A policy evaluation of Hawaii's coral reef management strategies

Jennifer Linney
California State University, Monterey Bay

CALIFORNIA STATE UNIVERSITY MONTEREY BAY

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Abstract: *Coral reefs play a critically important role in both the human and natural world. They are among the most biologically rich systems on earth and are of significant economic value to humans. They act as an important base for fisheries and provide food, jobs, and income to billions of people worldwide. These delicate systems are increasingly threatened by several factors including overexploitation, pollution, habitat loss, coral bleaching, and global climate change. The rapid decline and loss of the ancient and complex ecosystems had triggered major concern all over the world.*

Hawaiian coral reefs have experienced an increasing exposure to anthropogenic threats since development skyrocketed in the 1950's. Because this is a period of less than a century, the reefs in Hawaii are among the most pristine in the world in close proximity to human development. Their isolation provides an outstanding opportunity to study the direct effects of anthropogenic and natural impacts to coral reef ecosystems.

The purpose of this study is to examine the relationship between population changes in Hawaii, policy implementation, and trends observed in local coral reefs. This information will provide a better understanding of policy effectiveness, and provides a means to recommend possible policy improvements. Learning how to manage Hawaii's coral reef ecosystems can provide a valuable framework for coral conservation efforts around the world, and can be a key component in the movement toward coral reef sustainability.

Introduction:

The Hawaiian Coral Reef Ecosystem is significant to the future of coral conservation because it allows for the study of human-related impacts without much variability being contributed from other coral stressors and disease seen worldwide. The purpose of this study is to examine the effects of population growth and policy implementation on the coral reefs of the Main Hawaiian Islands (MHI).

Hawaii's current conservation policies coincide with the U.S. Coral Reef National Action Strategy (National Action Strategy), developed in 2002 to protect, restore, and sustain coral reef ecosystems. The National Oceanic Atmospheric Administration (NOAA) is required to report to the U.S. Congress every two years on the *Implementation of the National Coral Reef Action Strategy* in different locals. A companion assessment is prepared on the *State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States,* which gives an 'ecological snapshot' of coral reef ecosystems and is reproduced in alternating years to the National Action Strategy review. This study examines all *State of the Reef* documents published since 2002, and compare trends observed in Hawaii's coral reefs to policy implementation and changes in Hawaii's population size. Comparing these documents makes it possible to assess the policy's compatibility with Hawaii's population growth since 2002. This assessment will allow for recommendations to policy improvement or for a confirmation of policy success.

Geography:

The Hawaiian Archipelago consists of eight large islands and 124 small islands, reefs, and shoals. The islands are located in the middle of the North Pacific Subtropical Gyre and stretch over 2400 km in the North Pacific, ranging from 19°-28° N to 155°-178° E. The Archipelago is divided into two regions: The Northwestern Hawaiian Islands (NWHI), which consist primarily of uninhabited islands, reefs, and atolls; and the Main Hawaiian Islands (MHI), which are comprised of high volcanic islands with large human populations and a variety of surrounding reef types. Over 70% of the state's 1.3 million people live on the island of Oahu and over 7 million tourists visit the MHI each year. Coral reefs surrounding the islands are exposed to large, open-ocean swells and strong tradewinds that greatly influence the structure of the reefs and sculpt them into uniquely distinctive communities. Breaking waves are said to be the single most important factor in determining the structure and composition of Hawaii's exposed reef communities (Dollar, 1982; Dollar and Tribble, 1993; Dollar and Grigg, 2004; Jokiel et al., 2004)The MHI, particularly the islands of O'ahu and Hawai'i, possess the highest levels of coral biodiversity (Griggs 1993). Based on the structure of coral communities on dated lava flows on the island of Hawaii, it is estimated that it takes an average of about 50 years for Hawaiian reefs to regain peak diversity following a catastrophic event (Grigg and Maragos, 1974). The Hawaiian Islands are the most geographically isolated, yet populated areas on earth (Juvik and Juvik 1998). This isolation has enabled Hawaiian reefs to be sheltered from many of the stressors that cause coral degradation in other locations worldwide, and allows us to examine anthropogenic impacts first hand that are not seen on most other Pacific Island Coral Reefs.

Importance of the Reefs:

Economic Value:

The Hawaiian Coral Reef Ecosystem plays a critical role in the ecology, culture, and the economy of the islands. There are approximately 60 named species of coral within the Hawaiian Archipelago (Maragos, et al., 1974). The reefs function to protect and stabilize the shoreline from seasonal storm waves, and are responsible for the soft, white sandy beaches that make Hawaii such a popular tourist destination (Clark and Gulco, 1999). The reefs provide food products to the islands for recreational, subsistence, and commercial fishing and create world famous surfing and diving locations. The coral reefs of the Main Hawaiian Islands are estimated to have an average annual value of $364 million, which contributes significantly to Hawaii's estimated $800 million annual revenue from the marine tourism industry (Caesar and Van Beukering, 2004).

Cultural Value:

Polynesians who first settled the MHI had strong cultural ties to the coral reefs. According to the Hawaiian Hymn of Creation, the coral polyp was the first creature to emerge during creation. (Gulko et al., 2002) Hawaiians also use coral as a form of religious offering and maintain its importance through ceremonies that celebrate the animal's contribution to the island's resource base. Coral reefs have provided sustenance and medicines to the people of Hawaii for over 1600 years, and are a critical part of the cultural and social customs that are unique and important to ancient Hawaiians.

Ancient Hawaiians recognized the importance of coral reefs and fish stocks to their survival and developed a sophisticated harvest system (*kapu*) with a code of conduct that was strictly enforced. Their extensive understanding of the marine environment allowed Hawaiian communities to devise a plan that fostered the sustainable use of their resources. Harvest management was not based on a specific amount of fish, but focused on identifying the specific times and places where fish could be harvested without disrupting their basic processes or habitats (Friedlander 1997). After western contact, traditional Hawaiian fisheries management practices were virtually lost (Smith and Pai, 1992; Lowe, 2004). This traditional method is becoming more recognized and applied today, as sustainability and conservation are of increasing importance.

Medicinal Value

Many organisms found amongst Hawaii's coral reefs are species that hold the potential for natural medicines. For example, a chemical found in Hawaiian sponges has recently shown promise in fighting off tumors and malaria.

Medical researchers have also found that ground-up coral works well for bone grafts in humans. Modern medicine identifies coral as the first good artificial substance that human blood vessels can penetrate, and that the body accepts (Kawena, 1983). Corals are also providing researchers with insights into improving sunscreens. Many Hawaiian corals have evolved unique compounds that naturally shield them against UV radiation.

Conservation Value:

Hawaii's geographic isolation has resulted in some of the highest endemism of any tropical marine ecosystem on earth (Kay and Palumbi 1987; Jokiel, 1987; Randall, 1998). In all, there are at least

150 different coral species in Hawaiian waters, and about 25% of them are endemic to the Hawaiian Islands.

Native Hawaiian coral species include 47 hard, stony corals, which are the Island's most abundant coral (e.g., lobe, finger, and cauliflower coral). There are also 93 species of sea fan coral, a type of soft coral that grows from 500 to 2,000 feet (150 to 600 m) deep, and 13 species of other soft corals (e.g., black coral). The limited distribution of many of these endemic coral species has raised concern for their potential extinction (Maragos et al., 2995). With species loss in the oceans accelerating around the world, the irreplaceability of Hawaii's unique species makes it an important biodiversity hotspot. Because many of these endemic species are dominant components of the coral reef community, Hawaii's reefs are considered a unique ecosystem with an extremely high conservation value (Demartini and Friedlander, 2004; Maragos et al., 2004).

Since rates of human and industrial development have increased rapidly on the islands in a period of less than a century, Hawaii is proof of how quickly an ecosystem can be altered by the presence of man. With proper monitoring, the reefs of the islands can provide an outstanding opportunity for humans to learn how to live and manage our resources sustainably.

<u>Local Threats to the Reefs:</u>

Despite their economic and cultural value, Hawaii's coral reefs are experiencing increasing stress from anthropogenic and environmental sources. All of the most significant problems affecting Hawaii's reefs are a direct or indirect result of human activities either on land, or in the marine environment.

