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3/28/03

Restoration of Coral Reef Habitats Within the National Park System

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*Paper Presented at the 2003 Biennial Conference of the George Wright Society
Town and Country Resort and Convention Center, San Diego, California
April 14-18, 2003*

Introduction

Need to Extend NPS Restoration Expertise to Marine Environments:

The National Park Service has long been involved in a broad array of resource restoration activities designed to enhance the recovery of injured natural resources within terrestrial environments. When natural resource injury occurs from overuse, man-caused fire, physical abuse, accident, or other unnatural factors, rapid restoration and recovery is important, both to other resources that use and depend on the injured resource, and to the visiting public who is denied the opportunity to enjoy that resource use. Restoration actions are also necessary to reducing cumulative impacts to these already stressed systems and to speed the recovery of ecosystem function to minimize loss to other dependent organisms.

Within coastal marine environments natural resource injury is common. As we carry out our responsibilities to protect the resources with marine national parks, we need to extend our expertise on restoration of natural resources to the marine environment, particularly within coral reef ecosystems.

Coral reefs are often highly vulnerable to human caused injury. They occur in relatively shallow water, are highly visited and used by the boating public, and are often located near navigation and shipping channels. Injury from wayward shipping vessels, recreational boat groundings, anchors, sport divers and fishing gear frequently occurs, compounding other reef stresses and creating the need to repair and restore injury. At Biscayne National Park over small boat grounding incidents occur each year on the reefs and in shallow-water seagrass beds within Biscayne Bay. Five major groundings of large fishing boats, barges and container ships have occurred on Biscayne's reefs in the last five years. At Dry Tortugas National Park a major grounding of the motor vessel Mavro Vetrican occurred in 1989. There have been ... additional groundings on the parks coral reef resources since that time. The latest event came last year when two shrimp fishing vessels drug anchor and grounded on reefs immediately

next to the Fort. Similar high frequency of grounding events occur within Virgin Islands National Park and at coral reef parks in the Pacific. Many vessel grounding events result in massive damage that requires mitigative actions to achieve ecological recovery.

Funding Availability and Legal Obligations:

The *Park System Resources Protection Act* (16 U.S.C. 19jj, often called 19jj) provides a legal framework for the NPS to collect civil damages for injuries to park system resources caused by a third party, in order to restore those injured resources and resource services. Further this statute has allowed the NPS to recover damages for the purposes of restoring coral reef resources.

But engaging in restoration activities brings forth the need to develop acceptable restoration approaches, including:

- A logical process of assessing damage;
- Stabilizing impacts; and,
- Determining appropriate techniques to be used to restore structure and function, given the type and level of damage sustained within the incident.

NPS Interdisciplinary Restoration Team

To help address the issue of coral reef ecosystem restoration at Biscayne National Park and elsewhere, the Natural Resource Program Center in conjunction with Biscayne National Park staff has formed an interdisciplinary Coral Reef Restoration Team. This team is reviewing past coral reef and seagrass restoration actions, compiling available scientific literature on restoration techniques, and developing a guidance document that can be used to address future injury incidents within the park. The working group is attempting to:

- Define what constitutes restoration and what the goals should be for park restoration activities.
- Access past restoration techniques and method employed at Biscayne and elsewhere and determine which techniques are appropriate for use within Biscayne and other National Park units and under what circumstances.
- Develop a decision tree and guidance document that can help park staff make rapid decisions and correctly deal with a wide variety of grounding incidents.
- Complete a programmatic EIS on the decision tree and guidance document that can be applied to all future site specific restoration actions in response to injury incidents.

