

Long Term Monitoring of a Deep-water Coral Reef: Effects of Bottom Trawling

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Abstract

The deep-water *Oculina* coral reef ecosystem is unique and exists solely off the east coast of central Florida. *Oculina varicosa* forms azooxanthellate colonies up to 2 m in diameter which coalesce into dense thickets on 20-m tall mounds that are thousands of years old. Recently restored videotapes that were made in the 1970s with the Johnson-Sea-Link submersibles show large breeding aggregations of grouper associated with the coral habitat. Historical photographic surveys provide evidence of the status and health of the reefs prior to heavy fishing and trawling activities of the 1980s and 1990s. Recent quantitative analyses by point count of photographic images reveal drastic loss of live coral cover between 1975 and present. Submersible and ROV surveys conducted from 2001 to 2006 suggest that much of the *Oculina* habitat has been reduced to rubble by bottom trawling which unfortunately is a trend for deep-water reefs worldwide. In 1984, the *Oculina* reefs were the first deep-water coral reefs in the world to be designated a marine protected area (MPA). Unfortunately, the northern two-thirds of the reef system remained unprotected and was legally open to bottom trawling until the year 2000 when the boundaries were expanded to 1029 km² (300 nm²) from the original 315 km² (92 nm²). However, portions of the original reserve are still healthy and signs indicate improving grouper populations. In 2006, a high resolution multibeam map was completed which details the hundreds of pinnacles and ridges making up the reef system. Many new reef features were discovered both inside and outside the designated MPA.

Introduction

Deep-water coral reefs in the United States are formed principally by two framework constructing species of scleractinian corals, *Oculina varicosa* and *Lophelia pertusa*. Deep-water *Oculina* reefs grow at depths of 60-100 m and are only known off central eastern Florida, whereas *Lophelia* reefs in this region occur at depths of 490-870 m from North Carolina to Florida but are also known worldwide. Both types of reef form bioherms that are high-relief mounds of unconsolidated sediment and coral debris and are capped with thickets of the azooxanthellate coral. Both provide essential habitat for diverse communities of fish and invertebrates (Reed, 2002a,b; Koenig *et al.*, 2005; Reed *et al.*, 2005). Deep-water coral reefs have recently gained considerable attention as fisheries and oil/gas production expand to deeper habitats. Unfortunately many deep-water reefs have been severely impacted by bottom trawling but few have been mapped and little is known regarding the ecology of these diverse and fragile ecosystems.

The majority of deep-water *Oculina* habitat is known in Florida between 27°30'N (Fort Pierce) and 28°30'N (Cape Canaveral) in a zone 2-6 km wide and paralleling the 80°W meridian along the shelf edge break (Figure 1; Avent *et al.*, 1977; Reed, 1980). The coral forms azooxanthellate colonies, 1-2 m in diameter and 1-2 m tall, that coalesce into thicket-like habitats and high-relief bioherms that are similar in structure to deep-water *Lophelia* coral reefs (Reed, 2002a,b; Reed *et al.*, 2005).

The *Oculina* reefs were the first deep-water coral reefs in the world to be designated as a marine protected area. The *Oculina* Habitat Area of Particular Concern (OHAPC) was enacted in 1984 by the South Atlantic Fishery Management Council (SAFMC) which banned bottom trawling, bottom longlines, and anchoring in a 315 km² (92 nm²) area (NOAA, 1982). Historical accounts from *Johnson-Sea-Link* submersible dives in the 1970s described large populations of economically important reef fish including spawning aggregations of grouper associated with the coral habitat (Gilmore and Jones, 1992; Koenig *et al.*, 2000, 2005; Reed *et al.*, 2005). By the early 1990s, the grouper and snapper spawning aggregations had been decimated from commercial and recreational fishing (Koenig *et al.*, 2000, 2005). This stimulated the SAFMC to ban hook-and-line bottom fishing in 1994 to test the effectiveness of a fishery reserve. Unfortunately, the northern two thirds of the *Oculina* reef system remained unprotected outside the boundaries of the OHAPC and was legally open to mechanically destructive activities such as bottom trawling. Bottom trawling within *Oculina* ecosystem was primarily for rock shrimp and brown shrimp and this was the primary cause of major habitat destruction. In 2000, the *Oculina* HAPC boundaries were expanded to 1029 km² (300 nm²) which banned bottom trawling, and the boundaries of the original OHAPC, termed the *Oculina* Experimental Closed Area (OECA), continued the additional moratorium on bottom fishing (NOAA, 2000). In addition, the SAFMC has mandated that the rock shrimp industry implement a vessel monitoring system (VMS) for the fishery to aid in enforcement of the closed *Oculina* HAPC areas.

