Oculina Banks: Habitat, Fish Populations, Restoration, and Enforcement.

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Abstract

The shelf-edge *Oculina* coral reef ecosystem, known only from off the central east coast of Florida, is unique among coral reefs and exists nowhere else on earth. The azooxanthellate (i.e., lack symbiotic algae) branching coral typically produces 1 – 2 meter diameter coral heads which often coalesce into thicket-like habitats with exceedingly high biodiversity, similar to that of tropical coral reefs. Historical accounts indicate very high densities of economically important reef fish as well as grouper spawning aggregations associated with the coral habitat. The uniqueness, productivity, and vulnerability of the *Oculina* habitat moved the South Atlantic Fishery Management Council (SAFMC) in 1984 to declare a significant portion (92 nmi^2) of the habitat an HAPC. This legislative action purportedly protected the coral from trawling, dredging, and most other mechanically disruptive activities. Evidence of demographic impacts of fishing on grouper spawning aggregations further stimulated the SAFMC in 1994 to close the original HAPC for a period of 10 years to bottom fishing as a test of the effectiveness of a fishery reserve in protecting the reproductive capacity of groupers. Further expansion of the original HAPC to cover 300 nmi^2 was instated in 2000. A 1995 submersible survey suggested that much of the habitat, the economically important fish populations, and the grouper spawning aggregations described in the 1970s were decimated by 1995. A broad-scale submersible and ROV survey conducted in September 2001 found that most (90%) of the *Oculina* habitat within the EORR is reduced to an unconsolidated rubble and the damage north of the EORR may be greater. To our knowledge, only about 8 hectares (20 acres) of fully intact Oculina thicket habitat remain in the OHAPC and probably in the world. Restoration experiments were run from 1996 to 1999 to evaluate the transplantation potential of *Oculina*. High rates of transplant survival induced NMFS to support a significant restoration effort in 2000 and 2001. Results of the restoration efforts of 2000 indicate that restoration structures designed to simulate Oculina habitat are attracting groupers, snappers, and amberjack, and may be sites of grouper spawning aggregations. Oculina habitat and fish populations within the EORR were described quantitatively (expressed in terms of density, nos./hectare) using a system of two cameras with attached lasers. Although fish populations observed in 2001 were not directly comparable to those observed in 1995, there was a noted increase in grouper numbers and size and especially an increase in the abundance of males of gag and scamp, suggesting the reoccurrence of spawning aggregations of both species. Juvenile speckled hind were observed in Oculina thickets, suggesting a nursery function for this species. Evidence is very strong that shrimpers are still illegally trawling within the OHAPC, and suggestions are made to eliminate such threats to this vulnerable, but productive habitat. We have initiated work on a habitat map of the OHAPC and produced a protocol to continue habitat mapping.

INTRODUCTION

Background

The shelf-edge *Oculina* coral reef ecosystem, known only from off the central eastern coast of Florida (Figure 1), is unique among coral reefs, existing nowhere else on earth. This area is called the *Oculina* Banks because the coral, *Oculina varicosa* (ivory tree coral), grows primarily on limestone ridges and pinnacles which are distributed throughout the area. The Banks extend about 167 km (90 nmi) along the shelf edge from Fort Pierce to Daytona, Florida, from about 32 to 68 km offshore in depths of 70-100 m (Avent et al., 1977; Reed, 1980; Thompson and Gulliland, 1980; Virden et al., 1996). The azooxanthellate (i.e., lack symbiotic algae) branching coral typically produces 1 – 2 meter diameter coral heads which often coalesce into thicket-like habitats with exceedingly high biodiversity (Reed et al. 1982, Reed and Mikkelsen 1987), similar to that of tropical coral reefs. The Banks are important because they are unique and productive; very high densities of economically important reef fish as well as grouper spawning aggregations have been recorded in the past.

History of Research and Management in the Oculina Banks

From as early as the 1970s researchers conducted acoustic and submersible studies of the Oculina Banks. These studies included initial descriptions of the pinnacle and ridge structures (MacIntyre and Milliman 1970, Avent et al. 1977, Thompson and Gulliland, 1980) and various studies of the surficial geology (Hoskin et al., 1983; Hoskin et al., 1987; Scanlon et al., 1999). Other studies focused on the habitat-structuring organism, *Oculina varicosa*, in terms of its growth form and distribution (Reed 1980), growth rate (Reed 1981), reproduction (Brooke 1998), and the effects on survival of transplantation (Koenig et al. 2000), upwelling (Reed 1983) and bioerosion (Reed and Hoskin 1987). Studies on the habitat-associated invertebrate communities (Reed et al., 1982; Reed and Mikkelsen, 1987) indicated very high species diversity. Submersible studies in early April 1980 showed a very high abundance of reef fish, including groupers, snappers, and amberjack and the occurrence of grouper spawning aggregations (Reed and Gilmore 1981, Gilmore and Jones 1992). However, comparable observations made a decade and a half later in 1995 showed dramatic declines in both economically important species and in the grouper aggregations (Koenig et al. 2000).

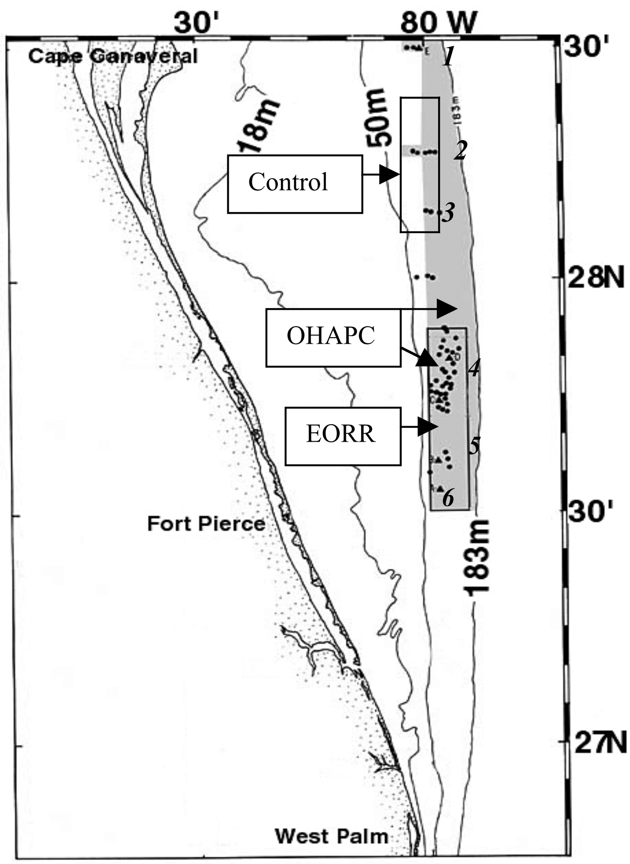


Figure 1. Chart of *Oculina* Banks Habitat Area of Particular Concern (OHAPC), includes the Experimental *Oculina* Research Reserve (EORR) showing dive areas visited in 2001 (numbers 1-6). Dots are historic dive sites visited in the 1970s and 1980s. Dive areas: 1. Cape Canaveral, 2. Cocoa Beach, 3. Eau Gallie, 4. Sebastian, 5. Chapman's Reef, and 6. Jeff's Reef. Note: the shaded area is the entire OHAPC, the EORR is the smaller inset box.

It was soon recognized that the Oculina habitat was not only unique and valuable fish habitat, it was also delicate and vulnerable to mechanical disruption. So, in 1984 a 92-nmi^2 portion was designated as the *Oculina* Habitat Area of Particular Concern (OHAPC) by the South Atlantic Fishery Management Council (SAFMC) within the Fishery Management Plan for Corals and Coral Reefs. This action prohibited the use of trawls, dredges, traps, and long lines in this area. In 1994, acting on information suggesting that aggregation fishing induced severe demographic changes in grouper populations, the SAFMC closed the original HAPC to bottom fishing for a period of 10 years and called it the Experimental *Oculina* Research Reserve (EORR). The intent of this closure was to experimentally evaluate the effects of a marine protected area (MPA) on fish communities and grouper spawning aggregations. In 2000 the SAFMC expanded the OHAPC to 1029 km^2 (300 nmi^2) and prohibited the use of all gears that could cause mechanical disruption of the habitat.

In early September 2001, eight days of the "Islands in the Stream Expedition" (Co-PIs: A. Shepard, C. Koenig, J. Reed, G. Gilmore) were devoted to submersible (Clelia) and ROV studies in the OHAPC. The objectives of this cruise included: (1) estimation of the percentage of live relative to dead and destroyed Oculina habitat within the OHAPC, (2) quantitative characterization of the living habitat, (3) quantitative evaluation of the fish populations in the EORR and comparison with historic observations, (4) evaluation of fish populations associated with the restoration reefballs deployed in 2000, and (5) to initiate development of a GIS-based habitat map of the OHAPC. The primary purpose of this paper is to report on the present condition of the OHAPC with respect to habitat, fish populations, restoration, and surveillance and enforcement.