Challenges of Coral Reef Restoration:

Ocean environments present special challenges to those wanting to mitigate natural resource injuries and undertake restoration actions. This is particularly true for coral reef ecosystems. Some of the reasons coral reefs are particularly challenging are:

- *Coral reefs often have an extremely high density and diversity of organisms and are ecologically complex.* All of the macro-organisms injured or disturbed by even a minor incident of small spatial extent can number in the several of thousands (Glynn 1976, Connell 1978, Gulko 1998). Human replacement of all organisms, or even types of organisms, impacted during an injury event is usually not possible, and natural recruitment and regrowth can require decades or more to occur (Salvat 1987). In the highly competitive and ecologically complex reef ecosystem, often the natural balance of organisms present is also important (Connell 1976, Glynn 1976). Organisms selected for transplanting or repair, if not placed carefully and with natural processes in mind, can gain an unnatural advantage, prevent recruitment of others, and eventually result in permanently altered communities.
- *Coral reefs occur in high energy environments.* Ocean surge, wave action and currents are continuous and often relentless in their effects on restoration attempts. Terrestrial approaches to replacing soil or substrate and transplanting vegetation to mitigate injured organisms often will not work within the reef environment without extraordinary measures to stabilize the material transplanted.
- *Many fragile and/or site specific micro habitat species.* Coral reefs are highly competitive environments and reef organisms have often evolved into highly specialized niches (Connell 1976). The organisms themselves are often fragile and easily destroyed if exposed to open reef surfaces, currents, increased light, or other environmental differences that may occur outside their preferred micro-habitat. Water depth can also be very important to what species occur and how they grow. If ship groundings remove reef structure, expose reef area, or destroy micro habitats that are suitable to individual species, the pre-injury reef community may not be able to be reestablished without recreating the original topographic structure and habitat complexity (Pearson 1981, Miller et al. 1993, Jaap 2000, Hudson and Goodwin 2001).
- *Lack of experience and knowledge in successful restoration techniques.* Restoration in coral reef environments is a relatively new science (Pearson 1981). Many techniques are still being work out and evaluated. Some techniques that have been applied are inappropriate for use in National Parks.

Because of the slow growth of coral and many other reef organisms, a long time period is often needed to fully evaluate results. In addition, to deal with high

energy forces within this environment, artificial materials and adhesives have often been used to stabilize reef substrate and to recreate the topographic relief and habitat complexity necessary to reestablish overall pre-injury species diversity (Miller et al. 1993, Hudson and Goodwin 2001). There has often been disagreement between “experts” on the success and desirability of these techniques.

- *Greater difficulty in defining goals.* Because the impacted site often can not be completely restored to its pre-injury state through mitigation actions, and because successful mitigation, aimed at preventing future resource loss or increasing rates of recovery, has often involved the use of artificial materials, there is disagreement on the appropriate goals for restoration actions. Different agency or organizational missions has led to differences in opinion on what is an acceptable mitigative action and in defining site specific restoration goals.

Challenges Faced When Attempting to Develop Restoration Plans

Because natural resource restoration in coral reef environments is a relatively new science, there are several challenges the Interdisciplinary Restoration Team is facing in developing a guidance document and restoration plans for the park. Some of these challenges include:

- Development of a descriptive lexicon of reef habitat injuries
- Classifying injury incidents as to size, type and restoration action categories
- Determining appropriate restoration actions for the differing reef habitat injuries.
- Deciding what actions are appropriate for National Park Service areas
- Deciding between short term benefits of restoration actions and potential long term detriments of adhesives or other foreign materials often necessary to mitigate injuries and speed reef recovery
- Establishing goals and measures of success that can be evaluated through monitoring and subsequent evaluation.

Restoration Goals:

One of the most widely accepted definitions of ecosystem restoration in terrestrial environments is:

“Actions taken to return an impacted site or ecosystem to a close approximation of its condition prior to disturbance” (Cairns, 1995)

A return to “a close approximation of its prior condition” is often the goal of terrestrial natural resource restoration efforts in national park service projects (NPS 1991).