Historical photographic records from submersible surveys of the eastern Florida shelf between 1975 and 1977 provide evidence of the status of the deep-water *Oculina* reefs prior to heavy fishing and shrimp trawling activities of the 1980s and 1990s (Avent *et al.*, 1977; Avent and Stanton, 1979; Reed, 1980). The *Oculina* reefs were first discovered during these submersible transects when over 50,000 35-mm photographs were taken. Twenty-five years later, in 2001, portions of these original photographic transects were resurveyed. In this report two sites are compared, one within and one outside the boundaries of the original OHAPC. The northern site remained open to bottom trawling during this time period. Quantitative analyses by point count of video and photographic images from 1970s compared to 2001 allows a direct comparison of changes in percent cover of live *Oculina* coral during this 25 year time period. This study has resulted in the restoration of these rare and invaluable photographic and video images, and will provide marine managers and scientists a quantitative assessment of the health of these reefs in the 1970s, prior to intense trawling, compared to the same sites today (Figure 2).

Methods

Historical (1975-1983) Submersible and ROV Surveys

From 1975 to 1977, Dr. Robert M. Avent conducted benthic surveys of the east Florida shelf and slope, consisting of 12 east-west photographic transects with Harbor Branch Foundation's (Harbor Branch Oceanographic Institution, HBOI) *Johnson-Sea-Link* (JSL) I and II submersibles and CORD Remotely Operated Vehicle (ROV) from Cape Canaveral to Palm Beach (Figure 1; Avent *et al.*, 1977; Avent and Stanton, 1979; Reed, 1980). The transects were spaced approximately 19 km apart, extended from depths of 30 m to 300 m, and consisted of 55 submersible dives covering 298 km. It was during this survey that the live deep-water *Oculina* banks were first observed and described in

detail (Avent *et al.*, 1977; Reed, 1980). Photographs were taken randomly every 1-2 minutes with a 35-mm Edgerton-type still camera and flash system (Benthos model 372, Benthos Inc.) that was mounted 29° from vertical providing average frame coverage of 6.3 m² at 3.0 m height and 2.5 m mid-frame width. Viewing angle in water was 54° wide and 42° fore-aft. Area was estimated from camera height and in-water viewing angle of the lens and was verified by flying the sub over a 10-m grid on the bottom. Photographs were originally analyzed using a microfilm reader with a grid overlay for describing habitat type, dominant fish and benthic invertebrates. Over one hundred 30-m rolls of 35-mm Ektachrome film (or black and white) were used and archived at HBOI. Each photograph has a date and time stamp in the corner. A software program was used to interpolate the navigation coordinates throughout each submersible dive. Navigation used LORAN-A which in this region had an accuracy of ±150-300 m. Coordinates and depth were determined for each photographic image. During each submersible dive, meticulous written transcripts were compiled by Dr. Avent and research assistants which described habitat, fish and benthic communities, and physical factors. Ship and submersible logs recorded coordinates, depth, and other data throughout each dive. Hydrographic and navigation information were entered into a computer database (unfortunately, the computer tapes are obsolete, but hard copies and photos are archived at HBOI).