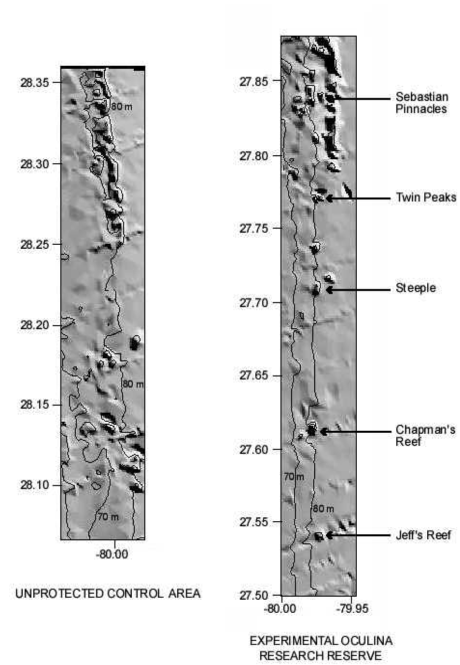


Figure 2. Shaded relief map (Scanlon et al. 1999). Coordinates are decimal degrees. Image to right is the EORR closed in 1994; image to left is just north west and includes protected habitat (OHAPC) and unprotected habitat (west of 80^{o}W longitude).

MATERIALS AND METHODS

Habitat surveys:

We used a Phantom S4 ROV for habitat surveys. Our objectives in these surveys were: (1) to sample as much of the high relief areas as possible to estimate the percent live coral habitat remaining in areas where it had once flourished, and (2) to revisit historical sites identified in the 1970s to see if the habitat has changed since then. The first objective was met by running the ROV from south to north (with the Florida Current) at speeds of 0.5 to 1.5 knots. The ROV was tethered to a down weight with a 20 m line so that the tension was taken off the umbilical. The umbilical was clipped to the winch cable that suspended the down weight off the bottom while the ship drifted under power to the north in the current. Although the ROV could be maneuvered up and down to some extent, the ROV operator, captain, and winch operator were in constant communication. The captain would anticipate high-relief structures with the echosounder and relay that information to the winch and ROV operators and the ROV operator would indicate to the winch operator the extent to which the ROV was to be raised or lowered to avoid collision with high-relief structures.

ROV transects were arranged so that they crossed ridges and pinnacles, the structures supporting Oculina thicket habitat. The ROV transects were random in the sense that we had no a priori knowledge of the habitat condition. Reference point coordinates were recorded while ROV transects were under way to identify changes in habitat and/or depth. ROV videotapes were later reviewed to determine the condition of the habitat on the ridges and pinnacles, and to classify habitats as intact, sparse, or dead. Intact habitats are undisturbed, being composed of large coral heads of 1 to 2 m in diameter, arranged in a thicket-like pattern, and providing multi-scale interstices for a variety of reef fish. Sparse habitat has the appearance of disturbed habitat and is composed of small colonies sparsely distributed in a field of rubble, providing little cover for larger species of fish. Dead habitat is composed of unconsolidated coral rubble, providing little to no habitat cover for any species of reef fish. The

ROV transects can be thought of as long thin random samples of ridges throughout the region. The relative area of each habitat class (intact, sparse, or dead) was estimated as the percent time the ROV passed over that habitat class. Our best estimates of habitat condition are in the EORR because our sampling intensity was greatest there.

We also tried to revisit a number intact coral habitat sites throughout the OHAPC that were observed and videotaped during the 1970s (Reed 1980). However, the coordinates of those sites were based on LORAN A and C, which is far less accurate than DGPS, which is now used for positioning. Thus, we could not be certain that the same sites observed in the past were revisited, with the exception of the Cape Canaveral site. That site is associated with a distinct ridge and cannot be confused because there are no surrounding ridges.

Habitat characterization:

A protocol for mapping deep reefs was developed by Koenig and Coleman (unpublished) and was adapted to the OHAPC conditions for the 2001 cruise (a copy is included in the Appendix). We used a submersible and an ROV in our studies and relied heavily on the side-scan sonar maps developed by Scanlon et al. (1999) to provide the locations (based on geomorphology) for investigation.

Habitat was characterized through the use of belt transects with the submersible. Harbor Branch Oceanographic Institution's (HBOI) submersible, Clelia, was equipped with two video cameras, down-looking and forward-looking, and a set of lasers associated with each. The down-looking camera had 2 parallel laser beams, 25 cm apart, in the field of view; these lasers gave us scale and allowed us to standardize quadrat size. The forward-looking camera had 3 lasers, two parallel beams 10 cm apart and one beam, in line with the others and 10 cm apart from the adjacent laser, converging on the other two. The converging beam was adjusted so it touched the adjacent beam at a distance of 5 m. The three lasers allowed us to determine sizes of fish, coral heads, and habitat features, but most importantly, distance. We used the distance estimates to determine visibility, and the area (length x width) of the belt transects. Transect areas were calculated (see below under 'Fish Populations') and fish counts were recorded for each transect as numbers per square meter of transect, then the fish densities for each transect were averaged for all transects within that habitat type and expressed as numbers per hectare.

Percent live coral cover was determined from the down-looking video. Random frames from transect videos were selected and standardized relative to the laser metric in the frame. Standard-size quadrats were overlain with a set of 100 randomly distributed dots. The percentage of dots touching live coral was taken as the percent cover. Randomly selected coral heads were measured using the laser metric in the frame.

Fish Populations:

The forward-looking camera with its three lasers was used to estimate fish density. We realize that the error associated with determining the density of small cryptic species is great, but our main concern was with larger economically important species (Koenig et al. 2000). Nevertheless, all fish seen in a transect were counted. Species that tend to follow the submersible and circle it, such as amberjack, were not repeatedly counted as they passed through the video field, but their total abundance was estimated as a group by observers in the submersible.

Estimates of the area of a transect require several values: the effective distance for identifying fish species (D), the camera's horizontal angle of view (A), and the length of the transect (L). The effective distance (D) may not be the limits of visibility, but instead the limit at which the fish can be identified with a high degree of certainty. In the work we report here, the visibility was consistently greater than 5 m, but we used 5 m as our standard distance for counting and counted no fish beyond that distance from the camera. The horizontal angle of view (A) depends on the camera used and the position of the zoom. Transects on the IIS 2001 cruise were run with an Insite-Tritech high sensitivity (0.0003 lux), high resolution (560 video lines), monochrome _ inch CCD underwater (rated to 3000 m) video camera with a 92 degree angle of view (no zoom). The exact coordinates (DGPS) of the sub at the start and end points of transects were recorded and transect length (L) was measured using an ArcView program.

First we calculated the width of the field of view (W) at distance (D) by:

W = 2 (tan (_A)) (D),

Then we calculated the area of the transect (TA) as:

TA = (L x W) – _ (W x D)

Estimating the area of a transect allowed us to calculate the average density (number per hectare) and standard error of observed fish species.

Restoration

In EORR locations like Sebastian Pinnacles (Figures 1and 2), virtually all the coral has been reduced to unconsolidated rubble, apparently by trawling (Koenig et al. 2000). Preliminary coral transplant experiments were conducted from 1996 to 1999 and demonstrated the high survival rates of transplanted coral. In 2000 on Sebastian Pinnacles, we started the first large-scale transplanting. Two types of transplant structures were deployed, reefballs (Figure 3) and reefdisks (Figure 4). Reef balls, perforated hemispherical concrete structures of 1-m diameter and 0.7 m high, simulate *Oculina* coral heads and provide fish with benthic structure similar to natural coral heads. Reefdisks, small 0.3 m diam concrete disks with attached vertical 0.4 m PVC posts with attached coral, were deployed to evaluate the effect of fragment size on transplant survival and growth (smaller fragments mean less impact to donor sites).

Figure 3. Reefball with attached Oculina. The orange float is for relocation with the ship's ecosounder.

Our purpose for deploying reefballs and reefdisks were two-fold, first to start large-scale restoration in denuded areas, and second, to evaluate the most effective restoration approaches. One hundred and five reefballs were arranged in clusters of 5, 10, and 20 in a randomized block design (Table 1) to determine the most effective cluster size in terms of attracting fish, and especially grouper spawning aggregations. Four hundred and fifty reefdisks (Table 1) were also deployed in a randomized block design to evaluate fragment size in terms of survival and growth of the coral transplants.

Figure 4. Reefdisks with attached Oculina fragments.

We observed reefballs and the reefdisks deployed in 2000 with the submersible in 2001, thirteen months after deployment. Although our observations were too soon after deployment to determine transplant survival and growth, we recorded the reeffish populations associated with the reefballs. Over time we will continue our observations of these restoration sites to follow coral growth and fish populations. We anticipate that coral fragments will grow to cover the concrete structures to further simulate natural habitat with a concomitant development of reeffish populations.

Surveillance and Enforcement

We looked for trawl tracks in all areas searched with the submersible. We also obtained a list of trawling violations in the OHAPC from the Office of General Council for Enforcement and Litigation, NOAA, NMFS, SERO. We also contacted the Coast Guard office in Charleston and will give a presentation to their group on the Oculina Banks and the necessity for surveillance and enforcement.

