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ABSTRACT

Deep-water coral reefs are impacted by a number of anthropogenic activities, primarily destructive fishing practices. In some locations, the coral framework has been reduced to such an extent that it no longer fulfills its original ecological function. Large-scale restoration of damaged reefs is neither logistically nor economically feasible, but habitat restoration may be viable in small ecologically significant areas. The *Oculina* Banks off the south eastern coast of Florida have been so severely damaged over the past 20 years that much of the coral has been reduced to rubble with no infrastructure. The framework coral, *Oculina varicosa* is a broadcast spawning species, which annually produces many dispersive larvae, however, there is no evidence of recolonization of denuded areas. It is possible that the rubble does not provide suitable substrate for planular settlement or that repeated impact from illegal trawling destroys any newly established colonies. Between 1996 and 2001, restoration modules were deployed in the Experimental *Oculina* Research Reserve (EORR) a small (315 km²) area of the *Oculina* Banks. In total, 281 large and 450 small modules were deployed (some with coral transplants) in various configurations. Coral transplants have survived and limited recruitment of new colonies had been observed in the older modules. It takes several years before recruits reach sufficient size that they can be positively identified with ROV and submersible cameras. Commercially important predaceous fish species have been observed in association with the large modules and small fish have taken up residence inside them. The restoration project will be assessed whenever possible for coral transplant survival and growth, coral recruitment, and habitat function for important fish species.

KEY WORDS: Coral, restoration, deepwater

***Oculina* Deposita Proyecto de la Restauración: Descripción y Gravamen Preliminar**

Los filones coralinos profundos son afectados por un número de actividades antropogénicas; sobre todo prácticas destructivas de la pesca. En algunas localizaciones, se ha reducido el marco coralino hasta tal punto que satisface no más de largo su función ecológica original. La restauración en grande de filones dañados es ni logísticamente ni económicamente factible, pero la restauración del hábitat puede ser viable en áreas ecológicamente significativas pequeñas. El *Oculina* ejerce la actividad bancaria de la costa del este del sur de la Florida se ha dañado tan seriamente sobre los últimos 20 años que mucho del coral se ha reducido al escombro sin la infraestructura. El coral del marco, varicosa de *Oculina* es una especie de freza de la difusión, que produce anualmente muchas larvas dispersivas, sin embargo, no hay evidencia de la recolonización de áreas denudadas. Es posible que el escombro no proporciona el sustrato conveniente para el establecimiento planular o que el impacto repetido de pescar con red barredera ilegal destruye a cualquier colonia nuevamente establecida. Entre 1996 y 2001, los módulos de la restauración fueron desplegados en la reserva experimental de la investigación de *Oculina* (EORR) un área pequeña (315 km²) de los bancos de *Oculina*. Un total de 260 módulos grandes y 450 pequeños fue desplegado (algunos con los trasplantes coralinos) en varias configuraciones. Los trasplantes coralinos han sobrevivido y el reclutamiento limitado de nuevas colonias había sido observado en los módulos más viejos. Toma varios años antes tamaño del alcance de los reclutas de suficiente que pueden ser identificados positivamente con ROV y las cámaras fotográficas sumergibles. Las especies predadoras comercialmente importantes de los pescados se han observado en la asociación con los módulos grandes y los pescados pequeños han tomado la residencia dentro de ellos. El proyecto de la restauración será determinado siempre que sea posible para la supervivencia y el crecimiento coralino del trasplante, el reclutamiento coralino y hábitat funcione para la especie importante de los pescados.

PALABRAS CLAVES: *Oculina*, Deposita Proyecto de la Restauración

INTRODUCTION

The Ivory Tree Coral, *Oculina varicosa* (Lesueur, 1820), occurs at depths between 5 m and 100 m on the Atlantic coast of Florida. It is facultatively zooxanthellate and can tolerate a wide range of environmental conditions including low temperature, high turbidity and low light levels. The shallow populations have been reported as far north as South Carolina, and as far south as the Florida Keys and the Caribbean, however the taxonomy of the Oculinidae of the Western Atlantic is somewhat confused (Dr. S. Cairns Pers. comm.), so the distribution descriptions may be incorrect.

