

TITLE: Managing NPSA coral reefs in the face of global warming

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PARK: National Park of American Samoa (NPSA)

Contact: Peter Craig 684-633-7082

USGS-Biological Resource Division

Contact: Charles Birkeland 808-956-8350

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ABSTRACT: It is predicted that coral reefs worldwide, including those within the National Park of American Samoa (NPSA), will suffer substantial mortality over the next 20-30 years due to global warming. Forecasts of this phenomenon developed as widespread mortality of corals began in the early 1980s, increased with frequency of extraordinary warm ocean waters, and culminated in 1997-98 when corals around the world were devastated by increased ocean temperatures in the warmest year on record (since 1861). Although adult colonies of some important groups of corals such as acroporids showed 90 - 99 percent mortality, some small (< 10 cm colony diameter) colonies survived. Competing hypotheses attribute survival to small colony size or young colony age. Whether the most effective strategy to maintain or restore NPSA reefs will be by transplanting coral fragments or by sustaining broodstocks depends on which of these hypotheses is correct. The particular environmental conditions and diverse coral communities in NPSA provide an exceptional opportunity to find which of these hypotheses is correct and to develop the best management procedures for dealing with the predicted stresses on coral reef systems. The proposed cooperative investigation by USGS-BRD and NPS would experimentally compare survival rates of transplanted corals of differing ages and sizes at a uniquely suitable location in American Samoa, Ofu Island, where transplants would be naturally subjected to differing regimes of stressful environmental conditions likely to affect their survival and growth. This provides NPS, in cooperation with USGS-BRD, the opportunity to help lead the world in development of a capacity to handle the imminent threat to coral reef resources.

DESCRIPTION OF THE PROBLEM

Introduction

Coral reefs are critical components of local and regional economies in the U.S. Reef-related tourism generates an estimates \$8.2 billion in local income and sales for U.S. States and territories (Turgeon and Asch 2001). Commercial reef fisheries add \$94.8 million to local economies in the U.S. The input from recreational fisheries has not been calculated for the U.S. as a whole, but for the state of Florida alone, recreational fishing

on coral reefs was estimated at \$500 per year. Because of the growing scientific and public concerns for coral reefs, President Clinton established a U.S. Coral Reef Task Force in 1998 as a joint project for the U.S. Department of the Interior and U.S. Department of Commerce. The U.S. Congress appropriated \$10 million annually from FY00-02 to the Department of Interior to enhance its coral reef conservation activities (Turgeon and Asch 2001).

The National Park of American Samoa (NPSA) has jurisdiction over 2,550 acres of coral reefs along 17 miles of coastline within park units on Tutuila, Ofu, and Ta'u Islands in American Samoa. Shallow coral reef ecosystems such as those within NPSA are among the most diverse ecological communities on earth, often supporting several hundred species of fishes and non-coral invertebrates in a small area. Coral reefs of NPSA are currently the most robust and pristine within the U.S. and its territories, and one of the primary management objectives in NPSA is to preserve these ecosystems for future generations. However, global warming and increasing local anthropogenic threats are predicted to cause major stress to coral reefs within the next few decades.

Global warming will result in increased sea surface temperatures which can be lethal to corals. During the warming event in the south central Pacific during 1994, extensive mortalities occurred among branching acroporid and pocilloporid corals throughout American Samoa and especially on a shallow reef on Ofu Island within NPSA (Craig et al. 2001). In 1999 and 2000, American Samoa narrowly missed being impacted by a warm water mass that caused several coral damage in the nearby islands of Fiji and (western) Samoa.

We need to develop techniques to counter the effects of global warming on corals in NPSA, manage coral reefs to maximize their resilience to stressful disturbances, and to facilitate the recovery of coral reefs following mortalities caused by such disturbances. Although the NPS cannot directly manage global warming, the situation at the NPSA reef at Ofu Island provides an especially good chance to develop a means of ameliorating the effects of global warming on coral reefs. The Ofu site is ideally set up for the proposed study because it consists of a series of large pools that differ in severity of fluctuating environmental conditions. These pools support a diverse community of 85 species of corals living in extreme conditions of fluctuation of environmental parameters (seawater temperature range of 6.3 °C per day and O₂ fluctuates 5 to 220 percent saturation daily) which will allow us to definitively determine whether management of corals by transplantation of adult fragments or by transplantation of juvenile colonies will be the most effective means of facilitating recovery of coral reefs during the imminent periods of extraordinarily warm seawater. The NPS, in cooperation with USGS-BRD, now has a special opportunity to develop a method to handle this global problem for reefs by local action.

