsatellite library resource generated in this study has been utilized in work on other reef fish. A final elimination of test markers produced 34 fluorescent PCR markers that are successful in other species, as well.

RECRUITMENT DYNAMICS AND DISPERSAL OF CORAL REEF SPECIES IN A NETWORK OF NATIONAL PARKS AND MARINE PROTECTED AREAS IN HAWAII

Researchers sought to determine the dynamics of living and non-living components of a marine protected area, including shore structure and the basic life history and recruitment for coral reef fishes, coral, and other invertebrates. These characteristics have direct implication for management decisions, and protected areas that utilize scientific data have demonstrated success in their implementation.

Each fish specie has unique needs for recruitment and most reef fish have shorter larval durations. Often, fluctuation in recruitment abundance relates directly to reproductive seasonality. There was no majority in the recruitment surpluses, but the study found that 18 species appear to exhibit late fall recruitment peaks. Another 16 species were observed to recruit in increasing numbers through the spring.

The presence of plankton positively correlated to higher species recruitment and improved growth of recruits. Yellow tang (Zebrasoma flavescens) showed rapid early growth, allowing adult settlement at a large size. Manini recruits in shallow areas or tidal pools, instead of directly on the reef, like other acanthurid fish. As nearshore grazers, they help maintain a coral-dominated reef system.
250-300 taxonomic groups of invertebrates recruited to Kona reefs during the study. Most species seem to have a complex life history with at least one larval stage. Non-target species may provide life history models for inferences about the dynamics of species with populations of recruits too low for any robust analyses. Variability of recruitment abundance suggests regional oceanography is not the only influence on community

structure in central Kona, but may also include habitat, disturbance, and anthropogenic influences. Most invertebrates settled in spring-summer, like similar recruits in other areas.

Abiotic factors were part of long-term data collection in a research partnership. The resulting geographic information system layers of special resolution imagery and benthic habitat characterization maps may be used to overlay pertinent data on ocean currents affecting larval dispersal, abundance, habitat selectivity, and distribution of reef species, and spatial analysis of dispersal patterns and population connectivity among marine protected areas.

EXPERIMENTAL CORAL FARMING FOR RESEARCH AND RESTORATION

This project involved a position for a United States Fish and Wildlife Service Intern. Work completed involved authoring a primary restoration proposal for the grounding of the M/V Cape Flattery, assisting in a habitat equivalency analysis, conducting field work to characterize coral reef communities that will be affected by planned Army Corps of Engineer projects on Oahu, and reviewing proposals for construction projects that may affect coastal resources in Hawaii.

In 2010, the internship yielded usable marine benthic maps within the 500-yard security zone of Marine Corps Base Hawaii. These maps assist resource managers in the development of conservation measures, as well as in the response to damaging events, such as ship groundings or plane crashes.

PROPAGATION OF HAWAIIAN CORALS FOR REEF RESTORATION

One means of conservation management may involve culturing coral for transplant onto reefs experiencing bleaching or other stressors. Establishing healthy colonies before transplant likely will give higher success rates to such a project, and this research yielded effective methods to that end.

It also supported use of minute fragments of coral as "seed" cultures, implying that both the aquarium trade and controlled laboratory experiments may require much less coral than currently harvested from the wild. To effectively grow coral for transplant onto reefs undergoing restoration, factors including water flow rates, amount of light, substrate type, and nutrient availability must all be evaluated.

Porites compressa and Montipora capitata served as test organisms for propagation experiments. Porites compressa shows significantly higher grow under lower water flow rates and higher light conditions. Montipora capitata grew better in low light and experienced bleaching under high light conditions, but showed an increase in growth and no harmful effects when higher flow was coupled with high light, likely due to increased gas exchange offsetting the harmful light levels.

Commercially-produced coral foods did not influence growth, but rather inhibited it at higher-than-recommended dosages. Corals grown in aquaria containing live rock, sand, and a pre-established community of fish and invertebrates grew more quickly than those without. Novel three dimensional substrata tested for growth yielded a ten-fold increase in Porites lobata tissue over a seven-month period. One square centimeter plastic mesh provided the best surface on which to grow corals. Such material may improve water motion around the attached coral nub. Tissue grew in just a few weeks on the mesh, its flexible nature allows for attachment without toxic adhesive, and the grid acts as a built-in tool for estimating scale.

Epoxy adhevisves are expensive and only useful for adhering of small coral fragments, in addition to their toxicity. Another successful method developed in the study is the suspension of coral fragments from fishing line, which has a number of positive implications in coral propagation.

CONNECTIVITY OF POCILLOPORA MEANDRINA POPULATIONS THE GENETIC AND OCEANOGRAPHIC APPROACHES

Investigators chose to study the larvae dispersal patterns of Pocillopora meandrina (cauliflower coral) on the Waianae coast of Oahu.

A ten-day trial to induce larval settlement in the lab ended unsuccessfully, without settlement, possibly due to the inability to simulate natural conditions for settlement in the laboratory. Adult tissue collected from four adult populations did not yield viable genetic information, due to multiple bands in the microsatellite sequencing. This was likely related to improper handling of the DNA samples. Although the reports are inconclusive, they do offer information on what should be avoided in the next attempt to determine larval and genetic information about Pocillopora meandrina

EVALUATING THE EFFECTIVENESS OF A MARINE RESERVE NETWORK IN WEST HAWAII TO IMPROVE MANAGEMENT OF THE AQUARIUM FISHERY

Due to declines in species taken by aquarium collectors, the West Hawaii Fisheries Council designated nine fishery replenishment areas. Baseline survey data taken from study sites open to collectors, as compared to existing protected sites and those that became replenishment areas, show significant impact of aquarium harvesting on select fishes. The mean abundance of aquarium fish in newly-established replenishment areas was 26% lower

than nearby reference sites. After their inception, data show a significant increase in fishes, especially the yellow tang (Zebrasoma flavescens), the most sought-after aquarium fish in Hawaii, which increased by 74%.

This may be due to observed large numbers of newly-recruiting fish, indicating that recruitment may be a key component of replenishing depleted fish stocks. Analyses of the relationship between environmental characteristics of the replenishment areas and the change in yellow tang population after their establishment indicate that high finger coral (Porites compressa) cover positively correlates to high numbers of juvenile yellow tangs. The most effective sites have an association with high numbers of adult fish that have wide reefs with high finger coral cover.

At the conclusion of almost five years of data collection, increases in aquarium fish abundance in west Hawaii's fishery replenishment areas clearly demonstrate the effectiveness of the protected areas. Not only are they ecologically important, these areas have supported revenue for the aquarium fishery. Total aquarium catch, and the catch for the two two species (yellow tang and kole) have increased to the highest-ever levels. Cost per unit effort is highest in west Hawaii compared to the rest of the state and rising. Compliance has been relatively good, with incidents of conflict between collectors and other users decreasing.