In deep water, *O. varicosa* forms massive bushes of fragile colonies, creating continuous tracts of reef on the slopes and tops of pinnacles, similar in structure to deep-water *Lophelia* reefs. The deep *Oculina* bioherms are the

only known monospecific coral banks that occur on the North American continental shelf at less than 200 m depth. Similar bioherms of *Lophelia pertusa* and *Enalllopsammia profunda* exist in deeper waters at the base of the Florida Hatteras Slope and the Blake Plateau (Reed 2000). All of these deep-water 'reef-building' corals have a similar growth pattern, which is unlike that of typical shallow water species. As the colony increases in diameter, the tangled outer branches block water flow to the core of the colony, and the inner branches of the colony die. Bioerosional processes weaken the dead coral branches, which eventually break and the colony falls apart. The outer living branches continue to grow, and new recruits may colonize the exposed dead core. As this process continues over thousands of years, these mounds and pinnacles can reach tens of meters in height, with the live coral forming a cover over the unconsolidated dead coral debris below.

The deep shelf-edge *Oculina* reefs form natural spawning grounds for commercially important populations of gag (*Mycteroperca microlepis*) and scamp (*M. phenax*) grouper. They also serve as nursery grounds for juvenile snowy grouper (*Epinephelus niveatus*), and feeding grounds for these and many other commercial fish species including black sea bass (*Centropristis striata*), red grouper (*E. morio*), speckled hind (*E. drummondhayi*), Warsaw grouper (*E. nigritus*), amberjack (*Seriola* sp.), red porgy (*Pagrus pagrus*) and red snapper (*Lutjanus campechanus*) (Gilmore and Jones 1992). Apart from the valuable fisheries species, the deep-water reefs also support very rich communities of invertebrates; faunal diversity on the *Oculina* banks is equivalent to that of many shallow tropical reefs. Over 20,000 individual invertebrates were found living among branches of 42 small *Oculina* colonies, yielding more than 350 different species (Reed and Hoskin 1987, Reed and Mikkelsen 1987, Reed 2000), many of which are important food sources for animals at higher trophic levels. These unique deep-water *Oculina* reefs exist only on the shelf edge off eastern Florida, and stretch over 90 nautical miles (167km) from Fort Pierce to Daytona (Avent et. al 1977, Reed 1980).

Three different fisheries have operated in the *Oculina* Banks area over the past three decades: a trawl fishery for rock shrimp (*Sicyonia brevirostris*), a trawl and dredge fishery for calico scallops (*Argopecten gibbus*) and a hook and line fishery for reef fish (Koenig et al. 2000). Both the rock shrimp and calico scallop fisheries began in the early 1970s (Allen and Costello 1972, Kennedy et al. 1977, Oleson 1982). The scallop fishery collapsed in the late 1980s (Stimpson 1989) and the reef-fish fishery increased in the early 1980s, especially at Jeff's Reef.

In 1984, the South Atlantic Fishery Management Council designated 315 km² of the deep *O. varicosa* banks as a Habitat Area of Particular Concern (HAPC), because of their importance to the life histories of many commercially valuable species. This area was closed to trawling, dredging, long-lining, and trapping (Federal Register 49 FR 29607). In 1994, the status of the same area was changed to the Experimental *Oculina* Research Reserve (EORR), which closed the area to all bottom fishing for a period of 10 years, and in 1995 the use of anchors and grapples was prohibited in the reserve. The EORR and a designated control (fished) area were mapped in 1995 with SIS side scan sonar, and visually surveyed using an ROV and the Clelia submersi-