Problem Statement

The response of corals in NPSA to the stresses brought about by global warming and other stresses is complicated by (1) possible differential survival rates between species

with regard to environmental conditions, resulting in variations in coral diversity across small gradients in water quality parameters such as temperature, and (2) differential survival under stress of small or juvenile coral colonies compared to larger or older colonies of the same species. An example of the first point is provided by findings of Craig et al. (2001) that coral diversity in the shallow, backreef Ofu Lagoon varied from 79 species (20 acroporids) in a 2 meter deep pool to 52 species in an adjacent 1 meter deep pool. Temperature variation was greater in the shallower pool, and the range of other environmental conditions such as salinity, irradiance, and dissolved oxygen may have also varied between the pools. An example of the second point is that the circumglobal seawater warming of 1997/98 caused nearly total mortality of adult acroporid corals (colonies > 10 cm) in certain areas while small or juvenile acroporids (colonies < 10 cm diameter) in these areas generally survived (Loya et al. 2001). Possible explanations for this differential survival may be physical (i.e., water circulates differently around small vs. large colonies) or physiological (i.e., younger colonies are more robust, perhaps because their energy is devoted to growth rather than reproduction).

Conservation of coral reefs in NPSA over the long term requires both maintaining healthy conditions within the coral reef ecosystem (to maximize resilience to warming events and other disturbances) as well as facilitating coral restoration after a disturbance causes large-scale mortalities. Understanding why younger and/or smaller coral colonies survive a warming event that kills larger, older colonies will allow NPSA staff to concentrate management efforts on the most critical life history stage (i.e., is it small size or young age that increases survivability during warming events?), and to form a restoration strategy for responding to future coral mortalities (i.e., if transplants are used for restoration, should they be small/mature or juvenile colonies?). If small but mature colonies survive a warming event well, management should emphasize minimizing anthropogenic stress on these and other coral broodstocks. Alternatively, if only juveniles survive warming events well, management should emphasize a restoration strategy based on transplanting juvenile colonies to the most affected areas.

Recommended Action:

The recommended action is to investigate the relationships of environmental parameters to coral diversity within NPSA, and to determine whether coral colony size or age is the primary factor favoring survival under stressful conditions such as the high temperatures that are anticipated from global warming. The study design and methods are described below.

Study Design

An understanding of the causes of coral diversity patterns and survival rates across a range of environmental conditions in shallow waters is needed to predict how such local and global changes are likely to affect shallow coral communities in NPSA. Most importantly, the determination of biological traits of corals that favor the survival and replenishment of reef communities after stressful conditions have occurred will hopefully allow the maintenance of reef communities in the NPSA following severe stress. The

proposed project will: (1) experimentally determine whether patterns of coral species distribution and diversity are caused by environmental conditions or random recruitment and (2) experimentally determine whether it is size or age that has been the aspect of small coral colonies that has been allowing their differential survival during extended periods of severe stress from extraordinarily warm seawater. This study is designed for a backreef lagoon in the Ofu Unit of NPSA, but the results would be broadly applicable to other coral reef areas.

To test both sets of hypotheses, two sites will be selected (Pool A and Pool B) within the moat on Ofu Island at depths of 1 m. The first null hypothesis is:

Ho₁ The distribution of species among the diverse coral assemblages in separate pools in the moat on Ofu Island is random, apparently based on where settlement happens to occur.

This will be concluded if the survival and growth of corals is the same in both the pool in which they were originally found and in the pool to which some of them were transplanted.

Ha₁ The distribution of species is determined by the environments being favorable in the pool where they are found and less favorable in the pool where they are not found.

This will be concluded if the survival and growth of corals is best in the pool in which they were originally found and less favorable in the pool to which some of them were transplanted.

The second null hypothesis is:

Ho₂ The survival of colonies of acroporid corals during periods of extraordinarily warm water is independent of colony size or age.

This will be concluded if the survival and growth of acroporid coral colonies transplanted to the pool in which they are not previously found is the same among colonies of different sizes and ages

Ha₂₁ The survival of colonies of acroporid corals during periods of extraordinarily warm water is independent of colony size.

This will be concluded if the survival and growth of small acroporid coral colonies (< 5 cm diameter) transplanted to the pool in which they are not previously found is better to survival and growth of larger colonies, whether the small colonies are juveniles or small fragments taken from larger colonies.

Ha₂₂ The survival of colonies of acroporid corals during periods of extraordinarily warm water is independent of colony age.

This will be concluded if the survival and growth of young acroporid coral colonies (juvenile colonies naturally found at < 5 cm diameter) transplanted to the pool in which they are not previously found is the same as older colonies of similar size (fragments of colonies < 5 cm diameter taken from larger older colonies) .