Climate Change:

Recent bleaching events and ocean warming trends have made climate change an important issue concerning coral in Hawaii. Hawaiian waters have shown a trend of increasing temperatures over the past several decades that are consistent with observations in other coral areas of the world (Coles and Brown, 2003) (Fig 1). The average annual sea surface temperatures (SSTs) in Hawaii have increased 0.8°C since 1956. These rising water temperatures are expected to increase the frequency and severity of bleaching events in the Hawaiian Islands (Jokiel and Coles, 1990). Climate change is a primary factor that contributes to coral degradation worldwide because when water temperatures get too warm, the *Zooxanthellae* host (on which coral depends for food and oxygen) die, in turn, killing the coral. This phenomenon is known as "coral bleaching" because coral appears to turn white when their calcium carbonate skeleton is exposed after the loss of *zooxanthellae*.

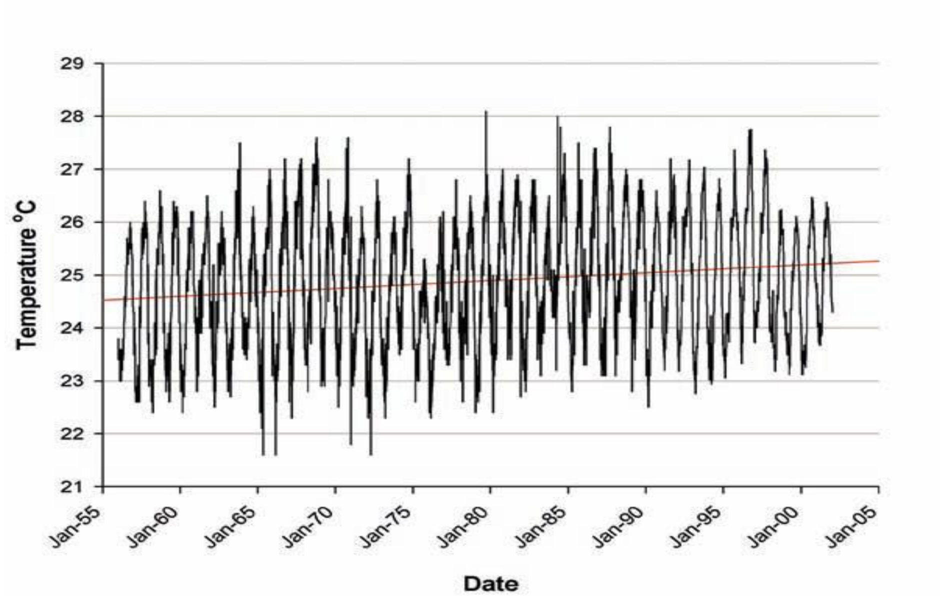

Figure 1: Weekly average temperature points for NOAA Fisheries temperature series taked at Koko Head, Oahu (21°17'N, 157°41'W) Source: Jokiel and Brown, 2004.

To date, there have only been three documented bleaching events within the Hawaiian Archipelago. The first occurred in 1996 on Oahu because of a prolonged increase in SST. During this event, waters were estimated to have increased by 1-2°C in reef areas. The second recorded event occurred in 2002 and the third in 2004, both in the NWHI (Kenyon et al. 2006). These observations suggest that bleaching events are becoming more frequent on the islands since all three of Hawaii's only recorded bleaching events have occurred in the past 15 years.

The phenomena of ocean warming can also indirectly kill coral by magnifying the effects of infectious diseases, which is another primary cause of coral death in Hawaii. The number, prevalence, and impacts of coral disease have been increasing worldwide in correlation with warming water temperatures. The severity of these diseases increases with temperature because elevated water temperature causes increased physiological stress on the corals, compromising their immune system, and potentially making them more susceptible to infections. Increased temperature could also benefit bacterial and fungal pathogens, making them more fit, virulent, and detrimental to corals.

Fishing and Poaching Pressure:

Hawaii's nearshore fish populations have been declining over the past several decades which could be a result of both fishing pressure and degraded habitat; specifically, coral reefs. Fish populations are important to the biodiversity and success of coral reef ecosystems because they are a critical part of the food web and help provide balance to the ecosystem. Changes in this population can have a significant impact on reef health. Poaching is also a consistent problem on the MHI because there are large numbers of un-licensed commercial and recreational fishers taking undersized or out-of-season fish and invertebrates. Most of this catch occurs in nearshore reef areas. A creel survey conducted in Hanalei Bay, Kaua'i in 1997 revealed that only 30% of omilu (a highly prized jack species) were legal for harvest and only 3% had reached the size of sexual maturity (Friedander and Parrish 1997). Increased fishing pressure brings more human traffic to reef areas which increases the frequency of vessel groundings and other anthropogenic stressors to coral reefs.

Invasive Species:

Hawaii is a world-renowned seaport and tourist destination. The planes and ships associated with this human traffic provide an easy means for invasive species to arrive in the ecologically sensitive Hawaiian Islands. Of particular concern to the marine environment, and the corals, is the arrival of invasive, non-native algae, pathogens, and invertebrates. There are presently 20 known, introduced marine algal species identified in the MHI and of these, four are successful and threatening to coral reefs. Several species of the red algal genera *Kappaphycus* and *Eucheuma* were introduced to open reef cultures in Kaneohe Bay, Oahu in the 1970s for experimentation. Now, 30 years later, two of the species, *Kappaphycus alvarezii* and *Eucheuma denticulatum,* have spread throughout Kaneohe Bay and are beginning to appear on outside reefs (Woo et al., 1999; Rogers and Cox, 1999; Smith, 2003). These species are particularly threatening to Hawaii's reefs because they are able to overgrow, smother, and kill reef-building corals. Other forms of invasive algae found on Maui and Oahu can produce large, tangled floating mats on the shallow reef flats (Hodgson, 1994). A recent economic evaluation has estimated that these blooms cost the state of Hawaii about $20 million per year in reduced property value, losses associated with deterred ecotourism, and the direct costs associated with removing large quantities of seaweed from the beaches (Van Beukering and Cesar, 2004).

Marine Debris:

Marine debris is a common occurrence on the reefs and shores throughout the MHI. Sources vary, but these past few decades have shown a noticeable increase in the amounts of debris washing ashore. In 1998, over 3000kg (7000 pounds) of nets and debris were pulled out of the waters of Kane'ohe Bay and Wai'anae, Oahu during three separate cleanup days. Between the years of 1996 and 2006, over 510 metric tons of debris was removed from the coral reef ecosystems and shorelines of the NWHI. Floating debris can cause chemical leakage or physical damage that can harm and degrade coral reef ecosystems. In Hawaii, the areas most affected by marine debris are enclosed areas with less water circulation such as bays and inlets, and areas of high human traffic.

Coastal Development and Runoff:

The coastlines of Hawaii are continually being developed for a variety of different land uses (Fig 3). Coastal development can trigger many conflicts including issues regarding shoreline access, the need for flood water storage and protection, infrastructure demands, and the pollution of coastal waters from runoff and groundwater contamination. The reefs that surround the MHI occur relatively close to shore, and consist of non-structural reef communities. (Crossett, 2008) (Fig 2) This puts them in closer and more frequent contact with anthropogenic stressors, such as pollution and human traffic, especially since most of Hawaii's development and population occurs on the coastline.

Habitat Type	Hawaii	Maui	Honolulu	Kauai	Total
Depth Curves (sq km)					
18 meter line	193.2	395.8	371.4	260.8	1,221.2
180 meter line	1,053.2	3,764.4	943.9	834.1	6,595.6
Mapped Coral Habitat (sq km)					
Coral Reef Hardbottom	105.7	274.0	291.1	269.0	939.8
Submerged Vegetation	0.0	0.0	0.0	0.0	0.0
Unconsolidated Sediment	25.3	188.7	116.3	73.3	403.6
Other Delineations	0.3	2.5	4.8	0.4	8.0

Figure 2: Approximate area (in square kilometers) of coral reef habitat surrounding Hawaii. Source: Rohmann ed al., 2005.