ble (Harbor Branch Oceanographic Institution). Analysis of the side scan information showed that terrain that supported *O. varicosa* thickets (high-relief, high-backscatter) comprised just 3% of the EORR, although small *O. varicosa* colonies were also found in surrounding low-relief high-backscatter areas (Koenig et al. 2000, Scanlon 1999). Much of the *Oculina* habitat had been severely degraded or destroyed since the initial surveys in the 1980s, although the Jeff's Reef area was still intact and healthy. The coral structure on parts of Chapman's Reef and Steeple had been damaged, and Sebastian Pinnacles and Twin Peaks were covered with small pieces of coral rubble. Fish communities had also changed from the diverse assemblages of economically important species observed in the early surveys. In 1995, the abundance of these species had declined (Koenig et al. 2000) and the dominant species had shifted from grouper species, particularly scamp (*Mycteroperca phenax*), to small non-fishery species, such as red barbier (*Hemanthius vivanus*) and roughtongue bass (*Holanthius martinicensis*). Spawning aggregations of gag and scamp observed on Jeff's and Chapman's Reef either had disappeared completely or been reduced to a few small individuals.

By 1998, efforts were underway to amend the *Oculina* HAPC even further. SAFMC was mandated by a 1996 amendment to the Magnuson-Stevens Fishery Management Act to describe and identify essential fish habitat (EFH), including adverse impacts on such habitat, in order to minimize damage to EFH resulting from fishing activities. In addition, the agency was required to identify other actions that encourage the conservation and enhancement of EFH (Magnuson-Stevens Act, 1996). On July 14th, 2000, the OHAPC regulations were expanded to include the known extent of the *Oculina* Banks (Federal Register 50 CFR 622). The rule retained the western and southern boundaries of the existing OHAPC, moved the northern boundary 68.5km to 28°30' north latitude, and moved the eastern boundary to the 183 m contour (Figure 1). Furthermore, two satellite HAPCs (10 km²) were established: Area 1 was bounded by 28°30'N, 28°29'N, 80°00'W and 80°03'W and Area 2 was bounded by 28°17'N, 28°16'N, 80°00'W and 80°03'W. Restrictions in the expanded reserve prohibit:

- i) Use of a bottom long-lines, bottom trawls, dredges, pots, or traps;
- ii) Use of anchors, anchor and chain, or grapple and chain; and
- iii) Fishing for rock shrimp or possession of rock shrimp in or from the area.

In 2001, the *Oculina* Banks were re-visited as part of NOAA's Office of Ocean Exploration Islands in the Stream cruise, using the Clelia submersible and Phantom S4 ROV for habitat surveys. Analysis of video transects taken along ridge features within the EORR (7,645 m) indicated that most of the habitat (90%) was comprised of unconsolidated rubble, with small areas (4%) of scattered coral colonies and intact (6%) coral habitat. Jeff's Reef and the western ridge of Chapman's Reef are the only remaining areas of live thicket habitat and together they cover approximately eight hectares. Video transects (2014 m) of ridges taken outside the EORR showed only unconsolidated rubble with occasional small colonies of live *O. varicosa*. Sparsely distributed small colonies of *O. varicosa* were also observed on low relief rocky substrate.

Some of these colonies were dead but standing. Historical coral sites (Reed 1980) were re-visited during the 2001 cruise, although there was uncertainty about some of the exact site locations, none of areas surveyed had intact coral habitat and most had been reduced to rubble. The exact causes of these extensive areas dead coral are undetermined. Impact from commercial and sport fishing is evident. Submersible and ROV surveys have shown evidence of extensive damage apparently due to bottom trawls, and because the *Oculina* habitat is at the edge of the Florida Current, bottom hook and line fishing requires heavy weights that may also damage the coral beds. Fishing lines have often been found among the coral and a large ball of long-line was observed on the reefs in 2001. Damage to the *Oculina* habitat has reduced the highly complex structure of standing coral heads to low relief, low complexity rubble substrate which may not be suitable for larval settlement. Very little natural recovery has been observed in the damaged areas. This may be due to lack of successful larval recruitment or by repeated impact from trawling.