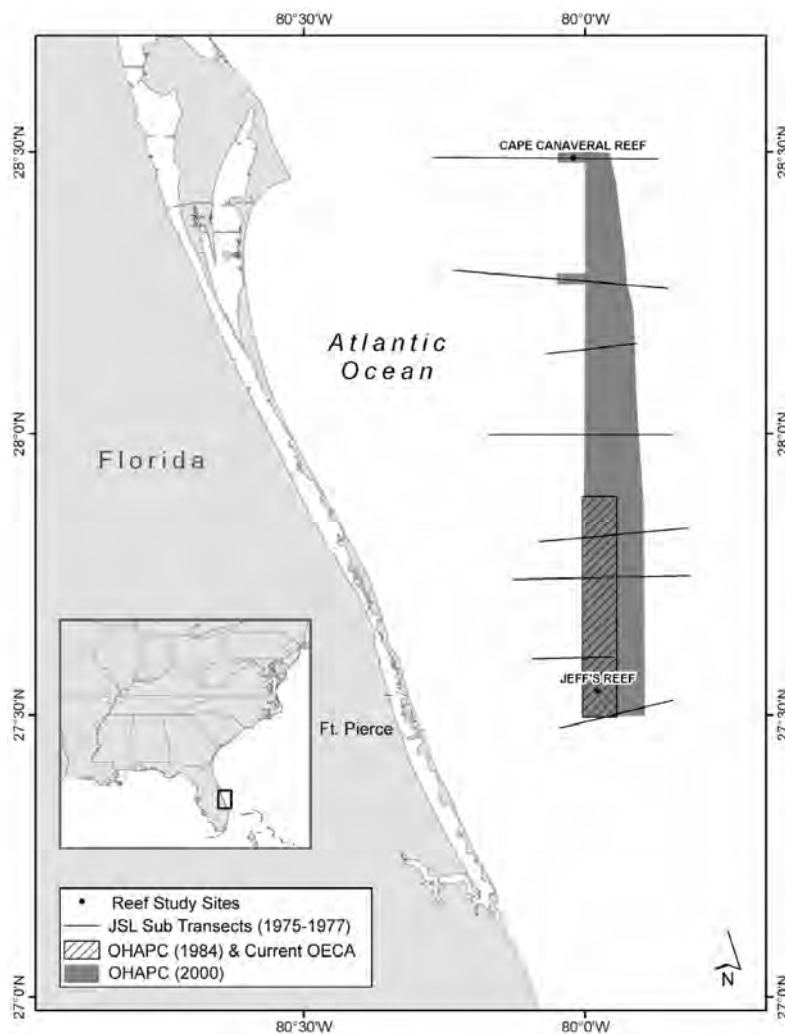


Figure 1. Map of the deep-water *Oculina* Habitat Area of Particular Concern (OHAPC) with historical submersible transect lines and *Oculina* reef study sites.

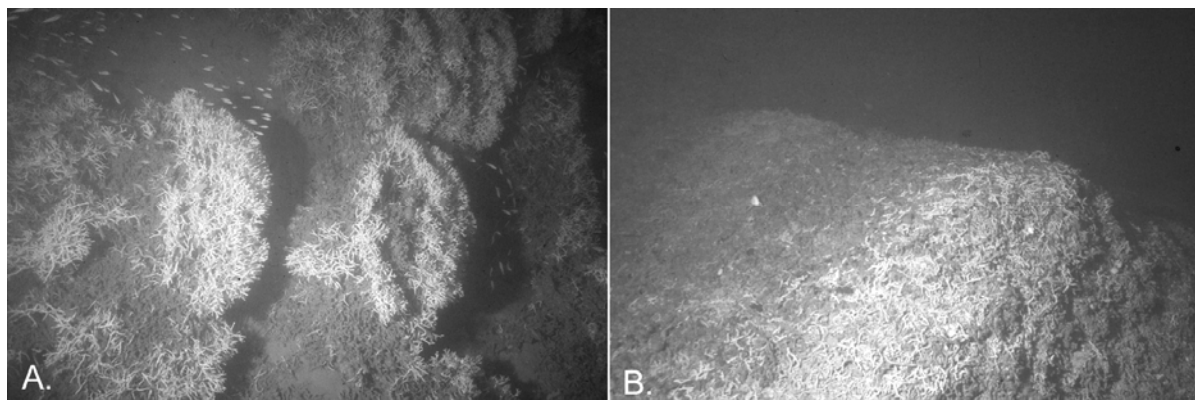


Figure 2. A. South slope of healthy deep-water *Oculina* reef (Jeff's Reef, 80 m); B. Peak of trawled *Oculina* reef.