For Ho₁:

1. Corals will be transplanted to sites where they do not naturally occur or where they are less common. *Porites cylindrica* (25% of coral cover in Pool B but absent in Pool A, cf. Craig et al.2001) and *Pocillopora damicornis* (twice as abundant in Pool A as in Pool B, cf. Craig et al. 2001) will be the main species used in the experimental test of the first hypothesis. Forty nubbins of *Porites cylindrica* will be taken from Pool B to Pool A. Twenty of these nubbins will be transplanted from Pool B to Pool A. The other 20 will be taken back and replanted to original sites in order to control for effects of handling, transportation and transplanting. Likewise, 40 nubbins of *Pocillopora damicornis* will be taken from Pool A to Pool B. Twenty of these nubbins will be transplanted from Pool A to Pool B. The other 20 will be taken back and replanted to original sites in Pool A to control for effects of handling, transportation and transplanting. The survival and growth of these 80 corals will be monitored for three years.
2. The nubbins of *Pocillopora damicornis* and *Porites cylindrica* will be taken from large colonies and should not be noticeable to NPSA visitors and should not substantially affect the health of the colonies. The skeletons of the nubbins will be stained with the medical bone dye Alizarin red S, a standard method for marking the initial size of coral colonies in growth studies. This will allow precise measurements to the nearest millimeter at the end of the experiment.
3. The nubbins will be attached to the substratum with Sea Goin' Poxxy Putty (Birkeland 1976). This epoxy resin is nontoxic to corals and has been a standard method of transplanting corals in the field for 25 years. It is so nontoxic that it is rapidly overgrown by encrusting organisms and is therefore not visible to visitors to the NPSA.
4. The temperature, salinity, irradiation, dissolved oxygen, conductivity and alkalinity will be monitored at 1 m depth in Pools A and B over 3 years by placing water quality data loggers at each of the two sites. This will allow us to determine any differences between Pools A and B in daily and seasonal environmental conditions.
5. Determine differences between sites in coral species diversity by mapping the sites for coral species and percent cover and documenting any changes over the three-year study.

6. Any differences between sites in biological factors affecting corals (e.g., predation, grazing, disease) will be documented by examining coral colonies in the moat for tooth marks and for signs of disease.

For Ho₂:

1. Craig et al. (2001) found 19 acroporid species in Pool B and nine in Pool A. Up to four acroporid species that occur in Pool B but not in Pool A will be selected for a transplant experiment whereby age and size groups of each species will be transplanted to Pool A to expose the transplants to the environmental conditions where they were not found. Conversely, at least two acroporid species that are found in Pool A but not in Pool B will be transplanted to Pool B.
2. Each species will be transplanted as at least eight newly settled juvenile colonies (< 5 cm colony diameter), at least eight small (< 5 cm diameter) fragments from larger colonies, and at least eight larger (> 20 cm diameter) fragments from larger colonies. Each transplant group (i.e., a single-species group) thereby consists of juvenile and small colonies (juvenile/small), mature and small colonies (mature/small), and mature and large colonies (mature/large). The juvenile/small colonies will be those settled as planula larvae (i.e., not small because of fragmentation or partial mortality of a colony). The mature/small colonies will be small pieces taken from large colonies. The mature/large colonies will be transplanted as large colonies. The survival and growth of each transplant group will be monitored for three years to determine whether it is size or age that determines the differential survival of acroporids to environmental stressors.

For controls:

The effects of transportation, handling, and transplantation will be controlled with the reciprocal transplants in the experimental design for Ho₁. To control for the possibility that coral colonies do not have time to acclimate to a new environment, we will also transplant a species that is common in both Pool A and B into the new environment of the other pool, i.e., the same species from Pool A to Pool B and from Pool B to Pool A. *Porites lichen* and *Goniastrea retiformis* may be appropriate species.

Methods

Site location. Two sites will be used in the moat of the reef in NPSA at Ofu Island, Pools A and B as indicated in Figure 1 in Craig et al. 2001. The experiments at each site will be done at a low tide depth of 1 meter. One water quality data logger will be placed in each pool. At low tide, Pool A is approximately 4,000 m², and Pool B is approximately 27,000 m² (Craig et al. 2001), and each pool contains many coral patches, which will be mapped and numbered. Several coral patches within each pool will be selected for the experiment. The resident coral colonies and the transplanted nubbins will be mapped. At least 100 quadrats will be sampled in each pool, and the average percent cover per

species will be calculated to determine coral species abundance in each pool (Craig et al. 2001).