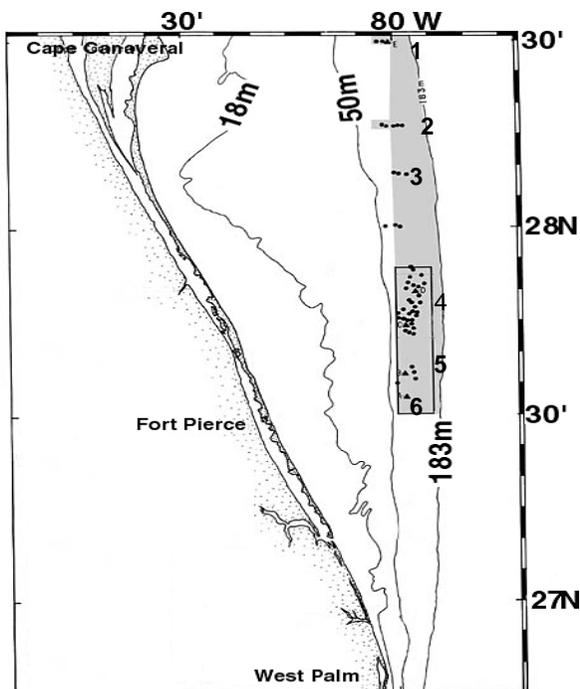


Figure 1. Chart of the *Oculina* Banks OHAPC showing dive areas visited in 2001: 1. Cape Canaveral, 2. Cocoa Beach, 3. Eau Gallie, 4. Sebastian Pinnacles, 5. Chapman's Reef, 6. Jeff's Reef. Dots are historic dives sites visited in the 1970s and 80s. The shaded area defines the expanded OHAPC boundary and the smaller inset box is the EORR and the original (1984) OHAPC boundary.

Despite regulations that have been in place for two decades, there is substantial evidence that illegal trawling still occurs in the OHAPC (Koenig 1997, Authors' Pers. obs.). In 2002, the SFMC recognized a need for increased protection for the OHPC and passed the rock shrimp FMP amendment 5 (Federal Register: 50 CFR 622.9) in January 2003. This requires the use of an approved vessel monitoring system (VMS) by rock shrimp vessels and requires the operator to have an operator permit, effective July 2003. The Florida Fish and Wildlife Conservation Commission (FFWCC) have also acquired a 20 m vessel, which now regularly patrols the *Oculina* Banks for illegal fishing activity.

Restoration

Despite evidence that trawling is at least partially responsible for the habitat degradation, we know almost nothing about natural senescence or mortality of *O. varicosa* colonies. Similar areas of dead coral have also been observed in deepwater *Lophelia pertusa* reefs (540 - 870 m) off the coast of Florida (Reed 2000), where there are no records of a trawl fishery. There are also areas of standing dead *O. varicosa* colonies, which have obviously not been impacted directly with fishing gear. Natural phenomenon such as protracted upwelling, benthic storms, or disease may be responsible for this mortality, but the cause is currently unknown. Dead colonies apparently fulfill a similar function to the live coral because they provide structure for invertebrates and fish, but when the coral framework is reduced to unconsolidated rubble, abundance and diversity of associated fauna declines and grouper spawning aggregations are lost (Koenig et al. 2000).

Artificial structures (shipwrecks) off St. Augustine and Jacksonville to in the northern region of the OHAPC are covered with *Oculina* colonies (Koenig Pers. obs.), however very few new colonies were observed at damaged sites during habitat surveys. This observation prompted a restoration effort with the objective of supplying appropriate settlement substrate for coral larvae and habitat for fish species. A pilot project was initiated in 1996 by Dr. Koenig (NMFS/FSU), who deployed eight concrete structures with live coral transplants attached in the EORR. The transplants were still alive the following year, so the project was expanded and 48 more blocks were deployed in 1997 and 1998. A larger scale restoration effort was undertaken in 2000 and 2001. This paper describes the projects and presents preliminary results.