RESULTS

Habitat Surveys:

We made 7 ROV transects over high-relief features within the EORR and 3 outside the EORR for a total of 9,686 m of ROV video on ridges. Only the portions of the transects that were on these features were counted, and several transects that did not include high-relief features were excluded. Within the EORR, 7,645 m of ridge features were viewed in 7 transects in both the Chapman's Reef area (3 transects) and the Sebastian area (4 transects). Of the 7,645 m of ridge transected within the EORR, 464 m (6%) were intact habitat, 302 m (4%) were sparse habitat, and 6,877 m (90%) were unconsolidated rubble. The only intact habitat we found was Jeff's Reef and the western ridge of Chapman's Reef. Jeff's Reef is about 4 hectares in area and the western ridge of Chapmans Reef about the same size, so the total area of live thicket habitat is about 8 hectares, or about 20 acres. The only sparse habitat we found was on the south-facing eastern ridge of Chapmans Reef. Outside the EORR, we found only unconsolidated rubble in 2,041 m of transected ridges. In nearly all cases, there were occasional small colonies of live Oculina associated with the unconsolidated rubble. We also observed sparsely distributed small colonies of Oculina on low relief rocky bottom often associated with large boulders. Some of these colonies were dead but standing.

We attempted to revisit sites documented in the 1970s (Reed 1980). Although there was uncertainty about the exact site locations, none of the sites assumed to be the same as those observed in the 1970s were now intact. The Cape Canaveral site, where the location was certain, was reduced to rubble.

Habitat Characterization:

Submersible videotape analyses are not yet finished. When finished we will have quantitative descriptions of the habitat conditions we observed with the submersible and will quantitatively classify habitats accordingly. The down-looking camera allows us to calculate coral habitat coverage and sizes of coral heads; the forward-looking camera allows us to calculate colony heights, diameters, and spacing. We also have descriptions of the surficial geology (Scanlon et al. 1999) and ROV transects over features of both high and low relief. We anticipate putting together a first-cut habitat classification scheme and map of the OHAPC over the next year which will be available in a GIS format for easy access to the geo-referenced data. In 2002 we are planning a multibeam survey which will give us a more accurate map of the geomorphological features upon which we will build our habitat maps.

Fish Populations

On the 2001 OHAPC cruise we were able to estimate transect areas and therefore described the fish populations in terms of density (numbers per hectare). This is a superior method of video sampling fish populations because it allows statistical comparisons of fish population densities both spatially and temporally, which is important for the evaluation of the effectiveness of an MPA. There is a clear relationship between fish population densities and habitat condition (Figures 5, 6,and 7) as observed in 2001in the southern part of the EORR at Jeff's and Chapmans Reefs. Even pelagic amberjack species were much more abundant in areas of intact habitat.

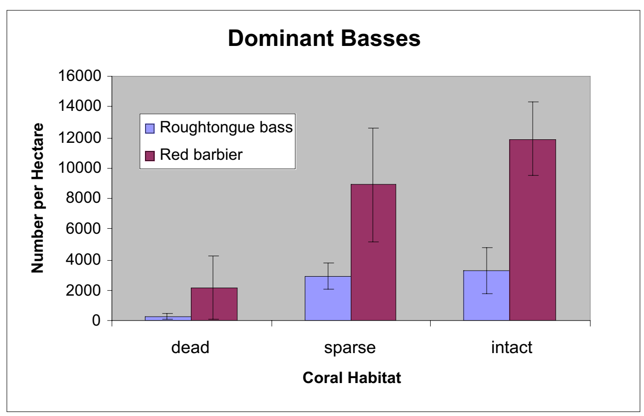


Figure 5. Density of dominant basses (Antheinae) in three habitat classes. Error bars represent standard errors.

We are unable to make quantitative comparisons between our submersible observations in 1995 and those made in 2001 because observations were made in different seasons, and because the approach used in 1995 was intended as a survey rather than a quantitative evaluation of fish populations. At that time we had no idea of the condition of the habitat and the associated fish populations, nor did we have sidescan images to guide us in our submersible studies. At that time the only live habitat we found was on Jeff's Reef, a 4 hectare ridge in the southern-most portion of the

EORR (Figure 2). So, our comparisons between 1995 and 2001 must be restricted to Jeff's Reef and must be qualitative.

Our 1995 observations were made in March, during the gag and scamp spawning season, and the 1980 observations (Koenig et al. 2000) were made during the same period. However, our 2001 observations were made during early September, well after aggregations have dispersed. Nevertheless, we saw more and larger groupers (we have not completed our fish measurements) in 2001 and male gag and scamp were common in intact habitat. This observation suggests that both gag and scamp aggregations are functional again in intact habitat areas where they were observed in 1980. We also observed juvenile (yellow phase) speckled hind associated with the Oculina habitat suggesting that Oculina thickets function as juvenile habitat for this species. Amberjack were more abundant in 2001 than in 1995.

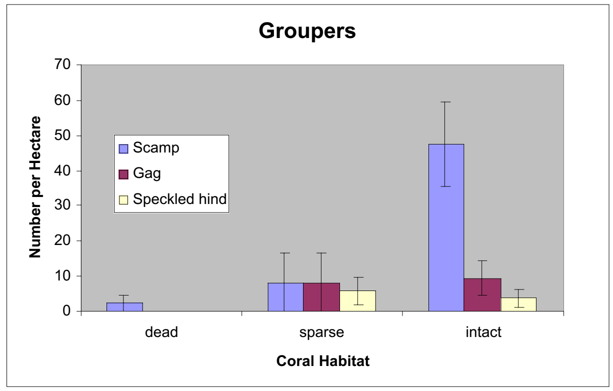
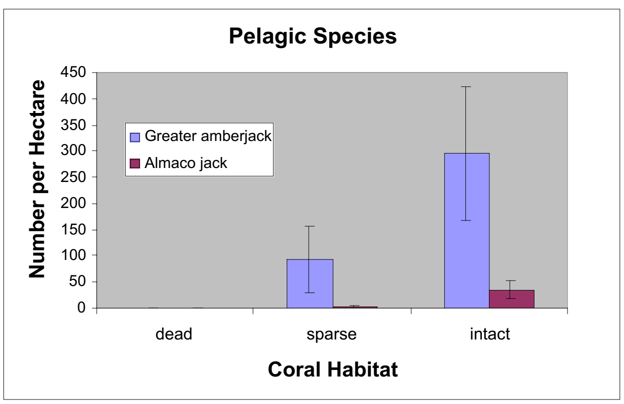


Figure 6. Density of groupers in three habitat classes. Error bars represent standard errors.

Restoration



Reef fish abundance around reefballs was much greater than over the dead habitat that surrounded them (compare Tables 2, 3, and 4). Especially important is the observation of economically important species associated with the reefballs. These species include groupers, snappers and amberjack. We observed behaviors similar to that of courtship behavior in scamp (see Gilmore and Jones (1992) for description), but it appeared to be between males. It is possible that some of the reefball sites are already functioning as spawning aggregation sites, but we won't be certain until we observe the area during the spawning season. We also observed male gag in the vicinity of the reefballs.

Figure 7. Density of pelagic species in three coral habitat classes. Error bars represent standard errors.

We could not be certain of the survival rates of the transplanted coral associated with reefballs and reefdisks. However, the few close-up views we had of the coral suggest very high rates of survival. We must wait until the coral has had more time to grow to be certain.

Surveillance and Enforcement

During our submersible observations of the reefballs and reefdisks we noted that two of the reefdisk clusters were missing and left in their place were several broken pieces of PVC. The PVC was broken, not detached, from the concrete-disk bases indicating strong mechanical impact. In the vicinity of the missing reefdisk clusters were apparent trawl tracks in the rubble (Figure 8).

Poaching trawlers apparently continue to operate within the EORR and other parts of the OHAPC. Arrests for poaching occurred on 21 July 1993, 2 October 1994, 19 November 1994, and 19 January 2000.

DISCUSSION

This report describes the present condition of the OHAPC in terms of the habitat, fish populations, and restoration work. The data are predominantly derived from the first leg of the 2001 “Islands in the Stream” Expedition which involved the use of a manned submersible (HBOI’s Clelia) and an ROV (see http://oceanexplorer.noaa.gov/explorations/islands01/islands01.html for details). We are still processing these data, so this report is not complete. In eight days, sixteen sub dives and thirteen ROV dives were conducted throughout the EORR and other portions of the OHAPC (Figures 1 & 2), resulting in more than 70 hours of underwater videotape documentation. Unexplored areas and their associated fish populations were surveyed, characterized, quantified, and video documented. Over all, the habitat is in very poor condition, with about 90% of it reduced to an unconsolidated rubble, and poaching trawlers continue to operate within the OHAPC. In contrast, the apparent success of the restoration experiments and the observations of increased grouper abundance suggesting the reoccurrence of aggregations is encouraging.

Figure 8. Apparent trawl tracks in the Sebastian area of the EORR.