However, because coral reefs are such highly complex and ecologically diverse systems, this terrestrial goal is not feasible for coral reef restoration projects. Studies have shown that, once physically damaged to any significant degree, coral reefs cannot be immediately “restored” to any close approximation of their pre-impact structural and ecological condition through artificial manipulations (Jaap 2000, Precht et al. 2001, Pinit et al. in press). Most marine biologists acknowledge that natural recovery processes are necessary to fully restore the ecological condition of the impacted site. However, the time period and rate of recovery to a pre-impact condition can be significantly enhanced through human mitigative actions. Injury to the geologic structure (if this occurs) can be mitigated and largely restored to provide a base upon which natural recovery processes can operate. In addition, natural biological processes necessary for full recovery can be enhanced by mitigative actions.

Structural and Functional Goal of Coral Reef Restoration

Because damaged coral reefs cannot be entirely reconstructed to a pre-impact condition, the goal of coral reef restoration activities becomes one of attempting to restore structural and functional components of the site in a way that will help speed natural recovery processes. It is important to achieve the following elements in this process:

- Resiliency to further erosion and loss;
- Self sustainability in terms of natural processes of repair and recolonization;
- Aesthetically similar in appearance to natural reef substrate; and,
- Substrate conditions such that, over time, the site will produce a quantity and diversity of organisms of similar composition to surrounding unimpacted areas.

The following goals for coral reef restoration actions have been adopted by others:

“Actions taken to reestablish a self-sustaining coral reef habitat that, in time, can come close to resembling a natural condition in terms of structure and function.”
(Key Largo Coral Reef Marine Sanctuary)

“A proactive program designed to speed recovery of a damaged reef to an endpoint that has aesthetic value and is functional as a coral reef ecosystem.”
(NOAA Office of Habitat Conservation)

“Actions take to accelerate natural reef recovery to an endpoint that may or may not resemble pre-disturbance conditions” (Precht et al. 2001)

All of these goals have a common element of “taking actions that will enhance natural recovery processes.” The amount of human intervention and the type of actions necessary to achieve this type of goal statement will vary greatly with the nature and extent of damage received from each vessel grounding incident, rate at which recovery progression is desired to occur, and the degree to which introduction of artificial materials is acceptable.

The NPS Coral Reef Restoration Interdisciplinary Team is recommending the following goal be adopted for NPS coral reef restoration projects:

“The goal of restoration undertaken will be to recreate a stable, self sustaining reef environment of similar topography and surface complexity to that which existed prior to injury, such that natural recovery processes, enhanced through restoration actions, will lead to a coral reef community of pre-injury ecological function, species abundance, and community diversity in the shortest time possible.”

Categories of Injury:

Geologic structure of coral reefs: To properly analyze and understand the nature of injuries that can occur to a coral reef, it is helpful to first understand the typical geologic structure and reef growth processes that occur within a coral reef ecosystem.

Coral reefs are created by living coral and other organisms which occur on the reef’s outer surfaces. Coral and some other reef organisms have the ability to secrete calcium-carbonate. The primary reef building corals use this calcium-carbonate to develop protective skeletal chambers in which they live. As the coral continues to grow outward, older inner portions of the coral’s protective chamber are closed off and a hollow matrix of hard calcium-carbonate skeletal material is created beneath the growing surface. This matrix creates space and habitat for cryptic and burrowing organisms to live in. Hard substrate created by individual coral colonies becomes further cemented with that of adjacent coral colonies through the secretions of burrowing organisms, other calcium-carbonate producers within the reef ecosystem, and through calcium-carbonate precipitation from seawater. As these ecological processes continue, the hard stable surface of the reef community continues to grow outward, while the inner most portions of the reef is slowly broken down and eaten away by bioeroders. Thus, the geologic structure of most coral reefs consist of a hard, rigid, exterior shell of cemented skeletal calcium-carbonate material with a softer interior of unconsolidated bioeroded calcareous sand, shell and coral fragments. Most of the living organisms occur on the outer reef surface or within the porous holes and cavities near the outer surface (Jones and Endean 1973)

Injury Types: Although diving, snorkeling and other recreational use of coral reef does result in some injury to corals and other reef organisms, the extent and nature of these

impacts seldom reach a level that requires mitigation for recovery to occur. Damage does not usually impact the reef's geologic structure and injury to biological organisms is usually isolated and often not fatal to the organism. This type of injury is considered limited surficial biological injury.