Some of the original videotapes (3/4 inch and 1/2 inch open reel) and 30-m rolls of 35-mm Ektachrome film were recently restored and archived. Unfortunately videotapes of that age are prone to hydrolysis problems. The restoration process stabilizes the polymers of the tape coating. The restored tapes were recently archived onto Beta SP videotapes and copied to digital video disk (DVD). Nearly 3,000 35-mm photographs that were over *Oculina* coral habitat were recently digitized with a Nikon LS-2000 Coolscan scanner, enhanced in Photoshop®, saved as high resolution TIFF files (300 dpi, 3.75 mB file), and copied to DVD. An Access database was compiled for the metadata and list of images for the photographic and video archives. Each photographic image filename includes JSL dive number and time (e.g., JSL I 0233 T 09-55-42.jpg = JSL I, dive number 233, photo time = 9:55:42 am).

Tethered, mixed-gas dives (lockout) were also made with the *Johnson-Sea-Link* submersibles from 1976 to 1983 on the deep-water *Oculina* banks for studies on biodiversity of animals associated with the coral, coral growth rates, and geology (Reed, 2002a). The scientist-lockout diver used a Kirby-Morgan band mask attached to a 30-m umbilical hose which supplied the gas mix (10% oxygen/ 90% helium) and voice communications from the submersible. During ascent of the submersible after each dive, decompression stops with oxygen and air breaks were initiated at a depth 58 m in 3-m increments and took place in the submersible's aft, two-man dive chamber. Once the submersible was on deck the R/V *Johnson*, it was mated to a double-lock decompression chamber (152-cm diameter) for the remaining decompression period (3-4.5 hours).

Recent (2001-2006) Submersible and ROV Surveys

Recent data (2001-2006) were collected using the human-occupied *Clelia* submersible (HBOI) and the NOAA NURC ROV (*SuperPhantom*). Submersible dives that were in proximity to the historical transects were selected for comparison of reef habitat over a 25 year period. Color videotapes (Mini-DV digital) were recorded with a pan and tilt videocamera which provided a 72.5° x 57.6° field of view (Sony DX2 3000A, three chip 2.6 mm CCD, with Canon J8X6B KRS lens, 6-48 mm zoom, and 0.3 m minimum focus). The downward-looking camera was equipped with four parallel lasers (17.5 cm apart along the edge of the diamond shape) providing scale for quadrat size. Ship navigation was determined with differential global positioning system (Magnavox MX 200 GPS) which is accurate to ±5 m, and submersible tracks were plotted with the Integrated Mission Profiler (Florida Atlantic University) which links to the ship's GPS. Still images were derived from randomly selected video frame grabs for quantitative point count analyses.

Quantitative Analyses of Photo Transects

The historical photographic transects were recently analyzed and compared with the recent dives on the *Oculina* reefs to determine changes of percent cover of living coral over time (Reed *et al.*, in review). For this paper, only the northern-most (trawled) study site (Cape Canaveral) is compared to the southern-most (untrawled) study site (Jeff's Reef). Each photographic image was overlaid with 100 randomly distributed points to determine percent cover for each habitat type (live coral, standing dead coral, coral rubble) using CPCe software (Kohler and Gill, 2006). Coral colony diameters were also calculated with the CPCe program.

Results and Discussion

Northern Trawled Site (Cape Canaveral)

In 1976, the Cape Canaveral photographic transect consisted of six *Johnson-Sea-Link* (JSL) submersible dives covering a total E-W distance of 42.0 km from a depth of 30 m to 305 m at the latitude of $\sim 28^{\circ}29'N$. The depth zone of distribution for living *Oculina* was 70-87 m over a distance of 2.4 km. One major, high-relief *Oculina* bioherm was encountered.

In 2001, fathometer transects were made at the Cape Canaveral *Oculina* bioherm site previously mapped in 1976. Although there were some discrepancies in the coordinates from LORAN A used in 1976 versus GPS in 2001, there were no other mounds or features in the region. In this case, the LORAN converted coordinates were 460 m SE from the GPS coordinates. Multibeam maps generated from surveys made in 2002 (Reed *et al.*, 2005), further verified that this was indeed the same reef (GPS at peak- $28^{\circ}29.802'N$, $80^{\circ}01.268'W$). This site had remained open to bottom trawling until 2000, when the OHAPC was expanded up to Cape Canaveral and incorporated this reef.