OPIHI POPULATION CONNECTIVITY

Three species of endemic Hawaiian limpets (opihi) revealed patterns of gene flow on the scale of thousands up to hundreds of thousands of years through mtDNA marker analyses.

They also show evidence of population partitioning, allowing them to exist in the same habitat without too much pressure from competition. The development of microsatellite markers will be useful to management for the detection of gene flow and migration rates of opihi on smaller time scales. Data from 515 microsatellite markers provides estimation of detailed patterns of population connectivity, population size, and growth rates. The design of no-take areas will benefit from the characterization of the spatial and temporal scale at which these limpets are connected across different islands.

RESEARCH ALGAL DYNAMICS (KALAELOA, OAHU)

To further address the issue of invasive algal succession in Oahu, researchers conducted rapid ecological assessments of sites in Maunalua Bay. A spatial contrast for pristine and invaded areas resulted which are of interest to mangers for baseline characterizations of impacted habitats. Photoquadrat estimated revealed that corals covered about 9% of the bottom, while turf algae covered 80% and the invasive alga Avrainvillea amadelpha covered 6.2%. Native macroalgae covered a mere 0.7%. Quantifying nitrogen and carbon isotopes for both Avrainvillea amadelpha and a native species, Neomeris, did not indicate any significant accumulation from any human sources. Complexity of benthic contours correlated positively with urchin density. A stand crop of the invasive alga did not exist in any site with complex bottom contours, nor in habitats with urchin densities greater than or equal to one per square meter. All herbivores examined found the invasive alga to be palatable. Areas of low grazing were the only ones with a standing crop of the alga.

POST-SETTLEMENT LIFE HISTORY OF KEY CORAL REEF FISHES IN A HAWAIIAN MARINE PROTECTED AREA

Surgeonfish provide vital service to coral reef ecosystems in their feeding on algae species. More detailed information on their basic life histories post-settlement will contribute much to resource managers' understanding of effective marine protected area design and location.

Work focused on the yellow tang and kole, while using the brown surgeonfish (Acanthurus nigrofuscus) as a control species. Novel methods used in this study to estimate age of fish relative to size and growth rate in the habitat have applications to other fisheries research.

Otolith readings imply longevity of up to thirty years for yellow tang, suggesting that protected areas allow for a longer lifespan. Transect observations indicate low mortality and little movement of tagged individuals away from home areas. That monitoring also shows that small-to-medium tang peak at depths of 40-60 feet, while the largest tang peak in shallow depths. Size distribution, sex ratios, length-weight relationships, reproductive indices, and age estimations all combine to form a more detailed picture of the life history of the target species.

INVESTIGATION OF CONNECTIVITY AMONG CORAL COMMUNITIES

Since coral reefs are under increasing stress, managers need the ability to gauge a population's ability and time required to recover from distress. A key component of recovery is available larvae to recolonize damaged reef areas. Discovering pathways for dispersal of coral larvae and other reef organisms aids managers in estimating this recovery, along with gauging the effectiveness of marine protected areas. Studying Pocillopora meandrina gives a representative model for scleractinian corals, which are keystone species. They are major reef builders, and thus provide shelter and food for many species, as well as undergirding primary productivity in the reef ecosystem.

Researchers estimated dispersal potential via data on larval competency periods and patterns described for currents and eddies along the Waianae coast (Oahu). They also examined microsatellite DNA markers from 150 adult tissue samples out of 4 populations of Pocillopora meandrina along the same coastline for later comparison with new markers. A trial of coral settlement experiments yielded information on improving laboratory conditions to induce coral larvae to settle.

A RAPID, LOW-COST TECHNIQUE FOR DESCRIBING THE POPULATION STRUCTURE OF REEF FISHES ON OAHU

Predicting the outcome of new management strategies or gauging the effectiveness of new ones is challenging without a cohesive picture of the life histories of reef organisms. Since few such life histories have been documented, researchers used a mathematical model to predict or evaluate conservation management by examining fecundity and biomass for three species: Centropyge potteri, Parupeneus multifaciatus, and Dascyllus albisella.

Growth of fish species in question seemed to have a lifespan of roughly two years. A complicated mode of reproduction reflected the life history of Centropyge potteri, as all males derive from previously mature females. Fecundity ranges from 270-1056 eggs per spawn, increasing as a power function with size. Size at maturity estimates for all three target species derive from statistical analyses in which 50% of individuals sampled show reproductive maturity.

Transect monitoring in Hanauma Bay and Maunalua Bay showed that only Centropyge potteri occurred in higher numbers in the no-take area (Hanauma Bay) than in the unprotected site. For that species, biomass and egg production were higher in the no-take reserve than

NON-NATIVE AND INVASIVE SPECIES

Introduced aquatic species in Hawaii range from innocuous to invasive. The Hawaii State Legislature has declared invasive species as "the single greatest threat to Hawaii's economy, natural environment and to the health and lifestyle of Hawaii's people."

Sources for introduced species occur through hull fouling, discharge of ballast water, or even purposeful introduction. 2007's rules on ballast water are being revised, and hull fouling regulations are in their formative stages. Invasive species are such a common problem that Hawaii's Departments of Land and Natural Resources, Agriculture, Health, Transportation, Business, Economic Development and Tourism, and the University of Hawaii coordinate to lead the Hawaii Invasive Species Council. The council stages an annual Invasive Species Week to raise public awareness and recognize contributors to removal of invasive species.

Hawaii Coral Reef Initiative research has focused on understanding the spread of these species, their sources, and means of controlling them to restore the health of Hawaii's coral reefs. Such research has led to a deeper understanding of introduced marine organisms in Hawaii than in any other tropical area.

ASSESSMENT OF NONINDIGENOUS INVERTEBRATE SPECIES ON CORAL REEFS IN THE MAIN HAWAIIAN ISLANDS

Rapid assessment survey of the main Hawaii Islands primarily centered on invertebrates, but also included fish and macroalgae. A workshop on the project, impacts of alien invasive species, and identification tools, along with a website of findings and diver invasive species reporting tool resulted from the study.

Non-native invertebrates composed no more than 10% of total taxa identified in the study, and were less than or equal to 2.5 % at over half the site, with none being invasive, abundant, or dominant. Studies of sites around Oahu comprise 17-23% of introduced or cryptogenic species. In contrast, studies of Kahoolawe, Midway, and Johnston Atoll revealed only 1% of taxa to be introduced. A significant relationship existed between numbers of nonnative invertebrates with native specie richness and ocean exposure. At the time of the report, two introduced species, the orange keyhole sponge (Mycale armata) and the snowflake octocoral (Carijoa riisei) appear to have been increasing in abundance and distribution on certain reefs. One species of concern, Gonodactylaceus falcatus (Phillippine Mantis Shrimp) has displaced the native shrimp species Pseudoquilla ciliata from coral rubble habitats at Waikiki, but because it resides in burrows, it was difficult to quantify with rapid assessments.