Habitat Surveys

ROV surveys were designed to sample the geomorphology most likely to support intact coral thicket habitat, namely, ridges and pinnacles. We found no new sites of live coral thickets and the status of known intact coral habitat was either similar or worse compared to past studies. Intact coral thickets were still in good condition at Jeff’s Reef and the western ridge of Chapman’s Reef, both of which are at the southern end of the EORR. In other places, live coral primarily inhabited low-relief (< 1 m) sites, but the small size and dead standing colonies suggest these low relief areas are marginal for the survival and growth of the coral. Future experiments should examine Oculina senescence and test the hypothesis that low relief provides marginal survival conditions.

Although trawling activities have undoubtedly contributed to destruction of *Oculina* coral habitat of the *Oculina* Banks, impacts from other factors may also be significant. The incriminating evidence implicating trawlers includes trawl tracks, lost and broken experimental coral transplant structures, and recent (2000) arrests of poaching trawlers. Also, reefs in the northern OHAPC that had extensive live coral in the 1970s and 80s had been reduced to rubble when revisited in 2001. Other factors that may account for damaged coral habitat include (1) Extreme temperatures. Bottom temperature in the OHAPC range from 7.4 to 26.7^{o}C, as upwelling events occur annually (Reed, 1981), but the impact on *Oculina* is unknown. (2) Excessively high nutrient and sedimentation levels. Upwelling events may raise nutrient and sedimentation levels by an order of magnitude, but *Oculina*, especially the shallow form, appears tolerant of turbidity and sedimentation (Reed, 1981, 1983). (3) High currents. Currents on the bottom in the OHAPC may exceed 100 cm sec^{-1}, enough to erode tips of coral branches (Reed, 1981; Hoskins et al., 1983), but it is unknown whether entire colonies can be destroyed by high currents and it seems unlikely that currents would destroy habitat in one area, but not in an adjacent area. (4) Pathogens. Deep-water corals may be susceptible to pathogens as are shallow-water reef corals, but there have been no directed studies of coral diseases in the OHAPC or in any other deep-water coral habitats. (5) Anthropogenic impacts other than trawling. Explosive depth charges used in the area during World War II may have also impacted the coral. (6) Freshwater seepage may cause localized mortality. However, among the many factors that potentially could have killed *Oculina* coral, the most likely for most of the OHAPC is trawling because most of the banks are reduced to unconsolidated rubble which would likely result from mechanical impacts. Nevertheless, further research on potential impacts from factors other than trawling could provide explanations for some of the coral loss.

Habitat Characterization

Quantitative habitat characterization is important because it allows meaningful temporal comparisons, an important consideration for MPAs. It is impossible to ascertain whether the habitat is growing or senescing from single observations. To determine the trajectory of habitat development periodic measurements must be made. For example, we do know whether sparse coral habitats are growing back from some historical mechanical disruption or if the habitat remains as such because ambient conditions don't allow continued growth and development. Also, we know that linear growth is between 1 to 2 cm per year, but under marginal habitat conditions growth might be very much slower than this.

In the future we intend to establish permanent reference stations in selected habitat classes throughout the OHAPC. Habitat classes will be based on quantitative descriptors of coral coverage and the size of coral heads. Reference stations with permanent monuments will allow quantitative evaluation of future changes in OHAPC habitats and fish populations. Selection of reference stations will be based on our habitat descriptions, which are a combination of geomorphology and benthic biological features, and will include selected historic sites observed and videotaped in the 1970's, in 1995, and in 2001. Emphasis will be on intact *Oculina* habitat, but we will also establish reference sites in other areas of the OHAPC, including sparse and dead coral habitat.

Fish Populations

Overfishing has resulted in a drastic decline of reef fish stocks throughout the southeastern U.S. (SAFMC, 1999). Most of the snapper-grouper complex that inhabited the OHAPC are considered overfished. These include red porgy, black sea bass, gag, scamp, snowy grouper, red grouper, Warsaw grouper, speckled hind, red snapper, and vermilion snapper. It is not certain whether hook and line fishing has continued within the EORR but clear evidence of it was reported to the SAFMC in 1997 (Koenig, unpublished data), three years after the area was closed to bottom fishing. Nevertheless, there are signs of recovery of the fish populations, especially the dominant groupers and amberjack. Future observations should be scheduled in the late winter and early spring so that comparisons can be made to historical observations.

Fish population quantification through the use of belt transects is much preferable to non-quantitative surveys because they provide a statistical basis for spatial and temporal comparisons. Such quantitative measurements are relative abundance, not absolute abundance, so comparisons in time and space must be consistent. That is, comparisons should only be made between the same seasons and at the similar times of the day because populations change seasonally (e.g., seasonal aggregations) and all fishes have diurnal activity patterns. Also, as shown in this report, comparisons must be within similar habitat types.

Positive trends in fish populations within the EORR include observations of relatively abundant gag and scamp populations and males of both species. Over the past couple of decades the size, age, and proportion of males of these species has declined in both the Gulf and the south Atlantic regions (Koenig 1996, Coleman et al. 1996, McGovern et al. 1998, and Koenig et al. 2000), apparently the result of intense aggregation fishing. But the protection of aggregations through the use of year-round MPAs appears to reestablish historical demographics, including sex ratio (Koenig, unpublished data from the Gulf MPAs). The presence of gag and scamp males in the EORR and the greater size of these fish relative to observations in 1995 support the contention that MPAs protect the demographics of these species. However, it is necessary to observe the spawning aggregations in February and March, the time of peak spawning, before we can be certain.

We observed juvenile speckled hind in association with the Oculina thickets of Jeff's and Chapman's Reefs (Figure 9). Speckled hind has been vastly overfished in the past several decades, to the point where they are being considered for threatened species status. Apparently, Oculina serves a juvenile habitat function for this recovering species.

Figure 9. Juvenile speckled hind on Chapman's Reef among Oculina thickets.

After just one year, all species of groupers observed in 1980, with the exception of Warsaw grouper, were seen in association with the reefballs. Also, there were signs suggestive of the formation of scamp and possibly gag spawning aggregations in association with these artificial structures. These signs included the presence of males of both species and scamp male gray-head patterns characteristic of spawning sites. However, these encouraging signs must be verified with observations during the spawning season.

Restoration

A good understanding of Oculina life history is important to the success of restoration efforts. For example, we know that coral fragments survive to grow into new colonies, but we also know that Oculina produces billions of free-swimming larvae each year. Why then does recruitment appear to occur in the OHAPC at a such a slow rate? On all the concrete structures we have deployed thus far (56 reefblocks and 105 reefballs) we have observed a new recruit only once. Yet artificial reefs and wrecks off St. Augustine and Jacksonville are covered with small Oculina colonies (Koenig, personal observation). Clearly, current regimes at several scales and settlement conditions play important roles in recruitment. But our understanding of recruitment process in this species is very poor.

Starting in 1996 and continuing through 1998 we tested the survival of Oculina fragments affixed to PVC posts on reefblocks (18 concrete blocks strapped together). We deployed 56 such reefblocks, half (28) of which had coral attached to the four upper corners of the blocks. Half the reefblocks were deployed in the northern portion of the EORR and half were deployed in the southern portion. Over the years, including 2001, we observed some reefblocks from different regions of the EORR with both ROV and submersible, as conditions would allow. In all cases that we observed where the coral was present, it was alive and growing. In not a single case did we find attached fragments that were dead, although some fragments were apparently stripped off by fishing activities, because in those cases the reefblocks were entangled with fishing line.

When we began our reefblock studies of Oculina fragment survival a significant problem we encountered was the collection of enough coral to conduct the transplant experiments. We selected heavily damaged sites for these collections and had to collect the coral with an ROV equipped with a front-mounted dip net. But recently we discovered that large deepwater wrecks within and just outside of the OHAPC are covered with large Oculina colonies (Figure 10). Some of these wrecks were sunk by U-boats during World War II, but some are thought to have been around since the turn of the last century. Some Oculina colonies on these wrecks are several meters in diameter (Mike Barnette, Association of Underwater Explorers, personal communication). This year for the first time we collected some of the coral growing on these wrecks to use in our restoration work. Mr. Barnette and his associates volunteered to collect the coral using trimix gas in open circuit SCUBA. They easily collected more than enough in a single dive. Now that we are aware of this coral resource, we are testing survival rates on coral that is broadcast directly onto the bottom from the surface without any structure to support the fragments off the bottom. If coral survival rates are high for this simple and inexpensive broadcast method, we will use it to start coral growing in rubble areas throughout the HAPC. Restoring destroyed Oculina habitat is similar to restoring a forest from a plowed field; it will take many decades.

Figure 10. Oculina coral heads on wreck in the OHAPC.

It is important to understand the causes of habitat loss before restoration efforts are put into place. Without this understanding, we can't be sure that our efforts will be productive. In the *Oculina* Banks the evidence is strong that trawling is responsible for a large part of the damage we have observed. That is not to say that trawling is responsible for all of it. We know nearly nothing about natural senescence of *Oculina* coral or natural causes of mortality. The reference sites we intend to establish will contribute to our understanding of natural (nonanthropogenic) mortality because we will be able to follow the course of development of individual coral heads over time while we are monitoring environmental factors. However, in areas where the habitat has been reduced to unconsolidated rubble, and there are trawl tracks and missing and broken reefdisks, the most likely cause of the destroyed habitat is trawling. Therefore our restoration structures were deployed in these trawl-destroyed areas.