When a vessel grounding occurs however, impacts to the reef are usually much more substantial and may require mitigation to increase recovery timeframes. Vessel grounding impacts can readily be divided into two impact categories:

1. Surficial Injury

This category involves injury to the biological organisms living on or very near the outer surface of the reef and the scraping, grinding or minor gouging of the reef surface. This category of injury may range from only minor injury to surface biota to much more damaging injuries involving broken coral heads, crushed organisms, and scraping of the reef surface over large geographic areas. However, the reefs geologic structure remains intact and natural topographic relief at the site remains unaltered. Included in this category of injury is the displacement of organisms, overturning and breakage of individual living coral heads and other benthic organisms; and/or burial of living organisms from fragmented material.

Impact assessments involving this category of injury are essentially two dimensional (length x width of surface area impacted) and impacts have been observed to eventually recover with little human intervention. Treatment may require only removal of loose or grated material to insure that organisms do not remain buried and adjacent areas will not be impacted from the loose material being washed around by ocean currents. However, if impacts are significant, recovery time can often be greatly reduced through mitigative actions that restore some of the living biological organisms to the site. Restoration actions can enhance recovery of ecosystem function as well as greatly improve esthetic appearance of the site.

2. Topographic / Structural Injury

Because coral reefs are geologically composed of a hard outer shell with a softer interior of unconsolidated sand, shell and coral fragments, groundings of heavy ships can cause injury to the reef's geological structural integrity. In this category of injury, the outer shell of the reef is cracked or penetrated and/or major portions of the reef's topographic relief have been altered.

This type of injury destabilizes the reefs surface and opens it to the relentless erosional processes of the ocean's currents. Studies have shown that once this occurs, recovery is not likely without mitigative actions to stabilize the site. Lack of human intervention following the incident will result in a continued degradation and enlargement of the impacted site through erosional processes over time. Such increased impacts can be significant and perhaps continue for decades. Stabilization of the site is mandatory even if no other actions are taken. This category of injury usually occurs with vessels over 30

feet in length and will likely include widespread injury and destruction of surface biota as well as possible loss of reef topographic complexity.

When this category of injury occurs, the impact assessment requires three dimensional analyses (surface length x width plus depth of fractured or lost substrate). If topographic height or structural complexity has been lost due to the grounding incident, restoration of the original reef form and structural complexity through mitigative actions may be very important. Many organisms within the coral reef community are highly sensitive to water depth, currents and light levels. All of these factors are changed when topographic relief and structural complexity is altered. If not restored through mitigative actions, natural processes will likely change the site into a permanently altered type of coral community.

General steps in response to ship grounding incidents:

The NPS Coral Reef Restoration Interdisciplinary Team has identified three stages of response that must be taken whenever a ship grounding incident occurs. These stages are: Emergency (from the time of the accident continuing through the time the vessel is onsite), Immediate (within the first five days following vessel removal) and Long Term. Recommended actions within each of these stages are as follows:

Emergency Actions:

While the vessel is on site, safety of personnel becomes a priority and within water actions should be limited. Included in emergency actions are:

- 1) Oversight of on-scene personnel safety.
- 2) Coordination with others (subject matter specialists, insurance companies, etc.)
- 3) Stabilizing the vessel
- 4) Photographic documentation of the grounding and removal operations.
- 5) Pulling GPS, radar and other equipment from the vessel, downloading and documenting vessel speed and course.
- 6) Containment of any spilled fuels and other hazardous materials.
- 7) Development of a plan for vessel removal.
- 8) Identifying other damage sites (where the vessel may have struck before its final “resting” place. If in a safe area then immediate work can begin on these sites.

Immediate Actions (following vessel removal):

- 1) Map and photograph all areas of injury.
- 2) Remove all loose rubble and broken dead coral.
- 3) Rescue live displaced organisms and place in protected site.
- 4) Reaffix coral if the original location can be determined and the reaffixed coral would not be in “danger”.
- 5) Remove any remaining ship debris, bottom paint, or chemical contaminants.