ASSESSING THE LIFE HISTORY AND MANAGEMENT OF ROI (CEPHALOPHOLIS ARGUS)

People across the Pacific Islands consider grouper (Cephalopholis argus) a preferred food fish. Its introduction into Hawaiian waters never led to the intended fishery. Instead, ciguatera outbreaks caused spear fishermen to avoid the fish, and their numbers rose until roi became the most abundant predator on many Hawaiian reefs. Here, their diet primarily consists of early juvenile reef fishes, resulting in reduced recruitment. Reduced recruitment means fewer species will survive to adulthood to reproduce and keep species' numbers at healthy levels. Introduced predators can lead to biodiversity and abundance reduction via predation or outcompeting native species for resources, and roi are now the dominant marine predator on many of Hawaii's reefs.

In examining roi stomach contents, twelve different families of fish appeared, indicating a varied diet. However, surgeonfish appeared more frequently than any others, indicating a preference for that family. During tank experiments to determine feeding frequency, roi did not feed on consecutive days. On average, roi's daily consumption rate is 0.8% of its body weight, which is lower than native predators' rates. In some species, biomagnification may play a role in the level of a particular toxin. Through this study, resource managers discovered a roi's diet does not play a role in its level of toxicity. Data indicate that the majority of roi are safe for human consumption. The few roi that tested positive for Ciguatoxin were taken in Kona. Age and size do not serve as predictors of ciguatoxity. No site from the study was safe from fish with Ciguatoxin, but it is a reasonable assumption that most are not harmful to humans upon consumption. This information will bolster roi sales.

Studies on experimental removal of roi found that the cost to clear one acre of roi in Puako is seventy-seven person-hours. Populations of roi remain less than 10% of the original number, but tagging shows that some individuals are moving into the cleared area at a rate of one-two per month from less than 200-meter distance. Low levels of site maintenance are required to keep areas cleared of roi.

Roi occurred in 66% of the tow board and belt transect surveys conducted prior to removal, and accounted for 14.3% of the total fish biomass. During a fish-down experiment, investigators removed 31 kilograms of roi. Habitat complexity did not correlated with biomass, numerical abundance, species richness, or diversity at the three study sites. A statistical model effectively predicts depletion levels. This may have application for management in providing an expected take before a removal event. Data suggested negative effects of predation by roi on native fish assemblages' numbers or density, but did not conclusively support it.

ASSESSMENT OF THE INVASIVENESS OF THE ORANG KEYHOLE SPONGE MYCALE ARMATA IN KAN'OHE BAY, OAHU

As with other invasive species, the orange keyhole sponge (Mycale armata) grows quickly and competes with corals for space in shallow reefs around Oahu and Maui. It likely traveled to Hawaii through hull fouling of ocean-going vessels, as it is native to regions around Australia. To avoid harm to established coral colonies on the reef, investigators sought to determine features of the sponge that influence removal, along with removal efforts that are less damaging to corals.
Mycale armata populations across eleven survey sites increased between 2005 and 2006. The growth trends set in 2005 continued through 2006, but the mean increase was lower than the first year's values and not significant. Mechanical removal of the sponge causes damage to the coral, and did not seem to be significant in controlling sponge growth. The removal method through air injection on the sponge surface was effective in reducing sponge coverage and less damaging to corals. Sponge cover decreased a mean of 42% below initial values using the air injection method. This is important for the dominant corals, Porites compressa and Montipera capitata. Training provided to Hawaii's Department of Land and Natural Resources' Division of Aquatic Resources allows for the techniques used in the study to be transferred to personnel of the Hawaii Invasive Species Response Team for long-term monitoring and possible removal efforts.

NON-NATIVE AND INVASIVE SPECIES

ECOLOGICAL ASSESSMENTS

The monitoring of Hawaii's ecological resources is critical to preserving the unique ecosystems that unfold among the islands. A combination of living and non-living factors receive attention, as well as any relationships that may exist between them. Such monitoring may occur on a small or large scale and over a short timespan or over years. Ecological assessments are complex and can be time consuming due to locational and temporal variability of ecosystems.

The Hawaii Coral Reef Initiative has funded a number of valuable ecological assessments that have contributed much to state managers' understanding of environmental processes, relationships, and changes. Indicators in the assessments range from endemic species to invasive species, and cover a range of habitats and time scales. Additionally, many of the Hawaii Coral Reef Initiative-funded assessments have involved refining methods for rapid, low-cost methods that yield a large amount of data for a comparatively small research effort. As a result, the state's Department of Land and Natural Resources' Division of Aquatic Resources has updated its rules to reflect outcomes of the studies funded by the Hawaii Coral Reef Initiative, so that policy may keep pace with an ever-changing landscape.

INTEGRATED MONITORING OF CORAL REEFS OF WEST HAWAII

Two monitoring methods, resource-fish surveys and benthic characterizations, have received refinements to an optimal end product. Resource fish surveys target large, mobile fishes that are part of the recreational and commercial fishing industries. Benthic characterizations serve as a medium- to large-scale survey approach that can easily produce information on benthic fish distribution and community structure.

The method uses transects for reference for digital photographs taken with a wide-angle lens 1.5 meters above the substrata. For efficiency, investigators determined that 100 images captured along a 200-meter transect at 10-meter intervals perpendicular to the transect can be completed by 3 divers in 2 dives for a site.

Field trials of integrative monitoring that included both small-scale and the benthic characterization approach yielded insight into fourteen reef sites in west Hawaii. 30 sites in Maui received resource-fish surveys. Four out of the fourteen sites had some sort of marine protection, but only one was fully closed to fishing. Biomass of fishes in protected sites was higher than the average. For scarids, acanthurids, and lethrinids, local habitat features showed significance relative to protection effects. Sites closest to harbors showed the lowest resource-fish biomass. Certain structural features seemed to drive higher biomass in some sites, as did inaccessibility.

Methods from the study contribute to standard monitoring protocols adopted by the state. An extensive, explicit set of written standard operating procedures received field testing through the study, giving managers an efficient, tested tool kit for use in monitoring programs through 2008.

STRUCTURAL, FUNCTIONAL, AND ECOLOGICAL ASSESSMENT OF EXISTING DAY-USE MOORING BUOYS (DMBS) ON OAHU, HAWAII

Forty-two legally permitted day moorings dot the south and west shores of Oahu. They receive regular usage from a number of commercial, government, and private parties. While geo-referenced, there have been no prior surveys on them. Areas of interest to divers will usually see the installation of moorings to mitigate the damage to coral and the benthos inflicted by repeated anchorings at a site by its user groups. It is necessary to assess the structural integrity, geographical location, attachment functionality, and ecological conditions to maintain safe mooring conditions for users. A baseline assessment also provides a frame of reference for impact to the moorings over time.