This year, 2001, we deployed another set of reefballs (120) in six clusters of 20 each and reefdisks (450) in 18 clusters of 25 each near the sets we deployed last year, in the Sebastian area of the EORR (Table 6). In the 2000 set we observed that smaller reef fish such as the red barbier and the roughtongue bass, which are extremely abundant in live Oculina habitat, occurred in relatively low numbers around the reefballs. Assuming that this was because of a lack of small-scale habitat complexity, we tested that idea by increasing the internal complexity of half of the clusters of reefballs with plastic-coated wire mesh. This experiment will be evaluated in the future.

Surveillance and Enforcement

Observations show that trawling activities have impacted and continue to impact the OHAPC. The typical penalty to trawlers caught poaching in the OHAPC is confiscation of their catch. This was the penalty imposed on the trawler caught poaching in 2000. However, if the fine is insufficient and is perceived by the captain of the trawler as the cost of doing business, poaching will continue. For example, trawlers presumably go into the OHAPC because catch per effort is increased. Say the catch per effort is doubled, but the trawler is only caught in the reserve 10% of the time he poaches. A confiscated catch is relatively insignificant to his poaching gains. I do not know how often night time surveillance of the OHAPC is conducted because I was told by Coast Guard officials that that is classified information and the Coast Guard will not release it, but I would doubt that it is more than once every 10 days. In that case, if our trawler example poaches every night he would only be caught 10% of the time on average.

The poaching arrests may not represent the degree of poaching that is going on in the OHAPC. When the trawler was caught in 2000 there were actually three trawlers observed in the OHAPC, but only one was run down after a half-hour chase (J. Reed, personal communication). And they were caught at 9 AM, not at night, suggesting that if they had left before sun-up they would not have been caught.

NMFS agents confiscated the plotter trawling zone information from the vessel caught poaching in 2000, but this information on illegal trawling locations is not available to fishery managers and scientists working in the area because it is considered proprietary and cannot be released without the consent of the vessel owner (Karen Raine, NMFS senior enforcement attorney, personal communication). However, this information is important to managers because it shows where surveillance should be concentrated and it is important to scientists to compare trawled and untrawled habitat.

Special protection should be given to the remaining Oculina thicket habitat occurring on Jeff's Reef and on the western portion of Chapman's Reef. To our knowledge these are the only Oculina thicket habitats remaining in the world, and it amounts to only about 8 hectares (20 acres). A trawler could easily destroy all of it in a single night.

I have several recommendations to improve surveillance and enforcement within the OHAPC. (1) The SAFMC and scientists conducting experiments within the OHAPC should be appraised of the level of night time surveillance that is taking place and has taken place within the OHAPC in the past so that the level of surveillance effort is understood by all concerned. (2) The information derived from poachers on the location of their illegal activities should be made available to managers and scientists so that this information can be used for management and restoration purposes. (3) Special measures should be taken to ensure that the only known remaining Oculina thicket habitat is protected. (4) Penalties to poachers should be stiff enough to deter future poaching, like confiscation of their vessels. (5) Novel approaches to surveillance/enforcement should be installed as soon as possible such as vessel monitoring systems (VMS) and listening buoys in key areas identified by confiscated plotter information and in the area of Jeff's and Chapman's Reefs.

Habitat classification and mapping in the OHAPC

Habitat maps are fundamental to the study and management of living natural resources. In the marine environment, the development of objective, systematic, and intuitively understandable habitat maps has just begun (Mumby and Harbourne 1999). In the southeastern United States, habitat mapping is urgently needed in areas of greatest fishery production, such as shelf-edge reefs so that management of these most essential of fish habitats can be effectively managed. We are in the process of developing a habitat map of the OHAPC (see our protocol to habitat mapping in the Appendix).

A habitat map includes three primary components: geomorphology, community structure and distribution, and a data management system. The geomorphological map consists of acoustic imagery of the bottom, either sidescan or multibeam, and is the first step in developing a map. Patterns of community distribution are then associated with the various geomorphological features and described using video documentation with ROVs and submersibles. The data management system integrates these data into a geographically referenced database, or Geographic Information System (GIS), that provides easy access to the data.

NMFS, with funding from the National Coral Reef Initiative, intends to support a synoptic multi-beam bathymetric and survey of the entire OHAPC in May 2002 (Andy Shepard, NURC-Wilmington, personal communication). And the principal investigators of this years Island in the Stream study have a proposal into the Ocean Exploration Program to continue the 2001 work into 2002. If these projects come about we will be able to put together a first-cut OHAPC habitat map by late 2002 or early 2003.

Acknowledgements

Thanks go to those who organized and helped run the "Islands in the Stream" cruise, including Andy Shepard and Tom Potts of NURC-Wilmington and John McDonough and Sammy Orlando of NOS, and Felicia Coleman of FSU. The principal investigators of that cruise, John Reed of HBOI, Grant Gilmore of Dynamac Corp., Andy Shepard, and the author of this report, contributed perspectives from the distant and recent past and coordinated the cruise objectives. Mike Barnette and other members of the Association of Underwater Explorers collected the *Oculina* coral for the restoration work off deep wrecks in the OHAPC. Kathy Scanlon of USGS, Woods Hole continues to contribute to our understanding of the surficial geology. I would especially like to acknowledge the support of the NMFS Panama City Laboratory with particular thanks to John Brusher, who reviewed all the ROV and submersible videotapes, Lyman Barger, who analyzed the ROV and submersible track data, and Andy David who helped organize and run the cruise. John Brusher and Chris Palmer of NMFS-PC and John Reed and Sandra Brooke of HBOI contributed significantly to the restoration work. Special thanks go to Lance Horn of NURC-Wilmington for his expert piloting of the ROV. Funds for the "Islands in the Stream" OHAPC study were supplied by NOS and NMFS-SEFSC.

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TABLES

Table 1. Time and location of reefball and reefdisk deployment in the Sebastian Pinnacles area of the EORR in September 2000.

Structure	Date	Location	Site	Latitude	Longitude	Deployment
ReefBall	9/8/00	Sebastian Pinnacles	B1a	27o 50.974'	79o 57.698'	Cluster-8, 1 frag.ea., no floats
ReefBall	9/8/00	Sebastian Pinnacles	B1a'	27o 50.895'	79o 57.710'	Cluster-2, 1 frag.ea, 2 floats
ReefBall	9/8/00	Sebastian Pinnacles	B1b	27o 51.098'	79o 57.750'	Cluster-20, 1 frag.ea., 2 floats
ReefBall	9/8/00	Sebastian Pinnacles	B1c	27o 51.200'	79o 57.700'	Cluster-5, 1 frag.ea, 2 floats
ReefBall	9/8/00	Sebastian Pinnacles	B2a	27o 51.501'	79o 57.742'	Cluster-20, 1 frag.ea, 2 floats
ReefBall	9/10/00	Sebastian Pinnacles	B2b	27o 51.600'	79o 57.700'	Cluster-5, 1 frag.ea, 2 floats
ReefBall	9/10/00	Sebastian Pinnacles	B2c	27o 51.700'	79o 57.700'	Cluster-10, 1 frag.ea, 2 floats
ReefBall	9/10/00	Sebastian Pinnacles	B3a	27o 51.960'	79o 57.831'	Cluster-5, 1 frag.ea., 2 floats
ReefBall	9/10/00	Sebastian Pinnacles	B3b	27o 52.085'	79o 57.902'	Cluster-20, 1 frag.ea., 2 floats
ReefBall	9/10/00	Sebastian Pinnacles	B3c	27o 52.208'	79o 57.911'	Cluster-10, 1 frag.ea., 2 floats
Reefdisk	9/9/00	Sebastian Pinnacles	D1a	27o 51.000'	79o 57.650'	Cluster-25, 1small frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D1b	27o 51.100'	79o 57.690'	Cluster-25, 1small frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D1c	27o 51.200'	79o 57.650'	Cluster-25, 1small frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D2a	27o 51.000'	79o 57.750'	Cluster-25, 1 large frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D2b	27o 51.100'	79o 57.790'	Cluster-25, 1 large frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D2c	27o 51.200'	79o 57.750'	Cluster-25, 1 large frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D3a	27o 51.500'	79o 57.700'	Cluster-25, 1small frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D3b	27o 51.600'	79o 57.650'	Cluster-25, 1small frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D3c	27o 51.700'	79o 57.650'	Cluster-25, 1small frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D4a	27o 51.500'	79o 57.800'	Cluster-25, 1 large frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D4b	27o 51.600'	79o 57.750'	Cluster-25, 1 large frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D4c	27o 51.700'	79o 57.750'	Cluster-25, 1 large frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D5a	27o 51.960'	79o 57.780'	Cluster-25, 1small frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D5b	27o 52.085'	79o 57.850'	Cluster-25, 1small frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D5c	27o 52.208'	79o 57.861'	Cluster-25, 1small frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D6a	27o 51.960'	79o 57.880'	Cluster-25, 1 large frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D6b	27o 52.085'	79o 57.950'	Cluster-25, 1 large frag.
Reefdisk	9/9/00	Sebastian Pinnacles	D6c	27o 52.208'	79o 57.961'	Cluster-25, 1 large frag.

