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## **INTRODUCTION**

In recent years, numerous discoveries of deep-water coral communities have altered the classical view of coral species only occurring in warm, shallow, clear tropical waters. Deep-water corals have been documented in depths exceeding 1,000 m, where temperatures hover between 4-8 °C and ambient light is totally absent. In contrast to shallow-water coral reefs built by hermatypic species possessing zooxanthellae, deep-water species are generally ahermatypic and lack zooxanthellae. However, deep-water coral species establish lush communities, and in some cases construct massive contiguous colonies similar in appearance and function to shallow-water coral reefs.

*Oculina varicosa* Lesueur, a branching scleractinian coral, occurs in shallow water to depths of over 100 m, extending from the West Indies northward to North Carolina and Bermuda (Reed et al., 1982). However, in a discrete area along the central eastern Florida coast, it forms massive colonies on high-relief pinnacles in 70-100 m of water (Reed, 1980). To date, *O. varicosa* has not been observed in any abundance in the Gulf of Mexico, and dense deep-water *O. varicosa* populations have only been documented on the shelf edge off eastern Florida (Koenig, 2001; Reed, 2002; Brooke and Young, 2005).

This report describes the size, structure, and distribution of *O. varicosa* colonies observed at one site in the Gulf of Mexico south of Cape San Blas, Florida.

## **SPECIES DESCRIPTION**

As described by Reed (1980), deep-water *O. varicosa* colonies are arborescent with highly anastomosed, irregular, dendritic branches averaging 6 mm in diameter (Figure 1). Cross sections of *O. varicosa* branches demonstrate dense, concentric layers of aragonite (Reed, 1980). Corallites are distributed spirally around the branches, and calices are generally 2-3 mm in diameter (Reed, 1980). Living colonies are typically pure white to pink in color, and microscopic examination of *O. varicosa* reveals a lack of zooxanthellae (Reed, 1980).

Reed (1980) classified deep-water colonies of *O. varicosa* located off the central eastern Florida coast into three categories. Small, individual coral colonies up to 2 m in diameter grow as discrete, branched, spherical heads (Reed, 1980). Of these, colonies less than 25 cm in diameter are often 100% alive, while larger colonies typically are dead in the center, possibly due to lack of water flow resulting from the extensive network of branches around the colonies' perimeter (Reed, 1980). The second category is typified by a linear shape 1-2 m in height and width, and attains a length of 3-4 m (Reed, 1980). This growth pattern may be associated with substrate preference related to the colony's exposure to nutrients carried by prevailing currents (Reed, 1980). Finally, colonies may form massive thickets of contiguous colonies up to 2 m in height, which are usually found on pinnacles possessing steep slope faces (Reed, 1980).

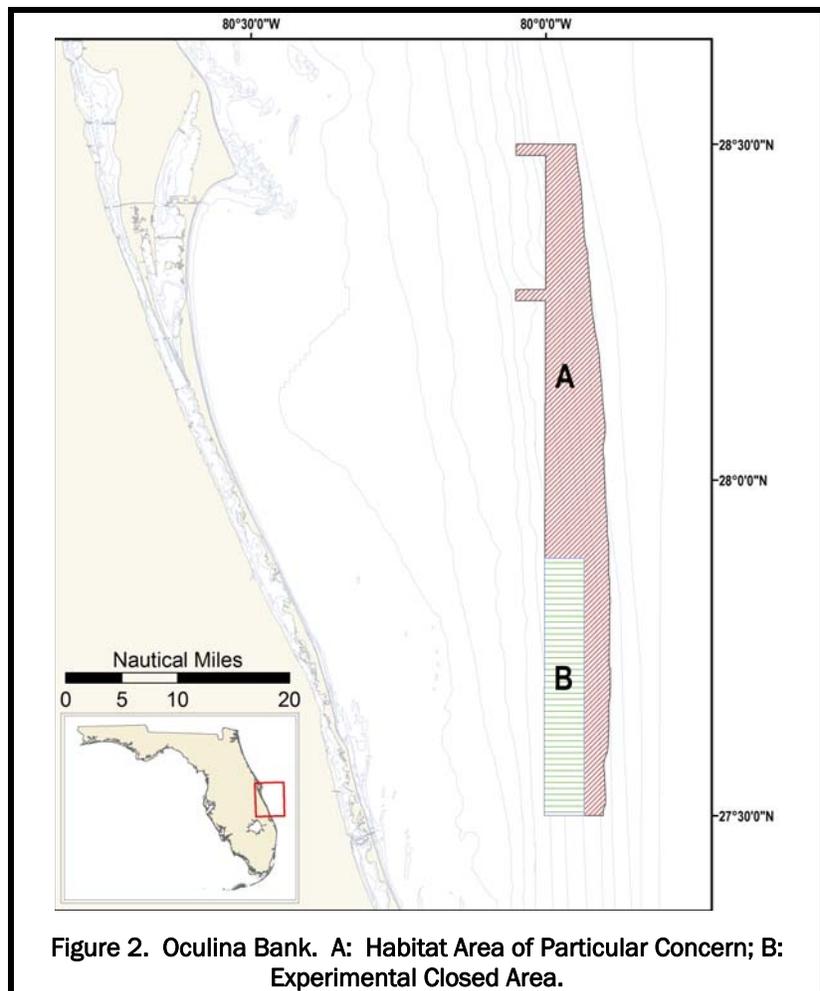
*Oculina varicosa* is a gonochoristic broadcast spawning species with high fecundity and a long-lived planktonic larval stage. Spawning is believed to occur during July and August in the shallow populations, and during September in the deep populations, with no obvious relationship to lunar or tidal phase (Brooke and Young, 2003; Brooke and Young, 2005). In a study by Brooke and Young (2003), embryogenesis in a collected colony of *O. varicosa*