A dive team has conducted the first mooring and nearby ecological surveys for Oahu. The assessment provides managers with a report detailing information on unsanctioned moorings, coral growth on permitted moorings, attachment methods, and ecology of the surrounding area. Unsanctioned moorings pose risk to the live rock substrate to which they may be attached, as well as threatening

large coral colonies nearby. Often, their attachment to dead coral means an unstable one, susceptible to breaks. Established, older buoys show significant coral growth. The report also provides management suggestions, documentation on replicable methodologies for employment on other islands, and a list of documented commercial operators who use the moorings.

ASSESSMENT OF MARINE SPECIES AROUND OFFSHORE ISLETS IN THE MAIN HAWAIIAN ISLANDS

Rapid assessments completed in two of the ten previously unexamined areas occurred in marine life conservation districts. All had varying reef conditions, and some distinct differences that could not be explained. For example, Kaemi and Hulu both have high water turbulence, but the coral cover at Hulu was two-to-three times that of Kaemi. The two highest areas of coral cover occurred at Molokini (Maui) and Kapapa (Oahu), respectively. Kaemi had the lowest cover, but also had high turbulence and algal growth. A minute and unidentified turf alga grew at all sites, averaging 50%-72% cover at six of the ten sites. Other than Molokini and Namoku, few or no apex predators appeared during the survey. Kapapa (ahu, showed the highest values for total fish, in spite of being a turbulent, low reef site and close to a heavily populated area. This statistic could be due to the abundance of pualu (Acanthurus blochii) and kole (Ctenochaetus strigosus), both herbivores that consume macroalgae and turf algae in that area. Puu Pehe and Molokini had the lowest overall values in all assessment categories. They are easily accessible and may be subject to poaching. Puu Pehe's low biomass may be due to limited live coral cover. Kaulapapa National Historic Park showed high biomass values, which may be due to its remoteness allowing low fishing pressure.

Fifteen of the twenty-two introduced species were cryptogenic, but potentially introduced. No introduced or invasive algal species were found at any of the sites. Invasive snowflake coral (Carijoa riseii) stood as the only introduced invertebrate species, seen at seven sites. In spite of its abundance on Oahu reefs, it was not present at any of the test sites around Oahu. The assessments did not encounter any recognized endangered or threatened species, however sixteen uncommon species did appear: five algae, five invertebrates, and six fishes.

A COMMUNITY-BASED RECOVERY PROGRAM FOR MAUNALUA BAY, OAHU

A three-year program, this study has developed from stakeholder requests to investigate urbanization, changes in use, and ecological changes due to other human impacts in Maunalua Bay, Oahu, in hopes of developing means of mitigation to recover the declining coral reef ecosystem present there. Meetings with members of government agencies, educational institutions, and stakeholder groups have resulted in a set of key goals and objectives and a course of action for the project. The working group extended its collaborative work to include the US Army Corps of Engineers for insight on how to address runoff from the nine subwatersheds ending in the bay.

Investigators conducted substantial water quality monitoring both at land point sources and in the bay, finding that dissolved oxygen decreased with distance seaward and with depth, as well as a gradient of clear water at the surface becoming more turbid with depth. A flood event created a week-long sediment layer, harmful to bottom-dwelling organisms, including coral. The flood also impacted salinity, and even after a week, the system had not recovered. Both storms and floods resuspend sediments, but flooding introduced a new load into the bay. Other outcomes of the study include biological surveys, coral biomarker analysis, and calculation of erosion in the upper watershed, heavy metal dynamics, and drainage planning.

Coral biomarker analysis revealed some stressors and responses decreased linearly with distance from shore, helping to indicate choice of biomarkers for future work. Protein levels indicated corals are under stress from land-based pollution. Removal of Avranvillea almadelpha revealed decreases in resuspendable sediment in cleared areas compared to uncleared areas. Cleared areas showed faster settlement of particulates, and remaining sediment was of a coarser, less harmful texture. Statistically, there was not a significant difference between cleared and uncleared areas.

RESTORATION WITHIN HEEIA AHUPUAA: EFFECTS ON SPECIES DIVERSITY AND WATER QUALITY

One of the primary functions of coastal wetlands is the transport of nutrients, sediments, and water. The Kaneohe Bay system has been especially impacted by invasive species. T

o support the grassroots restoration campaign of Kakoo Oiwi, researchers investigated the functions of wetlands and associated ponds as the ecosystem changed from an invasive species-dominated habitat into a restored habitat with native species occupying their original niches. The scope of work included nutrient transport, changes in species diversity and habitat, sediments, and water quality and flow.
In Heeia ponds and loi, thirteen species provided canopy. Loi hosted two sedge plants and one macroalga species.
Both ponds and loi held five species of introduced fish.

There has been a recorded loss of open water area between 2005 and 2010, but there may have been periods of overgrowth and recovery so the loss may not be a progressive one. Job's Tear canopies held the highest measured ammonium, while extremely low dissolved oxygen, nitrate, ammonium, and total suspended solids characterized neke.

ECOLOGICAL ASSESSMENTS

Native plants cleaned and filtered the water that was leaving the loi. Investigators also documented the response of canopy-forming species during storm events to allow managers' interpretation of changes in vegetation at the site over time. California grass mats become dislodged during storm events, and play a role in the reduction of waterbird and fish habitat as a result. A set of monitoring parameters for using simple, inexpensive equipment enabled Kakoo Oiwi staff to train long term monitoring interns or deploy single-visit volunteer groups in an easy-to-understand format. Laminated guides and posters give visitors to the wetlands site at Mahuahua Ai o Hui information on wetlands and monitoring. Species lists and vegetation maps provide baseline data for further restoration.

STRENGTHENING CORAL REEF MONITORING OF THE MAIN HAWAIIAN ISLANDS

Investigators aimed to increase the state's Department of Land and Natural Resources' Division of Aquatic Resources' capacity to effectively collect and analyze its data, while utilizing external information. Elements of the research include assessing ecological change over ten years at sites in west Hawaii, together with assessing the effectiveness of a marine reserve network for sustainable fisheries of main target species. The project extended data management from west Hawaii to include Maui and Oahu.

Evidence to support the replenishment effect of marine reserve areas of West Hawaii came through observing a general pattern of higher abundance of adult yellow tang (Zebrasoma flavescens). Sites with atypical amounts of physical relief showed extremes in the number of adult yellow tangs. Sites with high contour exhibited high densities of the fish, while sites with low contour exhibited low densities of the fish. This is important because the yellow tang may live for over thirty-five years, giving scope for further adult population increases over time. This will provide a buffer against overharvesting of the species in the aquarium trade.