Table 2. Reef fish associated with three clusters of reefballs with 5 reefballs per cluster.

5 per cluster				
Species			**Number**	**Percentage**
Roughtongue bass	Pronotogrammus martinicensis		7	41.18
Scamp*	Mycteroperca phenax		3	17.65
Red porgy*	Pagrus pagrus		2	11.76
Snowy grouper*	Epinephelus niveatus		2	11.76
Bank seabass*	Centropristis ocyurus		1	5.88
Tattler	Serranus pheobe		1	5.88
Bank butterflyfish	Chaetodon aya		1	5.88
		Sum	17	

*economically important species

Table 3. Reef fish associated with three clusters of reefballs with 10 reefballs per cluster.

10 per cluster

Species		Number	Percentage
Roughtongue bass	Pronotogrammus martinicensis	120	41.52
Greater amberjack*	Seriola dumerili	109	37.72
Almaco jack*	Seriola rivoliana	20	6.92
Scamp*	Mycteroperca phenax	15	5.19
Red snapper*	Lutjanus campehanus	6	2.08
Reef butterflyfish	Chaetodon sedentarius	4	1.38
Blue angelfish	Holocanthus bermudensis	3	1.04
Short bigeye	Pristigenys alta	2	0.69
Cardinalfish	Apogon pseudomaculatus	2	0.69
Bank butterflyfish	Chaetodon aya	2	0.69
Spinycheek Soldierfish	Corniger spinosus	2	0.69
Sharpnose puffer	Canthigaster rostrata	1	0.35
Wrasse	Labridae	1	0.35
Red barbier	Hemanthias vivanus	1	0.35
Snowy grouper*	Epinephelus niveatus	1	0.35
	Sum	289	

*economically important species

Table 4. Reef fish associated with three clusters of reefballs with 20 reefballs per cluster.

20 per cluster

Species		Number	Percentage
Greater amberjack*	Seriola dumerili	100	41.32
Roughtongue bass	Pronotogrammus martinicensis	53	21.90
Red barbier	Hemanthias vivanus	25	10.33
Almaco jack*	Seriola rivoliana	20	8.26
Scamp*	Mycteroperca phenax	14	5.79
Wrasse	Labridae sp.	10	4.13
Blue angelfish	Holocanthus bermudensis	5	2.07
Speckled hind*	Epinephelus drummondhayi	3	1.24
Reef butterflyfish	Chaetodon sedentarius	3	1.24
Red porgy*	Pagrus pagrus	2	0.83
Red snapper*	Lutjanus campehanus	2	0.83
Tattler	Serranus pheobe	2	0.83
Puffer	Canthigaster rostrata	1	0.41
Queen angelfish	Holocanthus ciliaris	1	0.41
Snowy grouper*	Epinephelus niveatus	1	0.41
	Sum	242	

*economically important species

Table 5. Reef fish community[1] recorded on rubble bottom in Sebastian area.

Species			Number	Percentage
Red barbier	Hemanthias vivanus		100	45.87
Roughtongue bass	Holanthias martinicesis		51	23.39
Yellowtail reeffish	Chromis enchrysurus		19	8.72
Tattler	Serranus pheobe		16	7.34
Wrasse	Labridae		15	6.88
Bank butterflyfish	Chaetodon aya		7	3.21
Reef butterflyfish	Chaetodon sedentarius		6	2.75
Blue angelfish	Holocanthus bermudensis		2	0.92
Snapper, unknown*	Lutjanus sp.		2	0.92
		Sum	218	

[1] fish observed in 5 transects covering a total of 3609 m^2

*economically important species

Table 6. Time and location of reefball and reefdisk deployment in the Sebastian Pinnacles area of the EORR in October 2001.

Structure	Date 2001	Location	Site	Latitude	Longitude	Deployment
ReefBall	22-24 Oct.	Sebastian Pinnacles	B4a	27 50.769	79 57.807	Cluster-20, internal complexity
ReefBall	22-24 Oct.	Sebastian Pinnacles	B4b	27 50.673	79 57.506	Cluster-20, internal complexity
ReefBall	22-24 Oct.	Sebastian Pinnacles	B4c	27 50.595	79 57.721	Cluster-20, no inter complexity
ReefBall	22-24 Oct.	Sebastian Pinnacles	B4d	27 50.465	79 57.708	Cluster-20, no inter complexity
ReefBall	22-24 Oct.	Sebastian Pinnacles	B4e	27 50.390	79 57.795	Cluster-20, no inter complexity
ReefBall	22-24 Oct.	Sebastian Pinnacles	B4f	27 50.254	79 57.791	Cluster-20, internal complexity
Reefdisk	21 Oct.	Sebastian Pinnacles	D7a	27 50.769	79 57.861	Cluster-25, 1 large fragment
Reefdisk	21 Oct.	Sebastian Pinnacles	D7b	27 50 662	79 57.853	Cluster-25, 1small frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7c	27 50.591	79 57.782	Cluster-25, 1 large frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7d	27 50.462	79 57.768	Cluster-25, 1 large frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7e	27 50.380	79 57.846	Cluster-25, 1 small frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7f	27 50.252	79 57.847	Cluster-25, 1 small frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7g	27 50.147	79 57.844	Cluster-25, 1 large frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7h	27 50.054	79 57.844	Cluster-25, 1small frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7i	27 49.976	79 57.848	Cluster-25, 1small frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7j	27 49.973	79 57.742	Cluster-25, 1 large frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7k	27 50.053	79 57.733	Cluster-25, 1 large frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7l	27 50.142	79 57.740	Cluster-25, 1 large frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7m	27 50.261	79 57.744	Cluster-25, 1small frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7n	27 50.384	79 57.736	Cluster-25, 1small frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7o	27 50.472	79 57.662	Cluster-25, 1large frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7p	27 50.591	79 57.684	Cluster-25, 1 small frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7q	27 50.664	79 57.756	Cluster-25, 1 large frag.
Reefdisk	21 Oct.	Sebastian Pinnacles	D7r	27 50.774	79 57.756	Cluster-25, 1 small frag.

APPENDIX

Protocol for OHAPC Habitat Classification and Mapping

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Introduction:

Habitat maps are fundamental to the study and management of living natural resources. In the marine environment, the development of objective, systematic, and intuitively- understandable habitat maps has just begun (Mumby and Harborne 1999). In the southeastern United States, this mapping is urgently needed in areas of greatest fishery production, such as shelf-edge reefs (50 – 120 m deep), particularly in areas where there has been extensive fishing-induced damage, attendant loss of fishery production, and declining biodiversity (e.g., Oculina Coral Banks off central eastern Florida, Koenig 2000). In addition, these areas are likely to experience heavier fishing pressure as shallower areas become depleted, and increased oil and gas exploration for new energy sources. Most of these areas in the Gulf of Mexico not only lack habitat maps, but also lack adequate descriptions of the benthic geomorphology, the basis on which habitat maps should be developed.

As pointed out by Mumby and Harborne (1999) a problem associated with most habitat mapping is that the term "habitat" is rarely defined explicitly. Thus, the terminology used in habitat mapping often mixes geomorphology (e.g., spur and groove) with physiognomy (e.g., coral reef), ecology (e.g., turf algae), and geological history (e.g., relict reef) in a non-systematic way. This is because the majority of habitat mapping is carried out subjectively on an *ad hoc* basis. In addition, very few habitat maps have quantitative descriptors for the habitat classes. Their systematic scheme of habitat classification presented here avoids a multitude of problems of interpretation and scale associated with non-systematic classification and ambiguous descriptions of marine habitats. It also provides a basis for the scientific investigation of habitat function on national and international scales.

The "Islands in the Stream"(IIS) expedition, by visiting offshore areas of the southeastern United States, Mexico, Belize, and Cuba, has the unique opportunity to lay the groundwork for an internationally consistent, objective, and systematic classification of shelf-edge habitats throughout the region. The purpose of this document is to provide the rationale and procedures for the development of benthic habitat maps in shelf-edge areas that will be surveyed by IIS-2001, 2002. The "islands" or sites to be visited can be thought of as representative sites for each region. We propose making habitat descriptions based on a combination of exploratory dives by submersibles, and relatively simple transect studies, to be conducted by a submersible, by ROV, and, where practicable, by SCUBA divers. Future habitat mapping could then be based on these descriptions, in a sense, to connect the dots that will eventually lead to complete coverage of shelf-edge reefs of the regions. Also, archived video records from this expedition, when connected to accurate geographic coordinates, would serve as benchmarks for future comparisons.