- 6) Stabilize or remove coral that is in imminent danger of “collapse” or “failure” that if it did could damage other coral.
- 7) Deploy removable objects (“sand bags”??!!) that could stabilize the site temporarily (not sure if this is possible or feasible.)

Long-term Actions

Long-term actions involve 1) any mitigation to enhance the rate of recovery and 2) all post incident monitoring.

Determining Appropriate Mitigation Actions: The amount and type of mitigation needed to help restore an injured site will vary with the type of site, type of incident, and the amount and type of injuries sustained. The NPS Coral Reef Restoration Interdisciplinary Team has developed a “Decision Tree” (Figure 1) to help determine the appropriate restoration actions. The first step is to determine if there has been an impact to the geological structure of the reef and site stabilization and/or restoration of topographic relief is needed. If so, this requires the development of a “Site Stabilization” / “Structural Restoration” Plan. The second step in this process is to determine if biological mitigation is warranted and necessary to reduce the time required for recovery to full ecological function and natural condition. If so, then this requires the further development of a Biological Mitigation Plan. The final step of the “decision tree” is to develop a Site Monitoring Plan to document future conditions at the site, determine success of restoration efforts, and to observe site recovery.

Geological Restoration (if reef crust penetrated and broken): If injury to the geological structure of the reef has occurred, steps must be taken to stabilize the site from further erosion over time. If the hard outer reef surface is broken open, erosional forces of the ocean currents and wave actions will cause the site to continue to grow and erode, and additional damage to the reef will occur. Exposed calcium carbonate material will dissolve and leach into the surrounding water environment causing increased turbidity. Natural recruitment and recolonization of coral reef organisms will not likely occur without surface stabilization and reef crust reconstruction.

A Site Stabilization / Structural Restoration Plan should call for sealing of any deeply cracked or damaged reef surface area against erosional forces and the recreation of any lost reef topography. This should be done with the use of coral rock and natural limestone materials (often broken and available from the site) cemented into place with a limestone aggregate underwater cement (or alternative adhesive material) of sufficient strength to withstand ocean forces and stresses on coral boulders used to seal or reconstruct the reef surface. However, the use of such adhesive aggregates should be reduced to the absolute minimum necessary and preferably be naturally erodible over long-periods of time. The goal of these efforts should be to stabilize the reef surface against erosional forces and mold reconstruction of the reef surface back to its

approximate original form. This is particularly important on spur and grove type reef formations (not only from an aesthetic but also a biological standpoint). If significant inward depth of reef material has been impacted and removed, rebuilding outward to its original form will insure that surface micro currents are not altered and that the water depth and sunlight regime will be restored such that similar reef organisms will recruit to the new reef surface.

Biological Mitigation: Once the site is fully stabilized and, if necessary, the topographic reef structure and form has been reconstructed, consideration can then be turned toward surface biological restoration. Full biological restoration of the site will likely take decades to occur. However, mitigative actions may serve to speed the overall recovery of the site and greatly improve the aesthetic appearance. Experience and prior studies have shown that natural reef surfaces (if stable) and reef damage repaired with natural reef limestone materials (arranged such that natural holes, caverns and reef porosity are created) will recolonize rapidly, particularly with boring organisms, surface algae, sponges, smaller polychaetes, fishes, crustaceans and other reef organisms. However, natural appearance and overall functional characteristics of the reef surface can be restored much faster with the transplanting of live corals and other slow growing sessile benthic organisms onto the site. Such organisms will have to be cemented in place and then allowed to recruit onto the natural reef surface over time. Again the less concrete adhesive that is left exposed in this process the better for future coral, sponge and other sessile benthic organism growth.