Assessments at Honaunau found little change in overall fish community structure in the twenty years prior to the study. However, mean fish abundance decreased by 37%, as did numbers of corallivores and detritivores. Notably, scarids and soldierfish increased in abundance. This is likely the result of increased recreation indirectly reducing the amount of fishing activities within the bay, thus reducing fishing pressure on these food species. Overall, the site showed a healthy and complex reef ecosystem with high coral cover and rugosity.

Investigators highlighted that while the large number of marine protected areas across the main Hawaiian Islands gives an impression of an extensive network, only 0.4% of nearshore waters are no-take sites. The total portion of waters in no-take or low-take areas include marine life conservation districts, limited access reserves, and military or security no-access zones is 4.8% Almost 95% of nearshore waters are open to recreation and fishing.

HUMAN IMPACTS

Increasing population, recreation, pollution, demand for land and fisheries, and basic human activities all play a role in shaping ecological systems. Understanding the scope of human impact on the environment is crucial to develop changes to how these activities are carried out so that the needs of a community may be met balanced with the requirements of the ecosystem.

ASSESSMENT OF HULL FOULING AS A MECHANISM FOR T

Many marine organisms are able to attach to the hulls of cargo ships and other vessels, as well as traveling in ballast water. Both mechanisms of transport allow for unintentional introduction of marine aquatic invasive species in Hawaii and around the globe, in spite of measures like steel hulls and anti-fouling coatings. Arthropods, sponges, seaweeds, cnidarians, marine worms, and fish and sea squirts compose the majority of a fouling community. Developed communities may provide a microhabitat for mobile organisms, such as fish.

A field survey on 35 ships' hulls revealed the presence of 112 species from 10 different phyla. 49 of those species were established aquatic invasive species, one was not, nine were new records, and one had unknown status. Interviews and site visits to local shipyards made it apparent that their management practices for toxic waste indirectly minimize the risk of exposure of aquatic invasive species in local harbors. Newly drafted guidelines from a collaborative working group formed during the study provide the least-damaging practices for large vessels to follow when entering port and those that are most limiting to the introduction of aquatic invasive species. Private sector stakeholders and government agencies both play a role in implementation of the guidelines.

Recommended guidelines would require a vessel to complete exchange of ballast water at least 200 nautical miles from shore. The vessel must also retain its ballast water on board while in a new harbor. It must also only discharge ballast in an approved reception facility. Additionally, before entering the US, the vessel would be required to use a ballast management method approved by the US Coast Guard. Findings show that holding the ballast water while in the harbor limits the release of aquatic invasive species.

Concurrent with the study, the principal investigators played a role in the State of Hawaii's development and adoption of new administrative rules regarding hull fouling and AIS management.

AN ASSESSMENT OF ANTHROPOGENIC IMPACTS ON TWO CORAL REEF SITES ON THE ISLAND OF HAWAII

Honokohau Bay is nearby to a wastewater treatment plant. The site has also seen a surge in industry and development. Kealakekua Bay experienced recent residential development, installation of three new golf courses, and an increase in tourism at the marine life conservation district.

Investigators sought to determine how nutrient enrichment and reduced herbivory affects benthic succession, as well as sites that could serve as fish nursery areas in west Hawaii. They also compared historical nutrient levels with current ones through modeling of land-based data. Groundwater entering both sites contained higher concentration of nitrogen compounds (nitrates and nitrites) than they did 30 years ago. This nutrient loading could be attributed to the increase in industrialization and tourism.

Nutrient concentration among the sites remained similar, but Kaawaloa Cove (inside the Kealekekua Marine Life Conservation District) showed a lower grazing pressure than Kahauloa Cove. Hawaii Coral Reef Initiative-funded data indicated two sites as possible candidates for reef fish nursery areas based on distribution of juvenile fish: Kahalahiki and Honokohau. These sites might be at risk from increased nutrient inputs, based on the Honokohau nutrient enrichment studies. Herbivory in the presence of nutrients kept algal biomass low in experiments, but in trials that caged the algae to exclude grazing, nutrients greatly increased their biomass. Slight differences at each site imply that other strategies may influence biomass beyond nutrients and herbivory.

CHARACTERIZATION OF HUMAN PATHOGENS AND FECAL BACTERIAL LOAD ON MAUI

Freshwater is seeping onto the reefs of Honolua, Ahihi Kinau, Kahekili, and Kihei, Maui and may be a source of human fecal bacteria and viruses, due to the presence of sewage injection wells in these locations.

On average, the nitrate-nitrite levels were high at the sites with injection wells, and in areas where seeps were not found, the near-shore environments had a higher concentration of nitrate-nitrite. There is indication that freshwater seeps supply nitrate-nitrite to near-shore environments and the presence of sewage injection wells enhances the effect. Seep water delivers orthophosphate (phosphate molecules) into the near-shore environment. Sewage injection wells increase the concentration of nutrients. A significant connection exists between eutrophication of coastal habitats, sewage injection wells, and freshwater seeps. Through DNA analyses, investigators identified Enterococcus spp. bacteria in sampled water, as well as bacteria in the order Bacteroidales. Mammals and birds may be the source of this in the soil. These levels fluctuate, and frequently spike. Human Bacteroides were rarely detected except for sites near a sewage injection well. Kihei showed high levels of these indicator bacteria. 68% of bacterial tests matched general non-pathogenic Bacteroidales, but only 6% returned positive for bacteria and viruses associated with human sewage contamination. These bacteria only persist in the environment for about 24 hours. The data does not conclusively prove that bacteria come from injection wells, though it may suggest that the injection wells provide bacteria with increased nutrients.

DISTRIBUTION, EFFECTS, AND RISK OF IRGAROL ON HAWAIIAN CORAL REEFS

Irgarol is a pesticide found in boat paints that harms corals and coral reefs. Investigators devised a method using analytical chemistry to quantify its concentrations at specific sites around Hawaii. The revised method will allow for monitoring of Irgarol through collection from the water column, suspended solids, and benthic sediments.

Each sample type required a separate extraction method, and has a unique detection limit under chromatography. Suspended solids have the lowest detection limit, at 15 nanograms per liter. Field surveys validated all detection methods. Sites with detected Irgarol ranged in concentration from 19.9-283 nanograms per liter in seawater and 1.05-3.83 nanograms per liter in suspended solids. Marine sediments did not have detectable levels of Irgarol. Seawater concentrations of Irgarol on coral reefs adjacent to marinas were below detection limits.

Investigators devised an accelerated solvent extraction method to quantify Irgarol in marina sediments. Using this method, Irgarol was below the level of detection in samples taken at all sites. This study is the first real study done on Irgarol.