Methods

The approach we propose to mapping shelf-edge habitat follows closely that used by Mumby and Harborne (1999) for habitat classification and mapping of shallow coral reefs in the Caribbean. They subdivided geomorphological and biological components into tiers. For instance, their first tier of geomorphological features contained major categories such as "forereef", "backreef", "reef crest", "lagoon", and the second tier for tier one category "lagoon" included such subdivisions as "shallow lagoon" or "deep lagoon".

Brief quantitative definitions are provided for each category and subcategory. For instance, "deep lagoon" was defined as > 12m deep, and "shallow lagoon" defined as < 12 m. For the benthic community, the first-tier category "coral classes" was defined as > 1% hard coral cover, and the second tier under this category included “branching coral”, “sheet coral”, “fire coral”, and “massive encrusting corals” with definitions for each. These benthic community categories are classified using standard multivariate hierarchical classification techniques. Measures of similarity of the communities are calculated first, then a clustering algorithm is used to classify community types.

We add to Mumby and Harbourne’s classification scheme by including the associated fish community. We consider this an important inclusion because fish production is the primary impetus for the habitat mapping, and changes that might occur when areas are declared MPAs would likely be most immediately apparent in the fish communities.

A classification of OHAPC geomorphology, benthic habitat characteristics, and fish communities are given in Tables 1, 2, and 3, respectively. Quantitative descriptors may be modified depending on the results of our studies. Each habitat class will have an associated geomorphology and fish community with quantitative descriptors defining the limits.

The choice of both similarity index and clustering method is important to the resulting classification pattern and should be chosen on the basis of ecological understanding (Krebs 1999). The communities of fishes and motile invertebrates associated with the various habitats can also be classified using the same similarity and clustering techniques. Habitats of special significance, such as the grouper spawning habitat, could be described in fine detail, whereas other shelf-edge habitats of lesser immediate importance could be described in less detail. Thus, the hierarchical approach to habitat mapping proposed here allows the researcher to describe and classify habitats of interest in great detail and those of lesser interest in a more general way, but additional descriptions can be added at any time as interest increases.

Habitat maps readily accessible to scientists and resource managers result from the application of this classification scheme. Indeed, the maps, even if applied only in the areas surveyed by IIS-2001, would provide a benchmark for monitoring temporal and spatial changes in the habitat and its associated community. Each location polygon on a habitat map would include the following in a GIS database:

- a geomorphological descriptor
- a benthic sessile community descriptor
- a motile community descriptor.
- an associated time of observation (to evaluate temporal changes)

Mumby and Harbourne (1999) used optical remote sensing (by satellite and/or aircraft) to provided a broad-scale map of the geomorphology of the regions. We can’t use this method because shelf-edge depths are too great to be detected by remote optical techniques. Thus, we will rely on acoustic remote sensing (side-scan sonar or multibeam bathimetry) to provide the primary geomorphological categories. Percent cover (and other measures such as density of dominant taxa) data must be collected optically *in situ*. Quadrat methods (e.g., strip transects) using a down-looking video camera with a laser metric are most efficient for this purpose at shelf-edge depths. A forward-looking video system should be used to record the abundance, size, and species composition of fishes and motile invertebrates and to observe growth forms of habitat components.

Procedure:

1. Examine and classify major geomorphological features of the shelf-edge reefs from the side-scan (or multibeam) images of the study area. (If such maps do not exist, they should be produced, otherwise habitat mapping is very difficult.)
   (a) Classify and define first tier (major) categories; examples include:
   - Pinnacles
   - ridges (Paleo-shorelines)
   - drowned patch reefs
   - low relief hard bottom
   - rocky outcrops
   - hard bottom with a veneer of sand
   - sand waves

(b) Subdivide first tier into second tier categories (and third, depending on level of interest). As an example using Paleo-shorelines, subdivided into:
   - upper ridge
   - escarpment
   - rubble bottom
   - other

2. Conduct a brief reconnaissance of the defined geomorphological feature to be mapped noting subcategories of features and discontinuities in habitat characteristics.

3. Make quantitative strip (belt) transects within defined geomorphological features using videography (digital is preferable) and visual observations (recorded on a tape recorder and written) with an ROV and a submersible. For example, surveys along a Paleo-shoreline ridge should be made parallel along the ridge, along the steep slope, and along the boulders at the base of the ridge, rather than perpendicular transects, which would cut across several subcategories.

The ROV can be used to document habitat features such as sand waves and silty sediments that have few benthic macro-organisms. The submersible would be most useful for "live bottom" characterization. Still photos of high resolution should be taken of dominant or representative organisms after transects are run. All surveys should record an accurate lat/lon position (or track) of the sub or ROV so that observational/video information can be referred to the acoustic image.

In high current conditions, as exist in the OHAPC, the ROV can be used for long transects with the current in a controlled drift. Such transects are useful for describing the habitat conditions, but not for quantitatively characterizing the habitat nor for quantifying fish populations.

Transects:

- *Documentation:* Use digital video and audio and/or written notes to record habitat features and fish community.

- *Number of transects:* At least five (5) transects within each defined feature should provide an adequate sample size (Aronson et al. 1994).

- *Length of transects:* Length should be at least 25 m.

- *Sub or ROV speed:* The speed at which transects are made should be slow enough to ensure clear images on the down-looking video, that is, speeds of 0.1 to 0.2 m/s (= 0.36 to 0.72 km/hr) or less. (Faster speeds produce blurred images in the down-looking video, depending on distance off the bottom.) This means that each transect should take between 2 and 4 minutes to complete.

- *Videography.* Transects should be run with two video systems in place, one downward-looking camera, and one forward-looking (oblique) camera. Each video system should have laser metrics in the recorded image. Submersible and ROV should maintain an elevation of approximately 0.5 to 1.0 meter off the bottom for transect duration to ensure that the downward looking camera produces a clear image.

  (i) Downward-looking video: two parallel-beam lasers a known distance apart, say 25 cm, can be used to judge quadrat size and organism size in the downward-looking video frames.

  (ii) Forward-looking video: Three lasers arranged horizontally in one plane projected at an oblique angle so that they reach the seafloor ahead of the path of the sub. Two lasers, 10 cm apart, project parallel beams and the third laser, 10 cm from the adjacent laser, projects a beam that converges on the parallel beams. The converging laser is set to touch the beam of the adjacent laser at 5 m and the distal laser at 10 m. The parallel beam lasers give scale at a distance, and the converging laser allows the determination of distance from the camera.

4. Samples of both sediments and dominant sessile organisms should be collected. Sediment samples (including rocks) can be collected using a Van Veen grab. Samples of dominant sessile organisms (or any unknown or

unusual organisms) should be collected with a manipulator arm and placed in a sample basket attached to the outside of the submersible or ROV.

(a) Sediment samples:

- *Method:* Store at room temperature in pint plastic freezer containers labeled with the lat/lon position of collection, date, and any other relevant information (e.g., in strong currents, record the direction and angle of the winch cable supporting the Van Veen so that sample position corrections can be estimated.)
- *Timing:* Sediment samples can be collected at any time, but for efficient use of ship time, collection at night is preferred.
- *Rationale:* Sediment samples are important for the interpretation of surficial geology and acoustic backscatter characteristics of the side-scan sonar.

(b) *Biological samples:*

- *Method:* specimens should be preserved aboard ship in 5% formalin and labeled with lat/lon, date, and other relevant notes (e.g., characteristics of growth, relationships with other organisms, etc.)
- *Rationale:* Biological samples collected for species identification primarily, but also for determination of ecological relationships.

5. *Data analysis and handling of records.*--Videotapes (mini DVs, preferably) and notes (written notes and audio tapes) from the various transects should be duplicated and carefully archived making sure that transect begin and end positions, and dates are recorded. Time and date should be recorded on the tapes. Videotape annotation should begin on board ship. Annotations should include: divers names, date, dive no. tape ID, time code in and out (min:sec), real time (hr:min), fish species and no. observed, invertebrate species and no. observed, brief habitat descriptions, human impacts, depth, and notes. Analysis of community characteristics can begin on board the ship, if there is an appropriate tape deck and high-resolution monitor available. Easily determined are the following:

- % cover
- density of dominant sessile species
- species composition
- species richness and other species diversity measures
- spatial pattern of dominant species (i.e., random, regular, or clumped).

Procedures for analyzing the video frames (quadrats) for these characteristics are standard and are clearly presented in Krebs (1999). Percent cover may be quickly analyzed from the videos using the method used by Aronson et al. (1994), which entails laying sets of random dots over random captured images from the down-looking camera. The proportion of dots touching live coral is an estimate of the % cover.