Objectives

- i) To rehabilitate fish habitat in destroyed areas by simulating *O. varicosa* coral heads with artificial reef structures seeded with *Oculina* fragments,
- ii) To restore coral habitat destroyed by mobile fishing gear through transplantation of *O. varicosa* fragments to denuded areas, and
- iii) To evaluate the efficacy of different restoration methods within the OHAPC.

METHODS

Restoration Modules

Between 1996 and 1998, 56 restoration modules or ‘reefblocks’ (81.3cm x 81.3cm x 71.1cm) were constructed from 18 concrete cinder blocks and deployed in groups at various locations within the in the EORR.

The first large scale restoration effort was initiated in 2000 when experimental coral transplant structures were deployed in Sebastian Pinnacles, a badly degraded region of the EORR. Two types of restoration units were utilized: reefballs and reefdisks. Reefballs were perforated hemispherical concrete structures (www.reefball.org) approximately 1 m in diameter, 0.7 m high and weighing 180 kg (Figure 2). Reefballs were chosen to simulate *O. varicosa* colonies and provide fish with benthic structure similar to natural coral heads. A small colony of live coral was attached to each reefball with the anticipation that the coral fragments would eventually overgrow the structure and form the foundation for coral recolonization. Corals were attached to the reef balls with cable ties and a quick-setting cement mixture approximately five minutes prior to deployment and were covered with seawater-saturated paper towels to avoid dehydration on deck. The reefballs were deployed in an experimental design to investigate the effect of cluster size and internal complexity on association of fish populations.



Figure 2. Reefballs with attached coral transplants and additional internal complexity created by vexar mesh. Floats help slow descent rate and can be used to locate reefballs for surveys

In addition to the reefballs, experiments using much smaller and simpler 'reefdisks' (Figure 3) were deployed in the same area of the EORR. Reefdisks were concrete paving disks (0.3 m diameter) with a vertical PVC posts (0.4 m). A coral fragment ('small' or 'large') was attached to the top of each post using cable ties. This experiment tested the effect of fragment size on transplant survival and growth, since smaller fragments require less coral and therefore lower impact on donor sites. These disk clusters also represented coral 'nurseries' where small pieces of adult colony are used to seed recovery of the damaged area. Raising the fragments off the substrate ensured that they were not buried in sediment before they could become established colonies.

Coral fragments were collected on scuba by members of the Association of Underwater Explorers (AUE divers) from an unidentified wreck at 90 m and from the 'Cites Service Empire' wreck at 64 m. Corals were maintained in chilled re-circulating aquaria until needed.



Figure 3. Reefdisks with 'large' coral fragments attached and ready for deployment

Module Deployment

In 1996, eight reefblocks were deployed during this pilot study, four at Jeff's Reef (intact coral habitat) and four at Sebastian Pinnacles (coral rubble). Live *O. varicosa* was attached PVC posts at each of the upper corners of the block.

In 1997, an additional 24 reefblocks were placed at four different locations. Jeff's Reef (27°32.55'N, 79°58.74'W) and Chapman's Reef (27°36.51'N, 79°59.07'W) were in intact coral habitat, whereas Sebastian Pinnacles (27°50.02'N, 79°57.70'W) and Steeple Pinnacle (27°43.57'N, 79°58.72'W)

consisted of dead coral and coral rubble. The blocks were deployed in two clusters of three at each location, one cluster with live *O. varicosa* transplants and the other without.

In 1998, 24 reefblocks were deployed in the same locations and configuration as was used in 1997. The blocks had an additional piece of PVC on the float line so that the blocks could be identified by year of deployment during future survey cruises.