IMPACT OF LAND DERIVED SEDIMENT ON THE CORAL REEF ECOSYSTEM OF PELEKANE BAY, HAWAII

Habitat characterization to quantify spatial and temporal changes on the reef environment focused on the Hawaiian finger coral, Porites compressa. Juvenile parrotfishes and other economically important species in the bay extensively settle around finger coral colonies. Silt and sediment from over two hundred years of land misuse enter the bay and impact coral growth. Pelekane also hosts the Puukohola Heiau National Historic Site, making it of cultural and historical significance. Restoring the coral reef near the site is of interest to many stakeholder groups.

A great deal of the sediment stems from the mouth of the gully south of Spencer Beach Park. Investigators collected bulk sediment samples from the gully and points parallel to shore, and monitored corals during biological assessments. The corals showed substantial (partial) mortality during conditions with high sediment loads. Sediment load correlates negatively with distance from the stream. Live coral increases and soft mud substrate decreases with increasing distance from the stream. The dominant corals in Pelekane Bay are Porites compressa and Porites lobata.

Measurements of coral heads revealed that size of heads with living tissue correlated negatively with increasing sedimentation. The mean size of the coral heads also decreased with increased sedimentation. Coral heads

with less tissue cover will not grow as fast as corals with full tissue cover. For the coral recruitment plates that were put out, the plate farthest from the stream returned with four settlements, none from the site next farthest, and one settlement from the site third farthest from the stream. The other five sites had no settlements.

ESTIMATING THE MAGNITUDE OF THE EXPORT OF DISSOLVED INORGANIC AND ORGANIC NITROGEN FROM NUUPIA PONDS TO KANEOHE BAY

This study is the first to estimate the magnitude of nutrient input through the tidal exchange of waters between Nuupia Ponds and southern Kaneohe Bay. The net flow of nutrients into Kaneohe Bay and the quantity of dissolved nutrients flowing into the south bay equates to that flowing from any of the streams entering the area. Concentrations of nitrates and phosphates in the ponds are about the same as they were at the same sites 15 years ago, but concentrations of ammonium are now lower. Annual outflow, primarily tidally driven, from the ponds into the southern Kaneohe Bay is greater than that of any of the streams draining into the area.

Nutrient concentrations in the outflow water are greater than that in the bay waters. The delivery of inorganic nutrients to the bay from the ponds per year is greater than the delivery of these nutrients to the bay by the streams entering the southern bay. Drogue studies indicate that water flowing into the bay from the ponds moves toward the reefs at the southeast end of the bay by the action of the trade winds.

HYDROLOGY AND WATER CHEMISTRY IN A LAGOON AT WAIOPAE

Investigators sought to detect anthropogenic nitrates in the lagoons bordering the eastern coast of the island of Hawaii, near Waiopae. The site is inland, relatively small, shallow, and has limited water motion.

Water samples taken at five different tide intervals showed varying nitrate levels. Nitrates were only detected at low tides, with the highest being the evening low tide sample. The highest values also occurred at the upland side of the lagoon. Nitrate values correlated negatively with salinity, chloride, and bromide. Previous data showed that nitrates are a component of freshwater. Based on the current data, the hypothesis is that as freshwater moves down the watershed, it interacts with cesspools. The conclusion is that nitrates from upland development and septic tanks seep into groundwater. The groundwater travels to the coast, carrying nitrates to waters around the reefs. High nitrate concentrations increase the growth of algae, which can threaten the normal balance of the ecosystem by displacing native organisms, smothering coral, and filling niches they would not occupy normally.

MARINE DISEASE

All living things are susceptible to disease. Fortunately, in Hawaii its prevalence – whether measured by distribution or severity -- is limited.

INVESTIGATION OF DISEASE IN CORAL AND REEF FISH ON MAUI

To determine the geographic distribution and prevalence of butterflyfish with tumors on Maui, investigators surveyed seven sites around Maui and Lanai. Values calculated for prevalence were low (less than 10%), compared to published values from the 1980s, with highest occurrence in the millet butterflyfish, Chaetodon millaris. 80% of infected fish were male.

Further investigation of molecular analyses did not indicate the presence of herpes viruses in tumor tissues, precluding the viruses as a cause of tumors in subjects at the site. 60% of taape and roughly 70% of goatfish examined showed apicomplexan parasites, suggesting that the two fishes share the protozoan.

Nine reef sites surveyed each had signs of disease, with 1.3% of colonies examined being infected. The two dominant coral groups exhibited six different disease states, with Porites having a 3.7% prevalence and Montipora 0.21%.

MONTINPORA WHITE SYNDROME

Montipora white syndrome is a disease found in Kaneohe Bay, Oahu. Microscopic diagnoses showed two forms of the disease: chronic and acute, with chronic being more common and widespread. Acute white syndrome is associated with microscopic ciliates, which move throughout the water column and seldom last longer than one month. Chronic white syndrome is caused by parasitic worms. In observations, Montipora capitata showed higher antimicrobial defenses than Porites lobata. Pocillopora meandrina had the lowest defensive response of the three species.

Investigators documented that Montipora capitata infected with white syndrome had higher levels of antimicrobial activity than healthy neighboring tissue. The antimicrobial activity may be induced in diseased tissues in an attempt to fight off an infection.

DISEASE INVESTIGATIONS IN INTRODUCED AND NATIVE HAWAIIAN REEF FISH

The 1958 introduction of the bluestripe snapper (taape) to Kaneohe Bay, Oahu led to rapid establishment of this species throughout Hawaiian waters. The species is aggressive in its competition for bait and local fishermen believe it is responsible for displacing native game fish. This competition has not been formally documented, but it is clear that they are encroaching on the native habitat of goatfish and deepwater snappers. Comparisons were made between the introduced bluestripe snapper and five species of the native goatfish to see if the taape was able to infect other fish, or vice versa.

Necropsies on 60 taape and 120 goatfish revealed that 50% of the taape and yellowstripe goatfish poopulations

harbored a protozoa infection that led to high mortality rates. All species shared parasites of similar morphology in the genus Goussia. While bacterial infection was low in all species, taape showed 80% prevalence of the red nematode, Spirocallamanus istiblenni. The nematode was prevalent in 15% of yellowstripe and 12% of yellowtail goatfishes. In this manner, both the introduce taape and native species of goatfish share parasites, though they are much more prevalent in native species. Examination revealed taape and some goatfish shared infection with apicomplexa type I, but it was not clear which species was vector to the other. A definitive vector of infection would require sampling taape in their native habitat.

This study is the first report of hematology on taape and goatfish (Pfluger's, many bar, and sidespot). White blood cell counts and estimated total solids in both types of fish were similar to reported values for scarids, grunts, and butterflyfish.

COMMUNITY AWARENESS

The Hawaii Coral Reef Initiative has contributed substantially to knowledge of marine science, conservation biology, and ecology. From research to an elementary curriculum, the state's managers and residents have learned much through to the Hawaii Coral Reef Initiative's programs and continue to malama coastal reefs.