Cape Canaveral Reef (1976)

The Cape Canaveral *Oculina* reef was discovered during a submersible dive in 1976 (JSL II-063). Bottom visibility was 5-10 m, current $21 \text{ cm}\cdot\text{s}^{-1}$ ($30 \text{ cm}\cdot\text{s}^{-1}$ at top of reef), and temperature 20°C . This bioherm was described from written transcripts and submersible logs as a coral mound with $30\text{-}45^{\circ}$ slopes, 18 m relief, and ~ 0.35 km wide at the base. Maximum depth during the transect was 87 m at the east base and 70-72 m at the top which was a SE-NW oriented ridge. The transect followed the east flank, the top, and west flank. No exposed rock was observed on the slopes or crest of the reef but appeared to be entirely covered with living and dead *Oculina* coral and sediment. Thus it is a bioherm and not a rock mound or lithoherm. Colonies of live *Oculina* were ~ 1 m tall on the flanks and the observers estimated coverage of 25%. Coral colonies along the peak were 45-60 cm tall. Some colonies appeared to have been severed into two or three pieces, possibly by an anchor or cable. A 6-m long, 5-cm diameter cable was found on the bottom near the reef. Dominant fish associated with the reef were snowy grouper (*Epinephelus niveatus*), greater amberjack (*Seriola dumerili*), and smaller reef fish including bank butterflyfish (*Prognathodes aya*), blue angelfish (*Holocanthus bermudensis*), and various damsels and wrasses. Continuing the transect west of the reef were a series of smaller reefs of moderate to low relief (3-5 m to flat pavement). Some had spurs of live coral, 1.0 m tall and 2.5 m long. The bottom undulated with exposed bedrock and a thin veneer of sediment, coral rubble, and live coral mostly 45-60 cm diameter. At a depth of 70 m to the end of the transect at 65 m, the bottom was sandy and no *Oculina* was found.

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Cape Canaveral Reef (2001)

The submersible dive (*Clelia* 616) in 2001 consisted of six transects on the 18-m tall bioherm. After 25 years since the first submersible dive, we found a reef that had been reduced to coral rubble. The peaks and flanks (N, S, E, and W) were covered in thick layers of unconsolidated dead coral rubble consisting of pieces ~2-10 cm in length. Some of the dead coral rubble on the upper south and east slopes and peak were somewhat consolidated rubble and well encrusted with demosponges and possibly blue-green algae. The flanks and peak appeared to be nearly 100% cover of dead coral based on visual observations. Apparent trawl tracks were observed as deep, straight grooves (~30 cm deep, 60 cm wide) cut into the coral rubble on the upper slopes and may be the result of doors from bottom trawls that are known to work in the area. A few 1.0 m colonies of standing dead coral were found at the west base. The only living *Oculina* coral observed was at the southeastern base from 82-85 m where a few 15-40 cm live colonies were observed apparently unattached on sand. There were also some 30-60 cm standing dead coral with live tips. The only fish were amberjack and few small reef fish.

Southern Non-trawled Site (Jeff's Reef)

The original photographic transect (1976-1977) off Fort Pierce consisted of four submersible dives from 30-261 m over 23.3 km; however, no live *Oculina* coral or coral rubble were encountered on this transect. During the same time period, a massive live *Oculina* bioherm was discovered just 4 km north of the transect line and is the southern-most living *Oculina* bioherm known.

This site (named Jeff's Reef after the *JSL* pilot, Jeff Prentice) was used for various experiments and studies over the past 25 years and so the exact location of the reef was certain as navigation equipment evolved from LORAN A to GPS. This reef was near the southern end of the original boundaries of the OHAPC that was designated in 1984 and so remained protected from bottom trawling during the entire period. However, it was open to bottom hook and line fishing until 1994 when that was also banned. Bottom fishing at these depths and within the Florida Current (Gulf Stream), requires the use of heavy weights which can certainly crush the fragile coral but not to the extent of a trawl net.