In 2000, a stern mounted hydraulic winch and a quick release hook was used to deploy the reefballs, which were also fitted with drag boards attached with biodegradable line. The boards ensured that released reefballs remained in an upright position during decent and settlement on the bottom. In total, 105 reefballs were deployed in clusters of 5, 10, and 20 at each of three locations in the Sebastian Pinnacles area of the EORR. This experiment was designed to test the effect of different reefball cluster sizes on rehabilitation of coral and fish habitat. In addition to the reefballs, 450 small reeferisks were also deployed in three replicate groups of 25 reeferisks for each of two treatments (large and small fragments) in the same three damaged areas of Sebastian Pinnacles.

In 2001, a total of 120 reefballs were deployed in six clusters of 20 on the tops of pinnacle ridges at Sebastian Pinnacles. All reefballs had coral transplants attached as before and in addition, half of the reefballs contained internal complex structure created by vexar mesh to try to mimic the internal microhabitat of coral colonies and attract some of the smaller fish such as red barbler and rough-tongue bass that are common in coral thickets. Replicate clusters of reeferisks were also deployed, as described for 2000.

RESULTS

Reefblocks

In 1997, an ROV was used to locate and survey three of the reefblocks at each site. In each case, the coral transplants were alive and appeared to have grown. There was also evidence of growth on the surface of the reefblocks but this could not be positively identified as coral. Fishing lines were wrapped around all of the modules deployed in 1996, strongly suggesting that bottom fishing intensity was high within the reserve. Additionally, a 'down-planer' (used by trolling fishermen to get bait closer to the bottom) was hanging on the side of one of the *Oculina* transplant modules, indicating that fishermen were targeting bottom-associated species (grouper and snapper) rather than pelagic species in the closed area. The continuation of bottom fishing in the reserve will clearly affect conclusions concerning the use of Marine Fisheries Reserves as management tools.

In 1999, a reefblock was surveyed at Jeff's reef using the Clelia submersible. Coral was alive and growing but some transplants were missing. New coral recruits were observed on a reefblock on the north side of Jeff's reef (27°32.6020'N, 79°58.7521'W), and a snowy grouper was seen next to the structure. In 2000, ROV surveys of the reefballs showed that, in addition to providing support for the coral transplants and larval settlement substrate, these structures provided artificial fish habitat. Many fish species were found around

these structures, and a scamp spawning aggregation appeared to be associated with one of the clusters in Sebastian Pinnacles. Thus, the fish population was locally enhanced when structural complexity was increased through the deployment of the reefblocks. In 2001, insufficient numbers of reefblocks were observed to draw any statistical conclusions regarding transplant survival, coral recruitment or fish assemblages associated with these structures, but in 2003, several coral colonies were observed on a reefblock deployed in 1998 using a Phantom ROV. The Largest colony was 810 cm in diameter and ~ 3 years old, assuming a growth rate of 1.6 - 2 cm/yr (Reed 1981). More than one distinct size class was observed, indicating that larval recruitment may be episodic.

Reefballs and Reefdiks

Reefballs and reefdiks deployed in 2000 were observed in 2001 using the Clelia submersible. Reef fish abundance and species composition around reefballs was much greater than over the surrounding dead habitat (Koenig et al. In review). These species included groupers, snappers and amberjack as well as the smaller fish species that are commonly found associated with healthy coral (Table 1). Observation of economically important species associated with the reefballs was particularly encouraging. The data show very little difference between number of species and total abundance of fish associated with the clusters of 10 and 20 but did show much fewer fish associated with the smallest cluster size. Distribution of economically important fish associated with the reefballs show similar trends (Figure 4). Courtship-type behavior was observed between scamp grouper associated with some of the reefball clusters, but spawning-season surveys are required to determine the extent of their function as aggregation sites. Male gag grouper were also observed in the vicinity of the reefballs. Submersible surveys of the reefballs and reefdiks showed that two of the reefdik clusters were missing and only broken pieces of PVC remained. The PVC was broken rather than detached from the concrete bases indicating strong mechanical impact. In the vicinity of the missing reefdik clusters were apparent trawl tracks in the rubble. Of the 40 reefdiks surveyed that still had transplants, 50 - 60% was alive, but fragment growth could not be scored with the available camera resolution. Most of the reefballs (75%) deployed in 2000 still had attached coral fragments and ~25% of these were alive. A preliminary conclusion is that coral fragments attached to the reef balls and disks can survive, but very small fragments (< a few cm) suffered higher mortality than larger transplants.