Before being altered for development, many of Hawaii's low-lying coastal areas were once wetlands or flood plains that served as natural filters to remove sediment and nutrients before stream water could enter the ocean. Domestic sewage and fertilizer runoff are major sources of nutrients that can find their way into Hawaii's nearshore waters. In Hawaii, large sediment loads are created by active developmental or agricultural practices that occur upslope of nearshore reefs. The removal of vegetation for stream channelization and the paving of upland areas also contribute significantly to sediment runoff. Sediment runoff on the MHI has been estimated at more than 1,000,000 tons per year from anthropogenic sources (USFWS 1996 in Green 1997). Sediments that find their way into nearshore waters often contain nutrients that can trigger a rapid and excessive growth of algae that can kill a reef. In 2004, a 30% decrease in coral cover in Honolua Bay, Maui was attributed entirely to burial by sediment that was caused by storm water runoff (Dollar and Grigg, 2004). Groundwater and surface water discharge are equivalent to about 20% of Hawaii's annual rainfall amounts (Yuen and Associates, 1992), which is of particular concern since Hawaii's groundwater typically contains three orders of magnitude higher concentrations of nitrogen and phosphorous than seawater does. Currently, sediment discharge is estimated as the leading cause of alteration of reef community structure on the MHI.

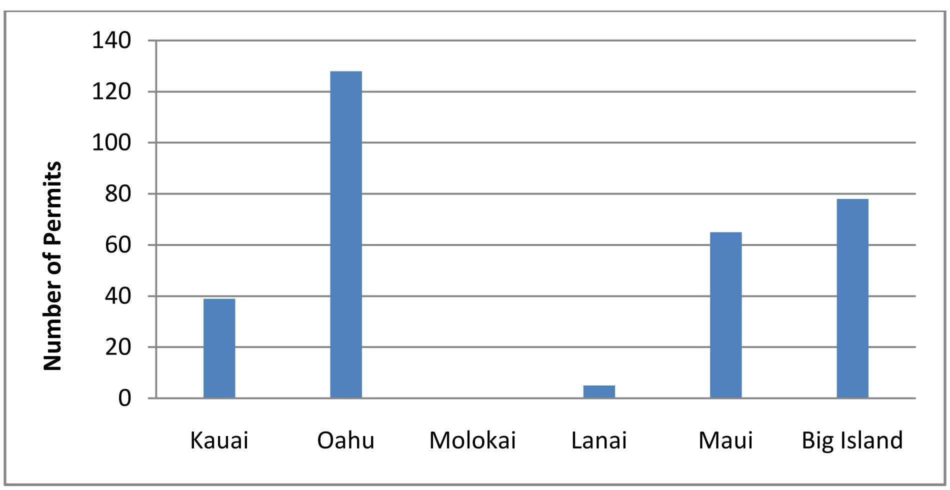

Fig 3: Number of General Construction Permits granted from 2005-2006. Source: Hawaii Department of Housing and Development.

Ocean Recreation:

Tourism is Hawaii's leading industry with over 7 million visitors traveling to the islands annually. Over 80% of Hawaii's tourists participate in some form of ocean recreation (Hawaii DBEDT, 2002). Many of these activities can be harmful to coral reefs, these include: boating, surfing, swimming, diving, snorkeling and fishing. Reefs are often damaged by anchors, ship groundings, motor discharge, noise, harassment, and pollution associated with many recreational activities. This is of major concern to coral conservation in Hawaii because between the years of 1982 and 2002, there was a recorded 66% increase in tourism, a growth of about 2 million visitors (Hawaii DBEDT, 2003). (Figure 4).

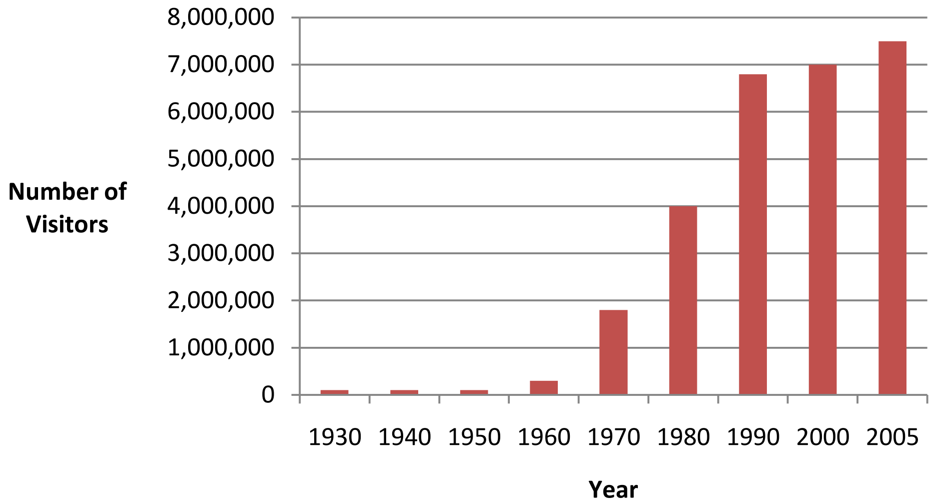

Fig 4: Number of visitors to Hawaii, 1930-2005. Source: Hawaii DBET

Oil Spills and Toxic Chemicals:

Because there is a heavy reliance for imported gas and oil on the MHI, spills are not uncommon. Most electricity production on the islands is based on fossil fuels (Pfund 1992). It is estimated that over 52 billion barrels of oil are shipped to Oahu's ports annually. Ship traffic, the proximity of reefs to harbor mouths, and vessel groundings have resulted in a 200% increase in reported oil spills between the years of 1980 and 1990 (Pfund 1992).

<u>Stakeholders:</u>

Stakeholders in the issue of coral conservation in Hawaii include, but are not limited to: Hawaii's Department of Business, Economic Development, and Tourism, Hawaii's Department of Health, Hawaii's Division of Aquatic Resources, landowners, commercial and recreational fishermen, tourists, residents, the environment, and local farmers. There are over 1,000 ocean tourism companies in Hawaii that generate an estimated $700 million in gross revenues annually (Clark and Gulko, 1999). Coral conservation policies can impact economic revenues as well as businesses practices. Whether they are concerned about the reef's ecological well-being, or how they are affected by new regulations, many stakeholders are associated with the coral conservation and policy implementation in the MHI.

Conservation Policies:

In 1998, the United States Coral Reef Task Force (USCRTF) was established by presidential executive order 13089 to coordinate efforts to protect, restore, and sustain local and international coral reef ecosystems. In 2000, the USCRTF adopted the *National Action Plan to Conserve Coral Reefs*, which highlighted 13 main conservation goals and was the first national blueprint for addressing the world's escalating coral reef crisis. In 2002, the USCRTF developed the *U.S. Coral Reef National Action Strategy (National Action Strategy)*, to further detail and implement strategies and actions designed to conserve and restore coral, as called for in the Coral Reef Conservation Act of 2000 (CRCA) (16 U.S.C. §6401 et seq.) The CRCA also requires the National Oceanic and Atmospheric Administration (NOAA) to report to the U.S. Congress every two years regarding implementation of the *National Action Strategy* in the periodic document, *The Report to Congress on Implementation of the National Coral Reef Action Strategy*. *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States,* is a companion document that is produced in alternating years and provides an assessment of the current ecological condition of coral reef ecosystems.

The National Action Plan to Conserve Coral Reefs:

The *National Action Plan* stresses the importance of developing a better understanding of coral reef ecosystems because it is critical to enhancing the effectiveness of coral reef conservation strategies. To better develop this understanding, the USCRTF aims to map, monitor, and study all coral reef habitats in the United States or associated locations. Another goal of the USCRTF is to increase understanding of the social and economic factors that contribute to, and affect coral reef conservation.

The *National Action Strategy* also addresses the importance of reducing the impacts of human activities by improving the use of MPAs, reducing fishing pressure, pollution, coastal uses, and international threats, restoring damaged reefs, and improving educational and community outreach.

Hawaii Coral Reef Initiative Research Program & the Hawaii Coral Reef Assessment and Monitoring Program:

The *Hawaii Coral Reef Initiative Research Program* (HCRI-RP) was jointly established in 1998 by the Hawaii Department of Land and Natural Resources and the University of Hawaii to support the research and monitoring of local coral reefs. Components of the program coincide with the most recent conservation strategies of the *U.S. National Action Plan*. The goals of the HCRI-RP are to: assess major threats to coral reef ecosystems, develop a database to store and access data, raise public awareness, and to implement training for coral reef managers.