Jeff's Reef (1977)

An extensive photographic transect was made by the PI in 1977 on this *Oculina* reef (*JSL* II-164). This 18-m tall bioherm was ~300 m wide and consisted of three E-W oriented ridges (80 m maximum depth). Described in Reed 1980, the mound appeared to be entirely coral and sediment and a true bioherm. The dive was divided into five photographic transects on the flanks and peak of the reef. The east, west, south slopes and peak ridges were covered with massive live *Oculina* coral, 90-150 cm tall. The steep south slope (45°) and south faces of the ridges were covered with dense coral, forming nearly continuous rows of coral bushes. The 30° north slope had more coral rubble, less live coral, and generally smaller colonies of live coral. On this dive numerous snapper and grouper were noted along with amberjacks, 3.0 m shark and 2.4 m tall giant ocean sunfish (*Mola mola*). On subsequent dives dense spawning aggregations consisting of hundreds of scamp and gag grouper were described in the early 1980s (Gilmore and Jones, 1992).

Average growth rate of *Oculina varicosa* at a depth of 80 m is 16 mm·y⁻¹ (Reed, 1981). At this rate a large 1.5 m colony may be nearly a century old. During a lockout dive from the submersible, the PI using a steel rod was able to probe the flank of Jeff's Reef to a depth of 4.0 m without hitting bedrock. A 6-cm diameter sediment core was also taken during the dive. The core consisted of dead coral branch fragments and mud sediment; a piece of *Oculina* branch within the core had a radiocarbon age of 480±70 y B.P. (Hoskin *et al.*, 1987). Using the radiocarbon date yields an estimate of 980 years for the development of this *Oculina* bank. Considering that the limestone base of these *Oculina* reefs would

have been exposed ~18,000 years ago during the low water stand (-80 m) at the height of the Wisconsin glacial period, these deep-water *Oculina* reefs maybe thousands of years old.

Bottom temperatures averaged 16.2°C and ranged from 7.4 to 26.7°C at the 80-m Jeff's Reef site during a long-term survey (Reed, 1981). Upwelling of bottom water from the Florida Straits produces episodic intrusions of cold water throughout the year at the shelf edge in this region which causes temperatures to drop below 10°C (Smith, 1981; Reed, 1983). During these upwelling periods, levels of nutrients and chlorophyll increase nearly an order of magnitude: nitrates increased from <2 µM during non-upwelling to 9-18 µM during upwelling; phosphate from <0.25 to 0.5-2.0 µM; and chlorophyll-a from <1 to 1-9 mg·m⁻³ (Reed, 1983). Salinity on the deep reef averages 36.0. The clear, warm water of the northerly flowing Florida Current in the region of the *Oculina* reefs typically only extends down to a depth of 50-60 m. Seldom does this water mass extend to the bottom and the reefs are often inundated with a turbid, bottom nepheloid layer. Bottom currents averaged 8.6 cm·s⁻¹ but may exceed 50 cm·s⁻¹ (1 kn); currents of 50-100 cm·s⁻¹ due to the Florida Current may affect the peaks of the higher *Oculina* pinnacles and may be strong enough to break the coral branch tips (Reed, 1981; Hoskin *et al.*, 1983). Long-term light measurements with Lambda quantum meters recorded an average of 0.33% transmittance of surface light which usually does not support macroalgae on the deep-water *Oculina* reefs or zooxanthellae within the coral (Reed, 1981).

Jeff's Reef (2001)

In 2001, ten video transects were randomly laid out on Jeff's Reef (*Clelia* 606). Since the 1970s, the reef looks relatively healthy compared to the northern (recently protected) sites. There is no evidence of trawl damage, but long lines and fishing lines are present on the reef. However, the fish populations remain impacted from 20 years of overfishing. Population densities for the dominant fish species correlated highly with habitat type (Koenig *et al.*, 2000; Koenig *et al.*, 2005). Gag (*Mycteroperca microlepis*) and scamp (*M. phenax*) grouper and juvenile speckled hind (*Epinephelus drummondhayi*) are predominately associated with the intact coral habitat. Although the fish surveys in 2001 and 2003 were not directly comparable to previous surveys, there was a noted increase in grouper numbers and size since the fishing moratorium in 1994. There was also an increase in the abundance of male gag and scamp grouper since the 1995 survey, suggesting the possible reoccurrence of spawning aggregations of both species. Still, very few commercial reef fish (snapper and grouper) were observed in 2003, even after a 10 year moratorium on bottom fishing. The most common larger grouper observed in 2003 were red (*Epinephelus morio*), scamp, gag, and snowy grouper (*E. niveatus*). In the 1970s and 1980s, black sea bass (*Centropristis striata*) were abundant, and large (50-100 kg) Warsaw grouper (*Epinephelus nigritus*) were common (G. Gilmore, pers. observations; Reed, 2002a). After 20 years, black sea bass and juvenile speckled hind were observed for the first time on the reefs during surveys in 2005 but the large Warsaw grouper were still absent.