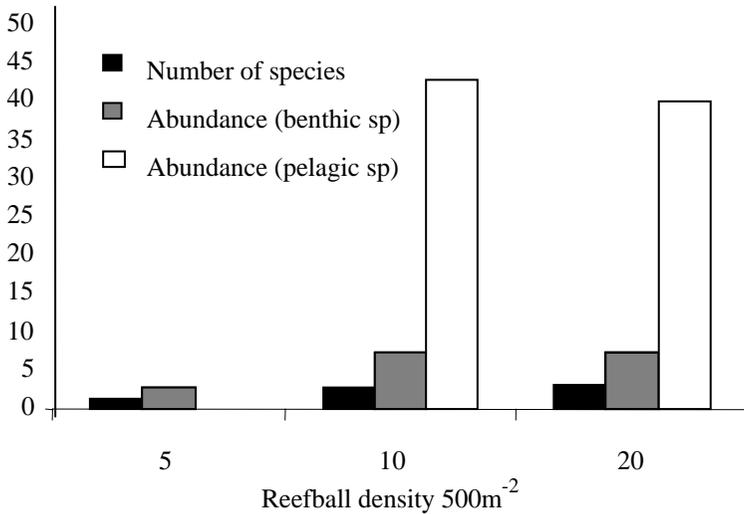


Figure 4. Economically important fish associated with reefball clusters of 5, 10 and 20 deployed on coral rubble at Sebastian Pinnacles in the EORR

DISCUSSION

Although reef restoration projects are common in shallow water environments, this attempt to restore a deepwater coral ecosystem is the first of its kind and preliminary results are promising. Coral transplants show moderately good survival rates, which may be increased with improved handling techniques, and several new coral colonies have been observed on the older structures. The reefballs were surveyed approximately one year after deployment, which was too soon to assess coral recruitment as colonies would have been too small to identify using submersible or ROV cameras. Recruitment of coral larvae may be episodic and variable since different distinct colony size classes were seen on one of the early reefblocks. If this is the case, it may take several years before recruitment success can be assessed. The number of fish species and total fish abundance were enhanced by the deployment of reefballs on the badly damaged Sebastian Pinnacles site. Hopefully, these structures will provide interim habitat for fisheries species until the *Oculina* habitat can recover. The restoration structures will continue to be monitored as funding allows for coral recruitment and growth and for development of associated fish communities.

Surveillance and enforcement of regulations in remote areas is difficult and expensive. However, surveillance of fishing activity, particularly at night when shrimp trawlers operate, has been minimal at best. A list of trawling violations in the OHAPC were obtained from the Office of General Council for Enforcement and Litigation, NOAA, NMFS, SERO. Since 1984, arrests for poaching occurred on 21 July 1993, 2 October 1994, 19 November 1994, and

19 January 2000, but levels of illegal activity are considerably higher than the arrest records indicate. The trawler caught in 2000 was one of three working in the OHAPC at the time and was captured after a half-hour chase (J. Reed, personal communication). The typical penalty to trawlers caught poaching in the OHAPC is confiscation of their catch, which is obviously insufficient to deter them

The recently initiated VMS systems allow full-time monitoring of commercial vessels therefore the level of surveillance in the OHAPC has recently been increased but compliance to regulations by the user groups is vital for effective resource protection. Although large-scale commercial fisheries, such as trawlers, have direct and devastating impacts on the coral habitat, small repetitive impacts from uninformed recreational fishermen may also have long-term consequences to the health of these reefs. Acceptance of the OHAPC regulations by the different user groups may be motivated through education of the public and fishing community on the value and fragility of the coral habitat.

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