RECREATION CARRYING CAPACITY AND MANAGEMENT OF HAWAIIAN REEFS

This study used social science research methods to indicate any existing conflict between user groups, capacity indicators (when 50%+ users feel uncomfortable with facilities or crowds), whether current conditions exceed standards, compromised experiences, user satisfaction, and support or opposition to management strategies.

The result of over 2,000 surveys conducted at random during three time periods across all days of the week showed that the majority of respondents were repeat users and satisfied with their overall experiences at the three sites (Kailua Beach Park, Diamond Head Beach, and Pupukea Marine Life Conservation District). The major user group was sunbathers and swimmers, though other groups including surfers and kayakers were well-represented.
Conflict among six user groups involved three major categories: discourteousness, proximity, and not watching where they are going. Respondents answered two questions on the conflict: how often does it occur, and how great of a problem is it.

At all sites but Pupukea, users reported substantial conflict, contingent upon their own activities. (Wind surfers, for example, reported conflict with boaters.) Conflict at Diamond Head was most problematic between all surfer groups.

To measure carrying capacity, respondents reported the number of visitors they observed, crowding on a subjective, 9-point scale, and expectations for personal norms on site numbers. The number of people observed in the surveys was very accurate when compared to survey staff's reported values. Sans Souci showed the highest numbers of interpersonal encounters compared to the norm and Sharks Cove, was most crowded. Sharks Cove and Sans Souci appear to be approaching carrying capacity based on data. People encountering more than their maximum encounter tolerance felt more crowded than those that did not experience those encounters. Respondents at all sites felt facilities (restrooms, trash cans, benches, and other amenities) were inadequate for the number of people visiting.

REEF PULSE

Reef Pulse: Hawaii, is an engaging, inquiry-based K-2 marine science curriculum. Designed on a learning cycle model (Engage, Explore, Explain, Elaborate), its six units take students on a journey through chemistry, astronomy, biology, earth science, and physics. Incorporating fun facts, Hawaiian traditions, songs, hands-on activities and games, it provides a broad range of opportunities for all learners. Available online, a teacher's resource guide provides ample support for teachers, including a lesson plan builder, scientific background information, extensions, modifications, and additional resources. Reader activities promote literacy for students.

BUILDING COMMUNITY AWARENESS AND INVOLVEMENT IN ALIEN ALGAE ERADICATION IN HAWAII

The removal of invasive algae is an ongoing effort throughout the state. All previously employed removal methods present potential deterrents. Manual removal by trained volunteers in large-scale cleanup events worked well, but was time-consuming and algal regrowth occurred quickly.

Physical in situ treatments altering temperature, salinity, or employing chemicals were effective, but their broader impacts on the ecosystem could prevent their use. Biological control by native urchin placement was also effective. However, long-term outcomes need to be examined to determine if viable parts of the invasive species pass through the urchin digestive systems, allowing algae to regrow when it is released back into the water. Taking the history of these methods into account, a combination of physical, manual, and biological techniques would be the most effective control of invasive alien algae on reefs in Hawaiian waters.

NON-ECONOMIC VALUES AND ATTITUDES REGARDING HAWAII'S NEARSHORE CORAL REEFS

Three focus groups and a telephone survey of 1,000 households yielded first-hand information on the general public's feelings about nearshore environments.

Since so many private citizens have a personal interest in the use of the habitat for recreation, subsistence, or other reasons, the fewest possible restrictions that both protect the nearshore environment and allow for ease of use should be enacted. Many reef users were less likely to desire restrictions on their activities, though they do believe there is a solution to solving usage problems. Non-users were more in favor of restrictions, as they did not have a vested interest in use of the nearshore habitat.

100% of surveyed individuals expressed non-economic interest in caring for the environment. Given three scenarios on how to preserve reefs, many chose restricting access to recreational use and allow limited fishing. Locals placed high priority on review of current restrictions and making changes as needed. Many suggested better enforcement of current restrictions. The public desires more communication with government agencies through electronic venues. They also expressed a desire for educational workshops both in the community and courses in the public schools. A large portion of respondents expressed desire for agencies that institute restrictions on the use of Hawaii's nearshore environments to

implement reviews of those restrictions to ensure their effectiveness, improved and more equitable enforcement, and new restrictions that arise only out of necessity and broad public support. Respondents also shared the opinion that human use should be protected, including subsistence fishing, recreation, and commercial operator activities.

REEF RANGER: A 3D CORAL REEF GAME

Game designers developed the ReefRanger 3-D game to introduce players to the complex world of coral reef management. It demonstrated how the health of one portion of the ecosystem could easily affect the health of other portions. It also highlighted how poor management could lead to degradation of one or more parts of the ecosystem.

Phase II of this game has more scenes and utilities to improve the performance of the game software. Users are able to edit, add, and submit new scenarios to aid in management of the reef. Procedures can be modified for the target audience. The goal of ReefRanger II is to enable young adults to learn about reef management and to understand ways in which they can then participate in real life. Helping users develop a sense of social responsibility can encourage sustained concern for good reef use and management procedures.

This game crosses age and cultural barriers, but long-term studies need to occur to monitor if and how this information impacts these young players for the long term.

2015 RETROSPECTIVE

From its inception, the Hawaii Coral Reef Initiative has funded numerous research projects spanning multiple years. Even after completion of these projects, the importance of these research topics have resonated with the scientific community and continued through other organizations. Outcomes of many of the projects have led to significant management impacts, with outcomes that are changing the face of Hawaii's coastal reefs for the better.

ALGAE

A large-scale project on nitrogen in the North Pacific Ocean indicates that nitrogen in the surface waters of the North Pacific Ocean has increased substantially over the last 30 years, due to enhanced deposits from the atmosphere. This may create more phase shifts in reef communities to algae-dominated conditions. A recent study found that turf algae already dominate half of all reefs surveyed, leaving scientists questioning if this is an indicator of coral recovery, or the beginnings of an algae-based ecosystem, rather than coral-based.

After the research on biocontrols using sea urchins, resource managers took interest and began developing plans for widespread use of the grazers to control invasive algae spread. Today, the state's Department of Land and Natural Resources' Division of Aquatic Resources operates the Anuenue Sea Urchin Hatchery, which cultures the collector urchin for invasive algae biocontrol. The hatchery rears about 5,000 urchins each month for release on impacted reefs in Kaneohe Bay to maintain initial clearing of invasive algae by the Super Sucker barge. The hatchery also host tour groups and uses social networking to increase community awareness about this important species.

Since 2012, team members have removed 250,000 pounds of Kappaphycus algae. Partners distribute the algae to farmers as compost. Since 2011, roughly 250,000 urchins have been released into the waters of the bay and the success of this effort is beyond initial expectations. A noticeable and lasting decrease in the amount of Kappaphycus has been observed in the bay. The State of Hawaii also maintains a phycologist under contract to ensure active and accurate algal management across Hawaii.