The *Hawaii Coral Reef Assessment and Monitoring Program* (CRAMP) was established in 1998 as an integrated statewide monitoring program that is designed to describe the spatial and temporal variation in coral reef communities. Spatial information can describe the major ecological factors that control the status of reef communities in the MHI. Temporal trends collected via a well designed survey program can potentially document patterns of reef decline, recovery, and stability. Consistent monitoring practices and research allow for the capacity to better manage, sustain, and conserve reef ecosystems by comparing observations of the reefs size and condition. CRAMP monitoring sites were selected to give a cross-section of locations that differ in perceived environmental degradation, level of management protection, quantity of previous data, and extent of wave exposure. (Figure 5) Monitoring site data is supplemented by using a rapid assessment technique (RAT). The RAT uses a single 10 meter transect to describe benthic cover and sediments.

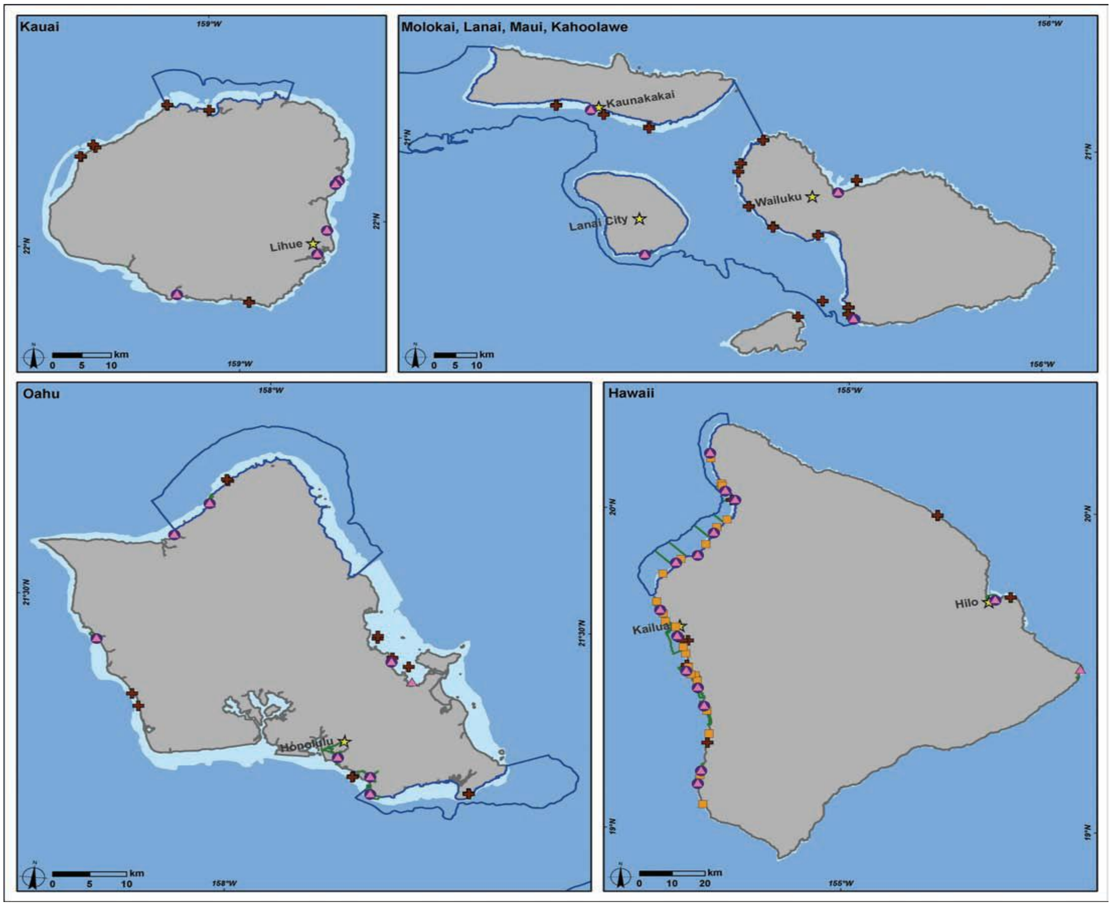

Fig 5: CRAMP Monitoring locations in the Main Hawaiian Islands. Map: A. Shapiro

Hawaii's Local Action Strategy (LAS):

In 2002, the USCRTF identified a need for a more local action strategy to conserve coral reefs in the MHI. Committees were created using members from state and government agencies to assess the effectiveness of management strategies. This committee also held a series of stakeholder workshops where the public could voice their issues and concerns relating to coral conservation in Hawaii. From this investigation, five initiatives were developed to enhance local coral protection:

First: Hawaii's LAS intends to work toward the development of an integrated fishery management plan that promotes a sustainable harvest in Hawaii.

Second: the LAS aims to minimize sources of land-based stressors by reducing sediment and pollutants through site-specific actions. Conducting extensive research and monitoring of the reefs will enable a better understanding of how land-based pollution affects coral reef health.

Third: Hawaii's LAS developed the Aquatic Invasive Species Management Plan (AIS) to address the growing threat of invasive species in the MHI. This plan aims to prevent any further introduction of invasive organisms by applying the use of ballast water and hull fouling mechanisms in Hawaii's ports. Designated teams are now located on each island to rapidly respond to, and monitor invasive species outbreaks.

Fourth: Hawaii's Living Reef Program was developed by the LAS to enhance the public's awareness on the importance coral reefs. This program is a collaborative effort of over 40 organizations and utilizes all forms of media to teach and encourage reef-friendly behaviors, and to stimulate community involvement.

Fifth: In 2005, Hawaii's LAS developed a plan to address recreational impacts to local coral reefs. The document highlights a five year strategy and sets the framework for the long-term management of recreational use in Hawaii's coral reef ecosystems. Management strategies include: restricting access to reefs, relocating access to artificial reef sites, regulating use of the reefs, and enhancing educational outreach. The success of these strategies, along with recommendations for improvement, is marked by ongoing monitoring and research.

Methods:

In order to effectively compare trends observed in Hawaii's coral reef ecosystems to population changes and policy implementation, it is necessary to review the state of the reefs for all monitored years (2002-2008). This data is then compared to changes in Hawaii's population since 2002 and a review on Hawaii's report of the *Implementation of the National Action Strategy*, which details policy effectiveness and shortcomings. By reviewing and comparing this data, it is possible to confirm the success of Hawaii's conservation policies or to make recommendations for policy improvement.

Results:

Assessments and Reports:

Implementation of the National Coral Reef Action Strategy:

Since 2000, the USCRTF has made much progress toward accomplishing the *National Action Strategy's* goals, especially in the Hawaiian Archipelago. Benthic habitat maps were released in 2003 that characterized 60% of the shallow water habitats in the MHI. These mapping cruises showed a much higher coral cover than expected in many locations on the windward sides of the islands. This data has supported a re-evaluation of management strategies, including the potential proposal of new Marine Protected Areas (MPAs)

Coral health and disease studies were initiated in 2005 to characterize the prevalence, abundance, and distribution of coral disease in the MHI.

In 2006, the Papahahanaumokuakea Marine National Monument was established in the NWHI and is one of the largest conservation areas under the U.S. flag, encompassing over 362,000 square kilometers. The monument is home to over 7,000 marine species, a quarter of which are endemic to the

Hawaiian Archipelago. Reducing the impacts of pollution is also a main concern of the USCRTF. Between the years of 1996 and 2006, over 510 metric tons of debris was removed from the coral reef ecosystems and shorelines of the NWHI.

State of the Reefs

2002

The first state of the reefs assessment was prepared in 2002, two years after the implementation of the *National Action Strategy*. Because it was the first assessment of policy implementation, and rather the first attempt at creating methods and guidelines for conserving coral reefs in Hawaii, this document focuses mainly on identifying local threats to reefs, and areas where improvements to policy are needed. The population of Hawaii at the time was 1.2 million inhabitants, a 9.3% increase since 1990 (U.S. Census Bureau 2002, Table 21). Only two types of coral disease had been identified in Hawaiian reefs at the time; a general necroses and an abnormal 'tumor' growth (Hunter, 1999). These diseases include: *Porites lobata, P. compressa, Montipora capitata, M. patula, and Pocillopora meandrina* (Peters er al. 1986, Hunter 1999). It was stated that the incidence of coral disease did not appear to be consistently associated with anthropogenic stressors (Glynn et al. 1984, Peters et al. 1986, Coles 1994, Hunter 1999). It was also noted in this report that no major die offs of corals had yet been documented in Hawaii from bleaching or other causes.