For the purposes of the habitat characterization and classification:

- habitat structuring organisms may be evaluated as major taxa, for example, gorgonians or sponges, or they may be further subdivided on the basis of morphology and color. (Species identification may be done later, if necessary, from both the videos and the preserved biological samples.)
- Similarity of benthic communities can be analyzed using Morisita's index of similarity. Krebs (1999) recommends this measure from over 20 such measures because it is not affected by sample size as other measures are. (The Bray-Curtis measure, used by Mumby and Harborne (1999) is strongly affected by sample size and is not recommended.) For cluster analysis, Krebs recommends average linkage clustering by the UPGMA (unweighted pair-group method using arithmetic averages) method. Computer programs compiled by Krebs (1999) to perform these and many more analyses can be purchased from Exeter Software (http://www.exetersoftware.com).

Operational Considerations

Sampling, behavior, site location, and speed

Transect type. Strip transect samples are preferable to square or round quadrat samples because transects (long thin quadrats) cut across many variations or patches (habitat heterogeneity) in the habitat and thus increase precision. For short transects, only a compass heading is necessary to achieve a straight line. It is far better to take multiple short transects than few long ones. Multiple random transects are useful for density (number per unit area) determination and many other community measures, but a single long transect will only allow the measurement of spatial pattern, as it is a single sample, or if subsampled, it is at best multiple samples in systematic arrangement. We therefore recommend many short random transects.

Transects in highly altered habitat. In areas with high incidence of habitat alteration, the focus may be on distinguishing between altered and intact habitat (e.g., the *Oculina* Banks). In this case, a systematic survey is preferable to random transecting to ensure maximum coverage of areas. Thus, in each geomorphological feature of concern, transects should be conducted in long parallel transects. The ROV is preferable over the submersible for this component because of the ease of deployment and use. This component is simply to search and find. Other than this change in transect protocol, the habitat characterization should proceed as described. Transect locations should be drawn out ahead of time across acoustic images of each feature of interest. Once an intact habitat is located, random transects should be conducted with the submersible (and/or the ROV) within that habitat.

Choosing transect locations. It is preferable, but not necessary that transect locations be chosen ahead of time. Transect start position and heading can be randomly generated using a random numbers table. These positions can be drawn out on an expanded side-scan image of the feature of interest. In this way, the topside sub tracker can orient the sub pilot to transect positions, especially in conditions of low visibility. The same methods can be used for ROV transects under low current conditions. However, in all cases, the transect start and stop position should be recorded.

In the absence of acoustic imagery, sea floor features can be located by repeated passes of the supporting vessel's echosounder over the bottom. Features identified in this manner can then be plotted, producing a very rough acoustic map that can be used to orient subsequent ROV or submersible transects. A quick reconnaissance dive using ROV would determine whether or not a submersible dive was desirable. Rough transect positions could be drawn across the plotted feature as a reference.

Submersible or ROV speed. If speed cannot be determined from the submersible's navigation system, it can be estimated by recording the time it takes to travel a known distance. If the point of convergence of the converging forward-looking lasers is set at 5 m in front of the submersible, an object at that point can be used as a reference point. If the desired speed is 0.1 m/s, then it should take 50 s to arrive at the reference point, and so on. In poor visibility, the laser metrics do not operate appropriately for determining speed. In this event, sub pilots should move at a speed equivalent to what might be considered a "slow walk" for a period of 4 minutes.

Returning to previously selected locations. There may be inaccuracies in determining position of the submersible due to a number of factors. Therefore, returning to the same exact location on a repeat dive or at some later date could prove difficult and time consuming. If it is necessary to return to the same spot, a monument may be erected at that spot. A monument constructed of a lead weight (5 kg +) and a hard plastic float (ca. 0.5 L volume) tethered to it at about 2 – 4 m above the weight will allow relocation acoustically and visually. Such monuments are simple and inexpensive and last many years; other more expensive monuments may have acoustic pingers to facilitate relocation.

Fish behavior relative to submersible or ROV. There are a number of factors to consider when sampling motile species (fish and invertebrates) if valid measures and comparisons are to be made. The most important consideration is that different species have different behaviors relative to the submersible and the time of observation. Factors associated with the submersible such as lights, disturbance of the bottom by thrusters, movement, and just the physical presence affect behaviors and therefore community measures. Some species tend to follow and circle the submersible (e.g., amberjack, scamp), some species remain stationary (e.g., bigeyes), others are cryptic (e.g., cardinal fish) and still others are cryptic at times and schooling at others (e.g., antheids). Observation notes should include such behaviors and any other behaviors, such as color changes and presumed courtship behavior. The most important temporal factors affecting behavior are time of day and season. Within a season, observations should be made during daylight hours, avoiding early morning and late afternoon (crepuscular periods). Annual comparisons should be made within the same seasons.

Data recording.-- Data collection should involve verbal records, written records, videography, and still photography. On each dive, the beginning of the record should include date, time, dive number, pilot, position, depth, and mission. Also, each transect should indicate transect number and position. Emphasis is placed on collection of high quality video imagery to record behavior and diagnostic characteristics of animals and plants, but still photographs should be taken frequently because their higher resolution is useful for organism identification.

Site-related descriptions: In the verbal and/or written site records the following items should be included.

- hierarchical habitat descriptors (use standard classification terminology)
- qualitative habitat descriptions including dominant organisms
- behavioral observations
- evidence of human impacts (e.g., trawl lines, fishing gear, artificial reef).

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Table 1. Geomorphological features of the OHAPC cast in a hierarchical classification scheme.

First Tier			Second Tier		
Code	Label	Characteristic	Code	Label	Characteristic

1	Pinnacle	Isolated limestone prominence	1.1	Low relief	< 0.5 m
			1.2	Medium relief	0.5 – 2.0 m
			1.3	High relief	> 2.0 m
2	Ridge	Long continuous limestone prominence	2.1	Low relief	<0.5 m
			2.2	Medium relief	0.5 – 2.0 m
			2.3	High relief	> 2.0 m
3	Depression	Scoured area typically at the base of a ridge or pinnacle	3.1	Low relief	< 2.0 m
			3.2	High relief	> 2.0 m
4	Flat	Featureless bottom of mud or sand	4.1	No relief	< 0.5 m

Table 2. Benthic habitat features of the OHAPC cast in a hierarchical classification scheme

First Tier			Second Tier		
Code	Label	Characteristic	Code	Label	Characteristic
1	Hard bottom with live coral	Live *Oculina* present (> 0.1% coverage)	1.1	Intact *Oculina* habitat	Intact colonies > 1 m diam in thicket-like habitat with > 50% coral coverage.
			1.2	Disturbed *Oculina* habitat	Broken and toppled coral heads with < 50% coral coverage.
			1.3	Small isolated *Oculina* colonies	No evidence of large coral colonies in the past.
2	Hard bottom without live coral	Little (< 0.1 % coverage) or no *Oculina* coral	2.1	Unconsolidated dead coral rubble	Rubble reduced to finger-size pieces
			2.2	Intact dead *Oculina* colonies	Colonies are dead but standing.
			2.3	Limestone ledges and rocky outcrops	Bare limestone prominences
			2.4	Limestone pavement	Bare limestone with < 0.5 m relief
			2.5	Hard clay outcrops	Rock-like clay prominences with extensive bore holes
3	Soft bottom	Mud, sand or clay	3.1	Silty sand	Very little epibenthos
			3.2	Sand shell hash	Moderate epibenthos
			3.3	Soft clay	White with little epibenthos
4	Artificial structure	Restoration structures and wrecks	4.1	Reef balls	Dome-shaped structures with attached *Oculina*
			4.2	Reef blocks	Block-shaped structures with or without attached *Oculina*
			4.3	Reef disks	Cement disks with *Oculina* attached to PVC post.
			4.4	Wrecks	Typically large with possible extensive *Oculina* growth on deck

Table 3. Habitat associations of economically and ecologically important reef fish of the OHAPC cast in a hierarchical classification scheme.

First tier			Second tier.		
Code	Label	Characteristic	Code	Label	Characteristic
1	Spawning aggregations of economically important species.	Densities > 30/hectare plus courtship behavior plus gonad evidence and/or observation of spawning.	1.1	Gag	Densities > 30/hectare, males present, hydrated ovaries, and/or observation of spawning.
			1.2	Scamp	Densities > 30/hectare, courting males, hydrated ovaries
			1.3	Black sea bass	Densities > 30/hectare, courting males, hydrated ovaries.
2	Economically important juveniles	Juveniles common	2.1	Speckled hind	Juveniles present > 10/hectare
			2.2	Snowy grouper	Juveniles present > 10/hectare
			2.3	Warsaw grouper	Juveniles present > 10/hectare
3	Economically important adults	Consistent presence of adults	3.1	Gag	Present
			3.2	Scamp	Present
			3.3	Red grouper	Present
			3.4	Red snapper	Present
			3.5	Red porgy	Present
			3.6	Warsaw grouper	Present
			3.7	Snowy grouper	Present
			3.8	Black sea bass	Present
			3.9	Greater amberjack	Present
			3.10	Almaco jack	Present
4	Ecologically important species	Species with high densities.	4.1	Roughtongue bass	Density greater than 1000/hectare
			4.2	Red barbier	Density greater than 1000/hectare
			4.3	Yellowtail reeffish	Density greater than 1000/hectare
			4.4	Purple reeffish	Density greater than 1000/hectare