The Hawaii Coral Reef Initiative's genetic research on algae has provided a wealth of taxonomic information critical to identifying invasive species and understanding their life histories. Over 20 species of crustose coralline algae are included in the 2015 limu list for the University of Hawaii's Marine Option Program Summer Course Quantitative Underwater Ecological Surveying Techniques (QUEST).

The Hawaiian Algal Database operates to provide genetic information for both freshwater and marine algae in Hawaii. Individuals may search by taxonomic level, location, or DNA marker.

POPULATION DYNAMICS

Support for the the Hawaii Coral Reef Initiative's findings on the effectiveness of marine protected areas comes from Maui, the state's first herbivore-focused fisheries management area in Kahekili. Five years after its 2009 inception, biomass of parrotfish more than doubled. The biomass of large individuals, which graze more efficiently, also increased. Surgeonfish biomass increased by 40%. Coral cover and crustose coralline algal cover have been on the ris, as well, adding support to the efficacy of these protected areas. The association between parrotfish recovery and crustose coralline algae cover suggests that the recovery of uhu is improving conditions for coral growth.

The West Hawaii Fisheries Management Council, whose work the Hawaii Coral Reef Initiative supported during its first ten years, is currently working to establish no-take fish reserves and a limited-entry commercial aquarium fishery. Since establishment of the fishery replenishment areas, the value of the yellow tang increased 79%. Abundance of Yellow Tang increased 64.5% inside replenishment areas from 1999 to 2015. Overall yellow tang abundance increased by 58% along the entire west Hawaii coast. Thus, spillover of yellow tang from protected to open areas augments adult stocks over a kilometer away. Kole populations increased by 49% in the same time period.

Further research on population dynamics of the yellow tang yielded genetic information that can be used to determine population connectivity and self-recruitment. The National Center for Biotechnology Information also hosts a library of yellow tang genetic information online.

Multiple, subsequent studies employ geographic information system mapping for investigating population dynamics. One investigator in the Hawaii Coral Reef Initiative's study went on to collaborate on further refinements of this technique for representing larval dispersal systems in a two-dimensional model to provide more accurate patterns of the process.

For opihi populations, specifically, SB2124 established a moratorium on the harvesting of opihi until July 1, 2019, "subject to open and closed seasons and traditional rights." A number of opihi monitoring programs are tracking the status of these culturally significant invertebrates.

Coral propagation is receiving growing attention. The Waikiki Aquarium currently maintains a "Coral Ark," which houses rare coral species to be propagated in the event of extinction in the wild. Montipera dilitata (rice coral) is rare species being successfully grown, along with species from Papahanaumokuakea Marine National Monument.

SEGRASSES

Community groups have contributed to subsequent algae removal efforts and public education about traditional seagrass transplant methods, maintaining over 28 acres of soft bottom that has been cleared of Gracilaria salicornia to allow seagrass regrowth. Watermen report less turbid water and greater varieties of marine life in the cleared areas.

2015 RETROSPECTIVE

ECOLOGICAL ASSESSMENTS

DAR still uses monitoring protocols developed by the Hawaii Coral Reef Initiative scientists. Recently, the investigators from the project published a report on long-term monitoring of the main Hawaiian Islands coral reefs. http://dlnr.hawaii.gov/dar/files/2014/04/NOAA_2013_WHi_-Mon_-Rep.pdf. Over 30% of west Hawaii's coastline is protected, and showing significant gains in fish populations (+26%).

OTHER INVASIVE SPECIES

Due to its toxicity, managers shifted to the recreational aspect of fishing to encourage Hawaii's fishing community to remove roi in greater numbers, rather than its role as a food source. Spearfishing tournaments allow for a sporting evening to remove roi from the nearshore waters.
While not yet detected in the northwestern Hawaiian Islands, snowflake coral is ubiquitous around the main islands except for Kauai, which only hosts a small, possibly eradicable population.

HUMAN IMPACT

An ongoing project through Kakoo Oiwi is Mahuahua Ai o Hui, to restore over 400 acres of Heeia wetlands. Since this research, the state converted a portion of the lagoons in Waiopae into a marine life conservation district in an attempt to protect herbivores in these areas. Healthy herbivore populations aid controlling overgrowth of algae, which occurs in nitrate-rich waters. By controlling algae growth, the reefs should maintain a more natural and balanced state.

Further water quality research found that Irgarol concentrations range from non-detected to 283 nanograms per liter in marinas around Oahu. Planulae of Porites hawaiiensis experienced significant reduction in settlement under Irgarol concentrations of 100 nanograms per liter in laboratory bioassays. Like the Hawaii Coral Reef Initiative-funded study, researchers did not detect Irgarol in seawater samples at offshore reefs.

Maui County Environmental Management recently completed a three-phase process evaluation of the Lahaina Wastewater Reclamation Facility to establish the impacts of possible upgrades to the facility. In its January 2015 Quarterly Report, the County requested termination of a six-year Consent Decree with the EPA and the State Department of Health, citing that all requirements of the decree have been met.

MARINE DISEASE

Partnerships with dive and conservation groups host events like floating workshops, which educate stakeholders and managers on reef degradation through disease.

Research to understand the current black band disease outbreak on Kauai is underway, as nearly half of corals there are affected. A novel method of applying a putty substance to affected lesions smothers the disease and is showing promise.

An outbreak of acute Montipora White Syndrome occurred in Kaneohe Bay in February 2015. Continued monitoring and investigation will serve to further characterize the disease. The Eyes of the Reef website allows for ocean user reporting of outbreak sighting for quick identification by experts.

Work at Duke University confirmed the outcomes of the Hawaii Coral Reef Initiative research on sea turtle disease. REEF, a marine enthusiast group, conducts biological surveys on organisms including the turtle, and raises awareness about fibropapillomatosis and reporting sightings. Acanthophora spicifera appears to be a key component of the green sea turtle's diet, being completed digested and assimilated for nutrients. Acanthophora spicifera has played a role in recent cancer research and may prove to be instrumental in work to cure fibropapillomatosis.

COMMUNITY AWARENESS

Classroom field visits by Hawaii Coral Reef Initiative staff have enriched educational programs for elementary students. Teachers at the middle and high school level adapt activities from Reef Pulse for use in their own classrooms across the country. Teachers have received lesson plans and supplies, as well as field trip opportunities. Gracilaria salicornia clean-up began in 2011 through the Hawaii Coral Reef Initiative is on-going, with community volunteers and university students participating in the efforts. The clean-up crews have removed approximately 100 tons of the algae by hand-gathering.

Scientists introduced the collector urchin (Tripneustes gratilla) and the Sailfin Tang to the area because of its preference for feeding on alien algae over native algae. This has had a positive effect on reducing the amounts of G. salicornia at Waikiki.