The 2002 State of the Reefs report identified the enforcement of existing laws and regulations as a major problem in the conservation and monitoring of Hawaii's coral reefs. It is noted that many state and federal laws concern coral reefs, or impacts on them, but there are few that deal directly with the protection of reef ecosystems (Gulko 1998). Many of Hawaii's regulations have not kept up with new technologies, new use of natural resources, population changes, or the changes required to deal with increased versus diminished resources. This report also notes that President Clinton's Executive Order 13089 for the Protection of U.S. Coral Reefs (1998) had not yet been put into effect in the MHI. This order is important because it mandates federal agencies to make better use of their programs to protect and enhance U.S. reefs.

The monitoring of fisheries activities was also noted as a topic of particular concern in 2002 because management strategies did not provide information on the recreational or subsistence fisheries that account for much of the catch on Hawaiian coral reefs (*State of the Reefs 2002).* Future management strategies are anticipated to consider the habitat requirements and life histories of the species of interest, the extent of fishing pressure in the area, and the degree of regulatory enforcement.

The 2002 State of the Reefs report identifies a need for a true coral reef ecosystem reserve in the MHI where all activities should be restricted. It is noted that this reserve will not be likely for many years, if ever, due to the population growth in Hawaii and extensive use of reef resources.

2005

Since policies had been in effect for a few years, the 2005 State of the Reefs report provided a much more detailed account on the status of coral reefs in Hawaii. The 2005 report is the first federal document to recognize coral bleaching events in the Hawaiian Islands. The report notes two bleaching events having occurred and being recorded in Hawaii. The first documented coral bleaching event took place in the summer of 1996, with the most severe impacts observed on Oahu, Maui, and Hawaii. The second major bleaching event took place in the NWHI in 2002 (Aeby et al., 2003). These bleaching events were triggered by a prolonged positive SST anomaly greater than 1°C that developed offshore during the time of the annual summer temperature maximum. High solar energy and low winds further elevated inshore water temperatures by 1-2°C, particularly harming reef areas with restricted water circulation such as Kaneohe Bay, Oahu.

The 2005 State of the Reefs reports that after several years of monitoring, the average prevalence of coral disease in Hawaii (no. diseased colonies/ no. total colonies) was estimated at 0.95%. It was found that differences in disease prevalence related to coral genera, with *Porites* having the highest prevalence of disease. The most common condition found on *Porites* was growth of 'tumors', a condition which occurs only on the MHI (Hunter, 1999; Work and Rameyer, 2001). The second most common disease reported was *Porites* trematodiasis, which occurs on both the MHI and the NWHI. This disease is caused by the larval stage of the digenetic trematode and can cause reductions in coral growth up to 50% (Aeby, 1992). The 2005 report maintains that no major die-offs of coral in Hawaii have been caused by disease. It is also noted that Hawaii has no water quality monitoring programs that can assess sediment or chemical impacts to coral reefs. Pollutant concentrations generally decrease sharply within distance from shore, which results in Hawaii's offshore water quality being generally good. The report does state though, that because of increasing human usage and the impacts of climate change, there is reason for concern about the health of Hawaiian reefs.

The 2005 State of the Reefs report included details from Hawaii's Coral Reef Assessment and Monitoring Program (CRAMP) which provides a description of the spatial differences and temporal changes in coral reefs of the MHI. Results showed an average coral cover for the 152 monitored stations to be 20.8% ± 1.7 standard error (SE). Six species accounted for most of this coverage: *Porites lobata* (6.1%)*, Porites compressa* (4.5%), *Montipora capitata* (3.9%), *Montipora patula* (2.7%), *Pocillopora meandrina* (2.4%), *and Montipora flabellate* (0.7%).

Temporal trends showed that coral cover at most stations changed less than 10% over the three-year monitoring period. Sixteen stations showed a decline in coral cover, with the most severe decline of 19% occurring at the Kamalp 3-m station on Molokai. Contrastingly, thirteen stations showed an increase in coral cover, with the greatest of 14% occurring at the Papalaula Point 4-m station on Maui. (Figure 6)

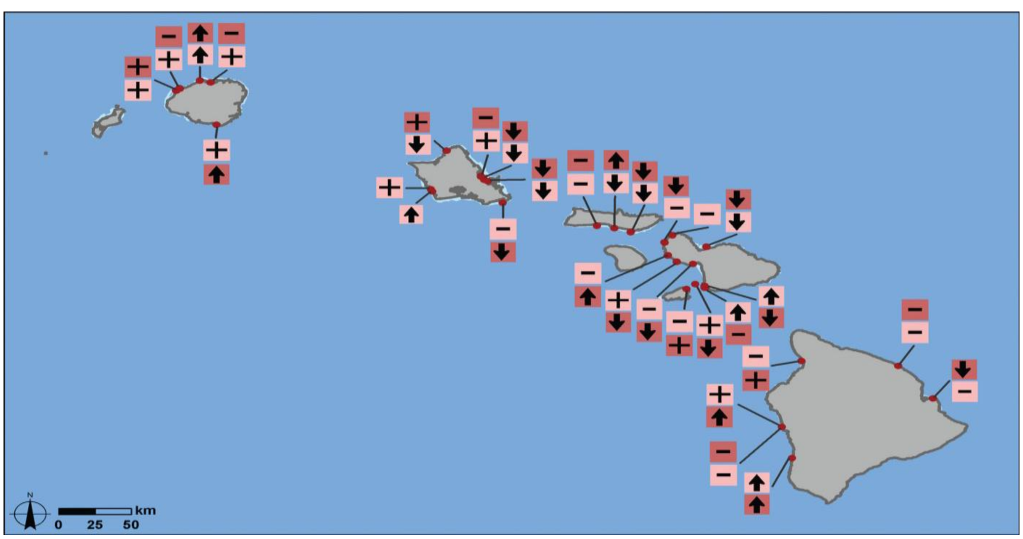

Fig 6: Results of CRAMP monitoring efforts from 1999 to 2004 showing trends in coral cover at sites across the state. Shallow sites (3 m roughly) are shown in light pink and deeper sites (8 m or greater) are shown in dark pink. Source: Jokiel et al., 2004.

Overall six reefs, which account for 10% of all monitored reefs, showed major shifts in absolute coral cover (>10%) which warranted more extensive study of the sites. Data showed that the most significant coral declines occurred on the islands of Oahu, Maui, and Molokai. (Figure7). Many researchers, locals, and natives have observed declining reefs in many areas of Hawaii over the past several decades. A study by Jokiel and Cox in 1996 suggests that degradation in Hawaiian reefs is caused by human population growth, urbanization, and coastal development.

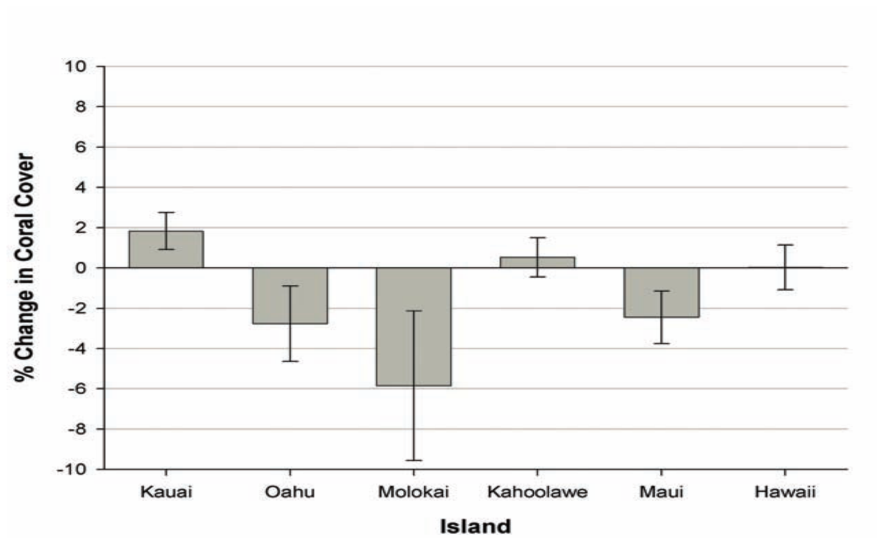

Fig 7: Trends in coral cover between 1999 and 2002 at CRAMP sites. Decline is shown for the islands of Oahu, Molokai, and Maui. Source: Jokiel et al., 2004.

The overall study showed that 13, of the 18 monitored sites had declined in coral cover since the first survey; a period of only 2 years. Declines during this time period are attributed to reef slumping (e.g. Kaalaea; Jokiel et al., 2004) and sedimentation (e.g. Honolua Bay; Dollar and Grigg, 2004). The 2005 report is careful to note that temporal trends should be interpreted with caution due to the short overall time span of the study.