Water quality. The water quality parameters temperature, salinity, irradiation, dissolved oxygen, conductivity and alkalinity will be monitored for the 3 year period. The mass mortality of reef-building corals associated with increased seawater temperatures has been of major concern around the world. At least 85 species of coral live in the NPSA moat on Ofu Island where the temperature may fluctuate daily through a range of 6.3 °C. The difference in species compositions among pools may be explained by the difference among the pools in seawater temperature ranges associated with the different tolerances among coral species. Irradiation is likely to be a major environmental factor for corals in the shallow water in the moat at Ofu Island at times in the summer when the sea is glassy calm at low tide. The waters around the corals in the moat of the NPSA reef at Ofu Island varies from 5% to 220 % saturation of dissolved oxygen. These aspects of water quality must not be dismissed, so we have planned to monitor these water quality parameters with a water quality data logger in each pool.

Coral transplants. To test H_{o1} , a total of 80 small coral fragments (nubbins) will be transplanted; 40 nubbins of *Pocillopora damicornis* will be transported from Pool A to Pool B, and 40 nubbins of *Porites cylindrica* will be transported from Pool B to Pool A. To control for effects of handling and transportation, half of the transported nubbins (i.e., 20 for each species) will be transplanted back to their place of origin and reattached. All transplanted nubbins will be attached to cleaned, hard, natural surfaces with a nontoxic epoxy (Sea Goin' Poxy Putty; Birkeland 1976). The location of all transplanted nubbins will be noted on the map of coral patches within each pool, and survival and growth rates will be monitored at least every six months for three years.

To test H_{o2} , a total of 96 coral fragments of the acroporid species will be transplanted into Pool A; for each of four acroporid species found originally in Pool B but not in Pool A (perhaps *Acropora aculeus*, *A. digitifera*, *A. muricata*, and *A. microphthalma*), groups of 8 apiece of large/mature, small/mature, and juvenile colonies will be transplanted into and attached in Pool A with the same method used for the H_{o1} transplants. Conversely, a total of 48 coral fragments of two acroporid species found originally in Pool A but not in Pool B (perhaps *Acropora nasuta* and *A. verweyi*) will be transplanted into Pool B.

To accurately monitor and compare the growth rates of the different groups within each transplanted species, all transplanted colonies will be dyed with Alizarin red S before they are attached. After the three year monitoring period, the transplanted colonies will be removed and the dye will provide the means for accurate growth estimation.

Field work. During the 3 year study, field work will be conducted twice annually at Ofu Island. Each year, there will be one 3 to 4 week field season in July or August for coral transplants and monitoring (i.e., coral surveys will be done the first year and then repeated the second and third years), and either placing the transplants (first year) or monitoring their survival and growth (second and third year). Each year, there will also

be a second 1 to 3 week field season in January or February for checking data loggers and monitoring the survival and growth of the transplants.

Equipment. This study will not require scuba gear or boats, as all field work will be conducted from shore with snorkeling gear. A data logger designed for long-term logging of multiple water quality parameters will be needed for each of the two pools. A laptop computer is needed for downloading of data from the loggers as well as data entry during field seasons. This equipment would be owned by NPSA, used for the duration of the study, and then returned to NPSA.

Effects on park. The study would have minimal visual effects on the Ofu Island NPSA pools. The two cylindrical data loggers (18" x 3") would be attached to the substrate at 1 m depth for the duration of the study. The 224 transplanted coral fragments would be small but unnatural until the epoxy encrusts over, which would take about two weeks. After that, the transplants will appear natural. The removal of the 224 coral fragments for transplanting would not substantially affect the health of the coral colonies because reattachment of branches broken from acroporid colonies by wave action is a common form of asexual reproduction in branching acroporid corals (Birkeland and Lucas 1990). This proposal has been approved by NPSA's superintendent.

Personnel

This project will be supervised by Dr. Charles Birkeland (USGS-BRD) and Dr. Peter Craig (NPSA). Graduate student Lance Smith of the USGS-BRD Hawaii Cooperative Fisheries Research Unit at the University of Hawaii will conduct this study.

PRODUCTS:

This study will provide NPSA with essential information that will contribute to the development of an overall strategy to manage predicted coral mortality due to global warming and other disturbances. Data will be submitted in format(s) compatible with NPS and other databases and GIS. Results will be published as NPS Pacific Cooperative Study Unit technical reports, and in refereed scientific journal(s) and will provide the materials for a PhD thesis for Lance Smith at the University of Hawaii. The two study sites in NPSA on Ofu Island could be used as permanent coral monitoring sites.

BUDGET:

In Kind Services (i.e., NPSA contributions):

- Coordination of permits and other logistics that cannot be done from Honolulu
- Checking of data loggers and transplants twice a year between the field seasons (i.e., around April and October)

Costs

Graduate student salary/benefits \$17,000/yr x 3 yrs	\$51,000
Air and per diem	10,000
Miscellaneous equipment and supplies @ \$500/yr x 3yrs	1,900
University Overhead @ 15%	<u>11,100</u>
TOTAL COST	\$74, 000

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