A biological mitigation plan should be developed prior to initiating biological restoration actions. This plan should take into account the observed natural distribution and abundance of organisms of different ages and sizes on similar adjacent sites, such that the placement of all transplanted organisms will allow future natural recruitment to eventually achieve a completely natural looking and functioning community. The biological restoration plan should contain the mapping of adjacent parts of the reef or adjacent reefs so that the diversity, density and topography can be understood and compared. This will also help provide a “guide” for monitoring and determining success.

Monitoring for Successful Recovery: Following completion of any restoration and mitigation actions, it is important to begin monitoring to determine if site recovery is occurring and restoration goals are being met. What to monitor depends on what has been done and the stated goals of the restoration action, but success criteria should be measurable and established prior to development of restoration plans.

Measures of Success:

As with any management action, it is extremely important to thoroughly think through what it is you are trying to accomplish with the action and how success will be measured. Because actions taken to enhance the recovery of injured coral reefs are primarily directed at regaining the structural and functional characteristics of the site, restoration actions are not measurable in terms of how immediately similar the restored site is to its

original condition or the species diversity and abundance of surrounding areas or reference site. Instead, success criteria should focus on the structural and functional aspects of the restored site. NOAA's Office of Habitat Conservation, Restoration Center for marine and aquatic habitats, has suggested the several types of criteria to be considered for measuring success of coral reef restoration projects (Pinit et al. in press). These are summarized along with additional suggestions here:

Structural:

- Morphological / Topographic form of the site - does it mimic what was there pre-impact or closely resemble a reference site.
- Sediment present - is it of appropriate grain size and not contaminated?
- Hydrodynamics - are water current patterns present similar to those that likely existed prior to the disturbance and do hydrodynamics allow for removal or dilution of waste products and dispersal of new recruits?
- Water Quality – does it meet standards that are similar to surrounding un-impacted reef?
- Similarity of abundance and diversity of flora and fauna to the natural un-impacted reef or reference site. (This might not be expected to be highly similar at first, but would be progressing toward more similarity over time if site restoration actions are successful).

Functional:

- Nutrient cycling - is found to be similar to un-impacted reef areas
- Oxygen production - is occurring and is adequate for the abundance of organisms present.
- Resilience of the repaired/replaced habitat to excessive erosion deterioration - is it similar in bio-accretion or erosion to those rates occurring on natural reef areas.
- Habitat use by food organisms and/or predators as refuge sites – site provides sufficient habitat and is used for refuge and cover.
- Overall biomass productivity – is expected to increase over time
- Ecological linkages to adjacent sites – organism on the site appear ecologically linked to adjacent reef areas. Movement in and out of the restored site by mobile organisms is common.
- Natural recruitment of reef organisms is observed to be occurring.

It should be kept in mind that for many of these factors, achieving success is a measurement of gradual progress toward complete ecological recovery.

SUMMARY / CONCLUSIONS:

1. Compared to terrestrial, wetland and stream restoration projects (which range in the thousands of implemented projects) coral reef restoration is in its infancy. Techniques and success of methods employed are still being tested and evaluated.
2. Goals of restoration actions need to be stated in terms of reestablishing structure and function to the damaged site, not in terms of approximation of the site to prior disturbance conditions.
3. Two factors should be of primary concern when evaluating coral reef damage from vessel groundings or anchoring:
 - A. Extent of penetration and fracturing of the reef's hard outer surface, which will result in further erosion.
 - B. Loss of reef topographic relief and structural complexity that may have existed at the site.

These two factors will largely govern the extent of geologic stabilization and structural restoration that needs to be implemented to achieve natural ecological function and processes that will lead to pre-impact conditions.

4. Human intervention involving site stabilization and reconstruction of geologic topographic structure is necessary whenever either of the two forms of impact above have occurred.
5. Restoration actions at sites not involving the above two factors, may be limited to loose substrate removal and/or biological mitigation for recovery to occur within decadal timeframes.
6. Transplanting of biological organisms on impacted sites (Biological Mitigation) can serve to greatly improve aesthetic appearances and help speed the overall site recovery process to pre-impact conditions.

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