The spatial patterns and temporal changes observed in coral community structure were compared to trends in human population in the 2005 State of the Reefs study. Results strongly suggest that Hawaii's growing population is causing increasing damage to the reefs. Long-term monitoring is required to differentiate between natural oscillations in coral structure versus alterations from anthropogenic sources.

2008

By the time the 2008 State of the Reefs report came out, eight coral diseases had been identified in the Main Hawaiian Islands. This is a significant increase compared to only 2 diseases being identified in 2002; a time span of *only six years*. Disease now affects all three coral genera and was widespread but occurred at low levels. Oahu, Maui, and the Hawaii had the highest occurrence and prevalence of disease (Aeby et al., unbublished data). (Figure 8). As a result, disease assessment is now part of the statewide coral reef monitoring program.

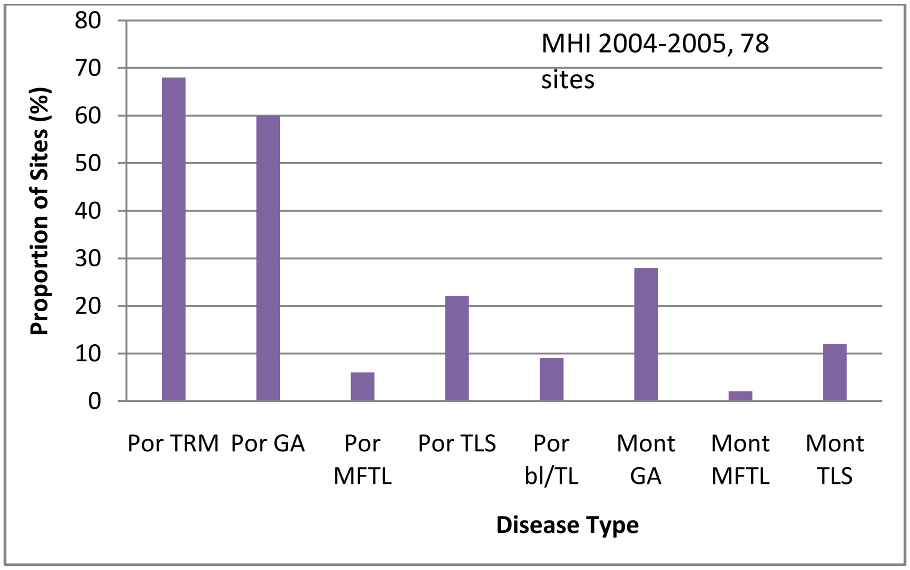

Fig 8: Frequency of occurrence of different coral diseases in the MHI. Por=Porites, Mont=Montipora, TRM=trematodiasis, TLS=tissue loss syndrome, GA=growth anomaly, MFTL=multifocal tissue loss, WS=white syndrome. Source: Aeby et al., unpublished data.

The 2008 State of the Reefs report indicated that there have now been *three* documented bleaching events within the Hawaiian Archipelago. The first two, as previously discussed, occurred in 1996 and 2002. The third recorded bleaching event occurred in 2004 in the NWHI (Kenyon and Brainard, 2006).

In 2008, the MHI average coral cover across 1,682 transect sites revealed a percent cover of 19.9% ± 0.6% SE, a decline of 0.1% in just two years. The relationship between coral cover to human populations in the upland watersheds indicate that larger populations result in lower coral cover. Long-term monitoring showed that 19 of the 27 monitored sites experienced a decline in coral cover. (Figure 9).

Island	Location	Depth (M)	1999	2000	2001	2002	2003	2004	2005	2006	Δ Since 1971
Kauai	Hanalei Bay	3	16	26	x	17	17	7	5	x	**-9**
		5	6	x	x	x	x	8	8	x	**2**
		7	23	x	x	x	x	23	16	x	**-1**
		8	28	30	x	26	36	29	29	x	**10**
		8	17	x	x	x	x	11	12	x	**4**
		14	17	x	x	x	x	25	19	x	**-1**
		16	25	x	x	x	x	22	18	x	**3**
Oahu	Kahe Point	3	9	13	15	17	17	8	6	x	**-14**

Oahu	Pili o Kahe	3	9	7	8	10	11	9	8	x	**-12**
Oahu	Kaalaea	2	62	51	49	67	59	x	58	x	**-35**
		8	3	2	4	3	3	x	x	x	**-4**
Oahu	Heeia	2	36	23	18	24	22	x	x	x	**-11**
		8	8	7	7	5	7	x	x	x	**6**
Oahu	Moku o Loe	2	30	20	16	13	14	x	x	x	**9**
		9	8	7	6	4	9	x	x	x	**9**
Oahu	Hanauma Bay	3	24	26	x	22	x	x	x	x	**-6**
		10	27	27	x	22	x	x	x	x	**-15**
Maui	Honolua Bay (N)	3	15	17	15	14	8	10	8	9	**-30**
	Honolua Bay (S)	3	21	27	23	24	21	23	11	9	**-34**
Maui	Kahekili	3	44	x	29	33	32	35	29	38	**-14**
		13	30	x	22	21	25	29	24	31	**-28**
Maui	Puamana	x	15	18	16	13	10	9	x	10	**6**
		x	3	3	5	6	5	6	4	5	**-7**
Maui	Olowalu	3	23	25	22	23	16	21	17	19	**-13**
		8	55	54	53	51	51	52	51	54	**-1**
Hawaii	Puako	3	x	x	x	x	x	x	x	x	**-5**
		10	x	x	x	x	x	x	x	x	**-18**

Fig 9: Average percent coral cover at selected sites that have been surveyed at time periods spanning 10 or more years. Overall percent change (Δ) from the initial survey to the last is listed in the last column. 'X' represents a lack of data. Source: Brown, 2004.

The 2008 State of the Reefs report concluded that a better knowledge of the spatial dynamics of Hawaii's Reefs is needed. With this understanding, it is possible to better assess impacts to coral reef ecosystems. It is important to determine where anthropogenic impacts are most likely to occur in Hawaii, as well as providing protection for sites with high biodiversity.

Population Changes v. Coral Trends in Hawaii

In order to compare population trends, to trends observed in coral reefs, data was related in linear from coral monitoring sites in each county, to population changes in each year. The comparison begins in 1999, because that is the first year data became available for percent coral cover in all counties.

Component	State Total	Hawaii	Honolulu	Kauai	Maui
Resident Population					
April 1, 2000	1,211,537	148,677	876,156	58,463	128,241
July 1, 2007	1,283,388	173,057	905,601	62,828	141,902
Net Change	71,851	24,380	29,445	4,365	13,661

Resident Births	130,786	15,925	95,352	5,729	13,780
Resident Deaths	64,005	9,110	45,337	3,201	6,357
Foreign Migrants	30,891	3,039	22,914	995	3,983
Internal Migrants	-20,583	15,147	-39,721	1,150	2,841

Fig 10: Changes in the resident population of Hawaii by county. Source: Hawaii DBET

Overall, the average percent coral cover in the MHI has declined since it was first observed and mapped in 1999. Nineteen of the twenty-seven sites surveyed experienced a decline in coral, and of those, eleven experienced a loss of 10% or greater. Observations revealed that the most populous islands experienced the greatest loss in offshore corals. A linear comparison between monitored sites on Maui and Oahu shows a correlation between population growth and coral decline. (Figures: 10-14) There was not enough data available to effectively compare coral cover to population changes on Kauai or the Hawaii.

Due to the short time span of the study of corals in Hawaii, it is necessary to interpret all results with caution. It is relevant to note that trends of significant decline have been seen since the first monitoring of corals in Hawaii, less than a decade ago. An overall decline in corals surrounding the island of Oahu was observed from 1999 to 2006 (Fig 11). This likely correlates with the growing population of the island observed during the same years (Fig 12).