Quantitative Changes in 25 Years

Trawled Site (Cape Canaveral)

In 1976, based on quantitative analyses of the photographic transects, live coral coverage ranged from 7.0-35.1% (\bar{x} = 19.2%), 31.4% standing dead coral, and 17% coral rubble (Figure 3). Maximum coral density for individual photographic quadrats ranged from 32.0-73.2% (\bar{x} = 44.4%) and maximum coral colony diameters were 1.4-1.7 m.

By 2001, quantitative analyses revealed living *Oculina* coral cover ranging from 0-0.9% (\bar{x} = 0.2%). Mean standing dead coral cover was 1.68% and coral rubble 80.5%. Over a period of 25 years, nearly 100% of the live coral had been lost apparently due to trawling damage. Mean live coral cover was

reduced from 19.2% to 0.2% ($p < 0.0001$; Figure 4), but concurrently, coral rubble cover had increased by 64%, from 17 to 80.5% ($p < 0.0001$).

Non-Trawled Site (Jeff's Reef)

Quantitative photo analyses from 1977 transects showed a mean range of live coral of 30.6-47.7% ($\bar{x} = 39.3\%$), 25.8% standing dead coral, and 25.3% coral rubble. Maximum coral density from individual quadrats ranged from 46.3-67.4%, and maximum coral diameter was 1.75-2.01 m although in many cases the corals appeared to grow together into continuous hedges (which exceeded the width of the photographs, ~2.5 m) and were difficult to determine individual colonies.

In 1996, the PI revisited the reef for the first time in over a decade (*JSL II-2800*). Video transects were made with similar methodology and generally in similar locations as the 1977 dive. Five transects were selected for quantitative analyses. Mean live coral cover ranged from 8.2-15.0% ($\bar{x} = 10.3\%$), standing dead coral 60.2%, and coral rubble 25.4%. Maximum coral cover ranged from 12-36%.

In 2001, the mean live coral cover (7.2-18.8%, $\bar{x} = 13.4\%$) was similar to the 1996 results but both had drastically reduced from 1977. Mean standing dead coral had decreased to 34%, and coral rubble was 43.4%. Maximum coral density ranged from 20.4-55.0%. There was a significant difference in percent cover of live *Oculina* coral between 1977 and 1996 and between 1977 and 2001 ($p < 0.0001$). Live coral cover decreased 30% between 1977 ($\bar{x} = 39.3\%$) and 1996 (10.3%), but increased slightly by 2001 (13.4%).

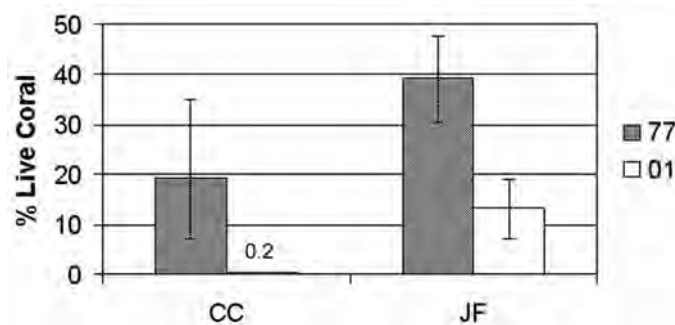


Figure 3. Mean percent live *Oculina* coral at reef sites in 1977 and 2001 (bars= range of transect means). CC= Cape Canaveral Reef (trawled site), JF= Jeff's Reef (protected site).