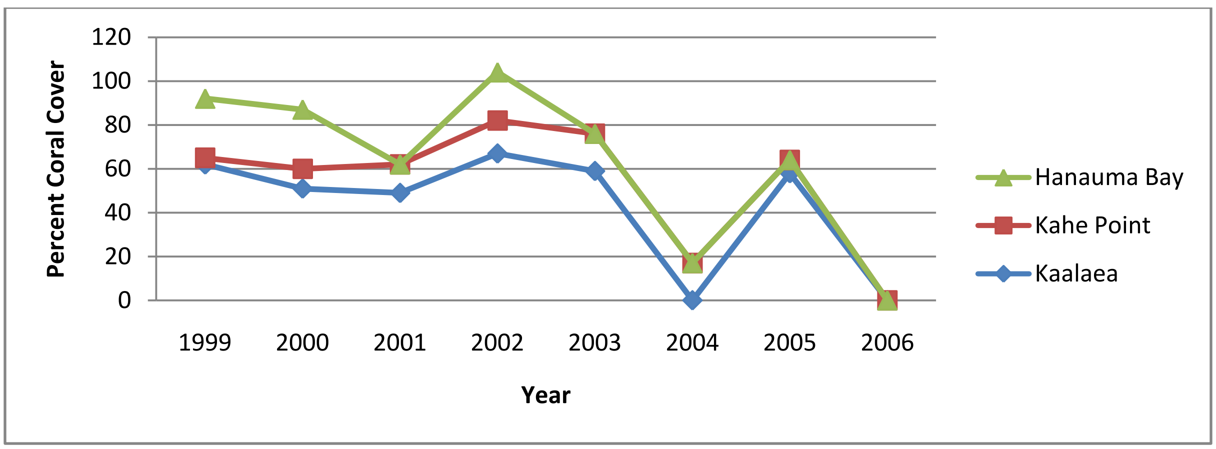

Fig 11: Trends in coral cover on three observed Oahu sites from 1999-2006.

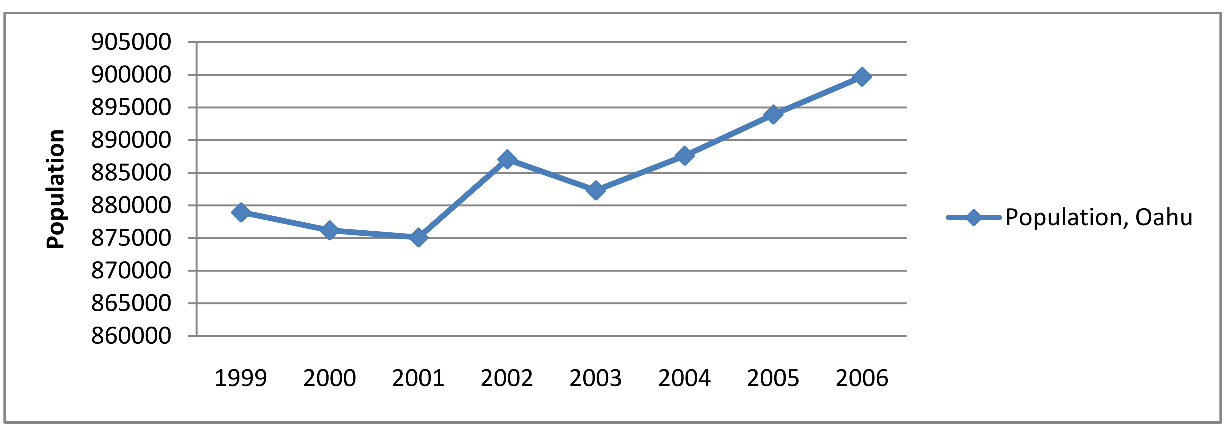

Fig 12: Trends in the population size of Oahu from 1999-2006.

A decline in corals was observed on Hawaii's second-most populous island, Maui, for the years between 1999 and 2006 (Fig 13). This too, likely correlates with the observed population increase on the island for the same years (Fig 14).

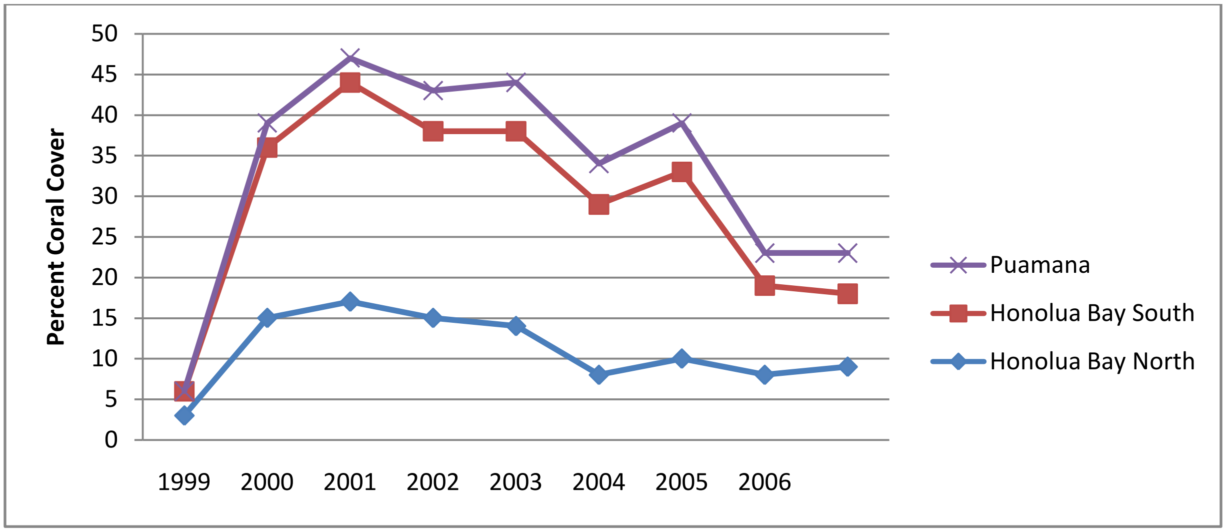

Fig 13: Trends in coral cover for three observed coral reef sites on Maui from the years between 1999 and 2006.

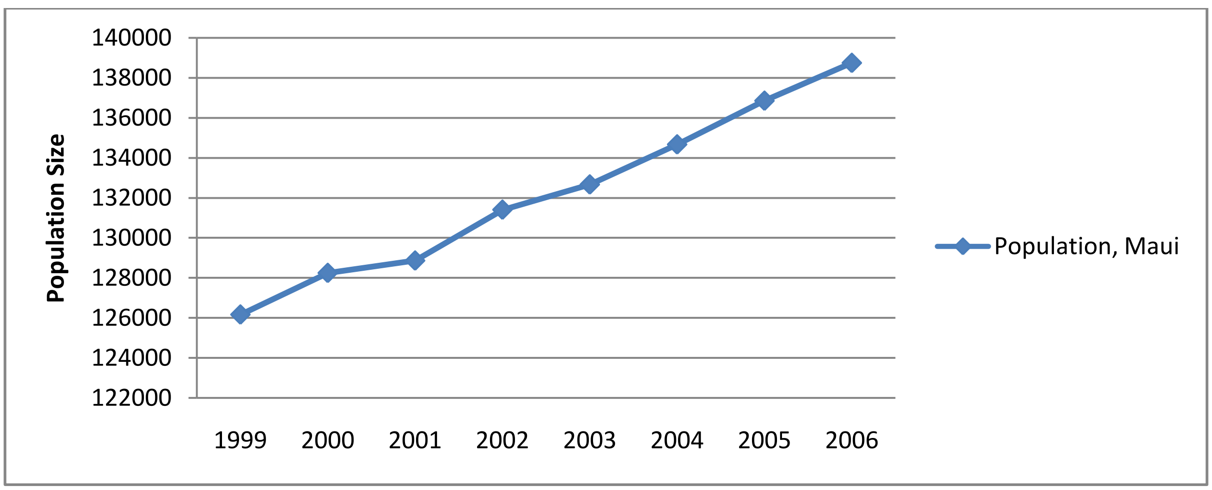

Fig 14: Trends in the population size of Maui from 1999-2006.

Future Projections:

Models projecting future population trends in Hawaii reveal a steady growth in the size of the human population on the Hawaiian Islands (Figures 15-17). This is significant to the future of coral conservation in Hawaii because this study has revealed a correlation between population growth and coral decline. If the state's population continues to increase, adequate funding and monitoring needs to be put into place to ensure survival of the reefs.