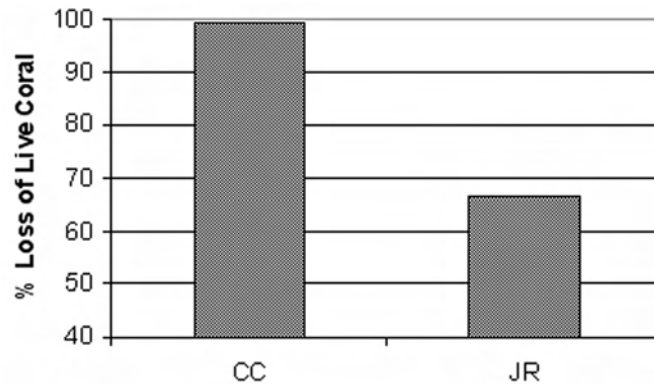


Figure 4. Percent loss of live *Oculina* coral in a 25 year period from 1977 to 2001. CC= Cape Canaveral (trawled site), JF= Jeff's Reef (protected site)

Conclusions

It is apparent that the protected reef did not have the devastating destruction from trawling, however it did show a loss in percent coral coverage over the 25 year time period. Although this could be due in part to a variety of factors including global warming, disease, or pollution like nearby shallow water reefs in the Florida Keys; damage from bottom hook and line fishing is certainly a factor. To date there is no evidence regarding the effects of global warming on deep reefs, nor is there any record of coral disease in deep reef corals. The 1996 survey was completed just after the moratorium on bottom hook and line fishing was placed in effect in 1994. Since 1996, however, the reef has shown a positive increase in live coral cover. This could be the result of fewer impacts of fishing weights and line breaking the coral. Fish populations have yet to recover from overfishing in the 1980s and 1990s but populations are showing signs of recovery. Speckled hind, which may be designated in the near future as a threatened species, and gag and scamp grouper which are predominately associated with the intact coral habitat, are showing up in greater numbers since the 1994 moratorium on bottom fishing.

During ROV surveys in 2002 and 2003 it was apparent that some rock-shrimp trawling and bottom hook and line fishing continue illegally within the *Oculina* HAPC. These observations included sightings of trawlers during the surveys; evidence of fishing lines and bottom longlines wrapped around coral colonies and remnants of new bottom trawl nets; artificial reef modules damaged by heavy gear; and apparent trawl tracks in the rubble noted near the damaged modules. Since 2000 several shrimp trawlers have been caught trawling illegally within the OHAPC, and as recently as February 2007, one trawler was caught within the OHAPC with 4500 kg of rock shrimp on board and allegedly had lost his 1300 kg trawl net and doors somewhere in the sanctuary.

An artificial reef restoration project has placed over 100 1-m diameter, hollow, concrete domes (Reef Balls, Reef Ball Foundation, www.reefball.org) in rubble areas of the OHAPC in 2000 and 2001 (Koenig *et al.*, 2005). Scamp and snowy grouper were observed to associate with the Reef Ball clusters very soon after placement. Several modules that were deployed in 1998 were also revisited in 2003 where numerous small colonies (1-10 cm) of *Oculina* were photographed growing on the blocks providing evidence of settlement by planula larvae (Brooke and Young, 2003, Reed *et al.*, 2005).

The expansion of the OHAPC in 2000 now covers the majority of the reef system, but hundreds of *Oculina* bioherms that were discovered in 2003 during multibeam sonar surveys still remain unprotected and vulnerable to bottom trawling. In 2003, the OECA (the original OHAPC boundaries) closure to bottom fishing was extended indefinitely to protect the overfished deep-water species of grouper and snapper. In addition, recent implementation of a vessel monitoring system (VMS) for the rock shrimp industry by the SAFMC has already proved to aid in enforcement of the closed *Oculina* HAPC areas.

Additional measures that could help protect these deep-water reefs would be surface monitor buoys with acoustic and video recorders which could relay via satellite real-time data on boat traffic and illegal trawlers. These could also be used by scientists studying the fish population dynamics and could include arrays of thermographs, current meters, and other equipment to help understand this remote yet valuable resource.

Acknowledgments

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