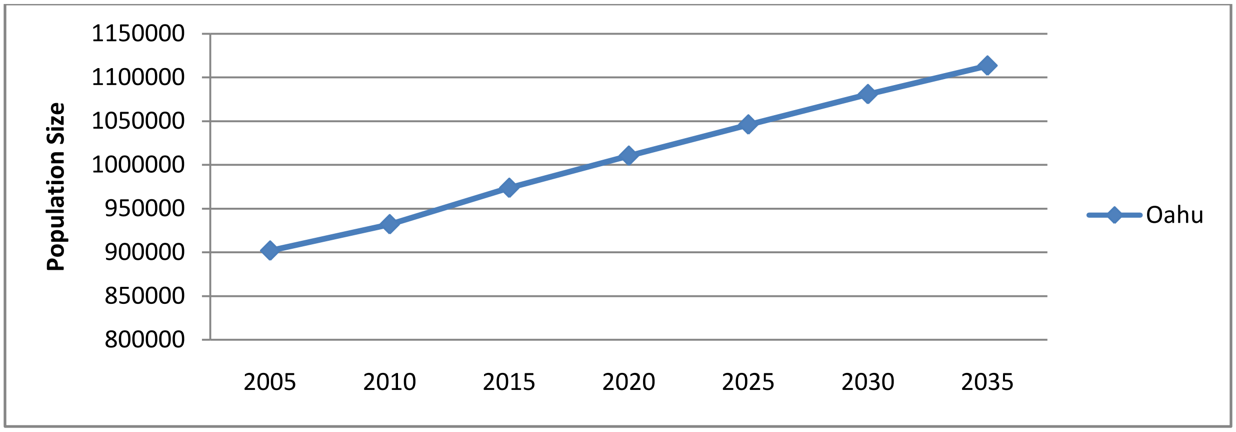

Fig 15: Population projection for the island of Oahu. Source: Hawaii DBET.

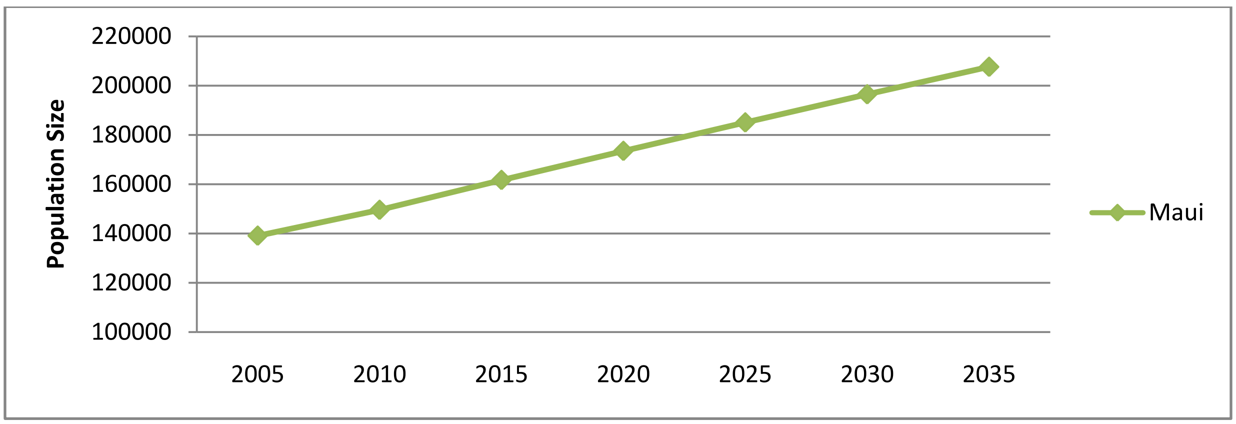

Fig 16: Population projection for the island of Maui. Source: Hawaii DBET.

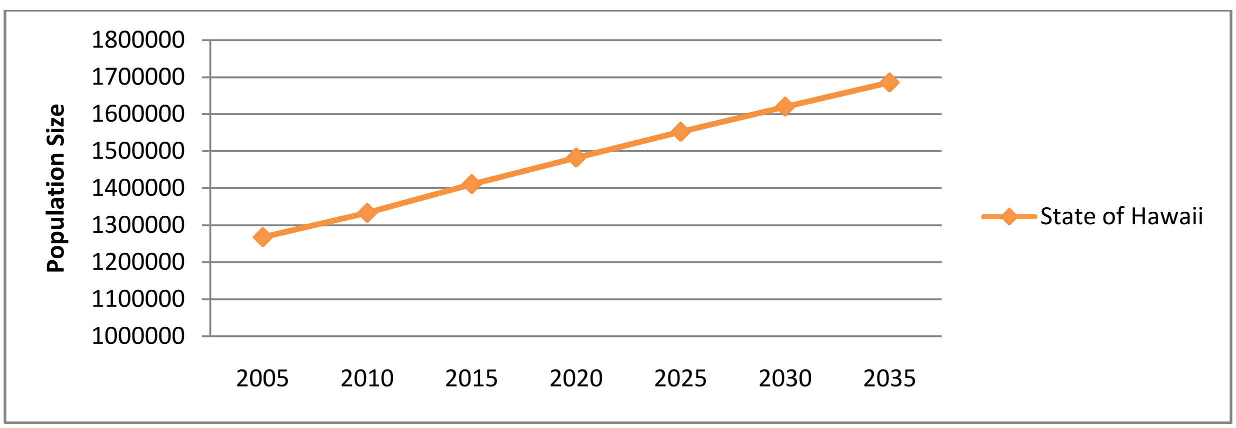

Fig 17: Population projection for the state of Hawaii. Source: Hawaii DBET.

Discussion:

The results of this study reveal a direct correlation between population growth and coral decline in Hawaii. This suggests that humans are an increasing threat to Hawaii's coral reef ecosystems. The effects of anthropogenic stressors needs to be better understood through monitoring of the reefs and policies need to be continually modified in order to develop the most effective coral management strategies for the state of Hawaii.

It is interesting to observe in this report that coral reefs have been declining overall since policy implementation in 2000. Extensive conservation and monitoring efforts did not take place before that time meaning that the results of this study need to be interpreted with caution. Policy implementation in Hawaii has been effective in developing groundwork for coral conservation in the future. Local threats to the reefs have been identified through research and methods are being developed to better understand their impacts and to address the threats in the most effective manners.

The study and management of Hawaiian coral reef ecosystems can provide valuable information to conservationists and stakeholders around the world. Coral reefs are primary indicators of detrimental human activity on land and because the Hawaiian system is so isolated from any other land source, it is easier to identify anthropogenic impacts to reefs and their effects. This attribute can be a valuable resource in the movement toward global reef sustainability.

The sustainability of coral reef ecosystems is critical for a number of reasons. Coral reefs are key components to the livelihoods and economies of people around the world and they provide a basis for fishing, tourism, and recreation. Reefs are a critical habitat for a number of species and are considered among the most biologically diverse ecosystems on the planet. Coral reefs are of terrestrial importance because they provide a buffer zone between land and open-ocean wave action. This reduces rates of erosion and protects against damage from high wave energy.

Hawaiian reefs can be valuable resource in climate change research. Because the systems are so sensitive to changes in temperature, and are among the most isolated in the world, Hawaiian reefs can be leading indicators of the direct effects of climate change.

Overall, coral conservation policy implementation in Hawaii has made outstanding progress in formatting a means at better understanding, monitoring, and protecting the reefs. It is necessary to better enforce regulations and policies concerning the reefs in order for efforts to be most effective. It is suggested that monitoring reports be produced annually, rather than biannually. This may increase the understanding of what is happening to Hawaii's coral reefs on a more time-efficient scale and policy can be adjusted accordingly, before too much damage is done.

It is also recommended that policies addressing threats to the reefs be applied on a more location-based scale. Many factors, including the varying locations of more vulnerable coral species, the variability of water circulation patterns, and the variability of locational human activity, can cause coral reefs to be impacted differently by stressors on different areas of the islands. It is recommended that conservation and management policies be developed to suit the locations of each reef. For example, reefs in areas with lower water circulation are potentially threatened more by sediment runoff and climate change. Other locations have a higher prevalence of coral species that are more susceptible to disease. Management strategies that address threats unique to individual locations could be more effective in improving reef health. Location-specific strategies could result in a lower fiscal cost if money is not being expended on policies that may have no benefit to an area. (Ex: it may not be necessary to enforce fishing or human traffic regulations in areas where little activity takes place.) Further monitoring and assessment may be necessary in order to modify current strategies and to decide what methods are best for specific locations around the MHI. The development of an effective reef management strategy in Hawaii could provide a framework for coral conservation around the world.

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