occurred over a period of approximately 9 hours at 25 °C, resulting in small well-ciliated, azooxanthellate planulae. Following embryogenesis, ciliated planulae exhibited an immediate vertical migration to the surface, after which time they began to swim throughout the water column or became demersal (Brooke and Young, 2003). While it is unclear what cues trigger larval settlement, in a laboratory setting, *O. varicosa* larvae actively swam for 1-2 weeks before beginning to exhibit benthic-probing behavior (Brooke and Young, 2003). Settlement on the sides of the culture containers was observed between 21 and 27 days; however, some of the larvae continued swimming for up to 42 days, after which time the experiment was terminated (Brooke and Young, 2003).

## **OCULINA BANK**

According to available literature, profuse *O. varicosa* habitat is strictly found along the central eastern Florida coast, in an area rightfully named Oculina Bank (Figure 2). Oculina Bank resides in close proximity to the outer continental shelf (OCS) edge. The depth of the western edge of Oculina Bank is approximately 55 m, while the eastern boundary, located less than 5 km east is approximately 122 m. The northward end of the bank towards Cape Canaveral is more longitudinally compressed, with *O. varicosa* thriving in a corridor approximately 3 km across.

The geology of Oculina Bank generally consists of sandy, silty, and muddy sediments, punctuated by limestone ridges and pinnacles locally known as “cones.” These cones are concentrated along the 79-m contour (Scanlon et al., 1999). Generally, the sediments found in the deeper portions of Oculina Bank (e.g., at depths greater than 90 m) have a higher percentage of silt than do the sediments in the shallower areas to the west. Sediment samples taken near pinnacles and in scoured areas generally consist of sands and gravels, and contain less than 20% silt. Strong bottom currents have winnowed the sediments from the pinnacle and scoured areas, leaving behind only coarser sands and gravels (Scanlon et al., 1999).



**Figure 2. Oculina Bank. A: Habitat Area of Particular Concern; B: Experimental Closed Area.**

*Oculina varicosa* coral rubble can be a major component of the sediment. Anthropogenic and natural events can produce significant quantities of *O. varicosa* rubble. In some cases, this rubble accumulates in piles exceeding 1 m in depth. This is particularly evident on artificial reefs and shipwrecks, where the apparent natural succession of *O. varicosa* produces a layer of rubble underneath healthy coral thickets.

The geological origin and nature of the pinnacles has not been fully explained and documented. However, dredge samples obtained by Macintyre and Milliman (1970) from the pinnacles consisted mainly of oolitic limestones with some algal limestones and dated from the late Pleistocene to the early Holocene eras. The presence of shrimp (*Callinassa* sp.) burrows and relict hermatypic coral heads suggests a shallow water origin. Macintyre and Milliman (1970) interpreted the pinnacles to be oolitic dunes that were deposited and petrified in a marine environment during the Holocene transgression. Subsequent erosion by the strong Gulf Stream currents and growth of ahermatypic corals has produced the irregular high-relief pinnacles currently found on Oculina Bank. The pinnacles vary in size and shape, but some rise as much as 18 m or more from the seabed. The texture of the cones in the absence of *O. varicosa* is generally smooth and pockmarked. When colonized by *O. varicosa*, the habitat complexity and amount of surface area associated with the cones is greatly increased.

Due to its proximity to the OCS edge, as well as to the Gulf Stream, Oculina Bank can experience extremely dynamic conditions. Typically, the Gulf Stream meanders inshore during the warmer summer months, bringing with it warm (e.g., 29 °C) surface waters and a swift, northward-moving current. A “rip,” as well as a distinct color change, indicating the delineation of the faster moving water body, usually marks the Gulf Stream current. This delineation may change daily or hourly. It is not uncommon for this boundary to be found west of Oculina Bank (i.e., 80 °W longitude). The Gulf Stream surface currents can exceed velocities of 2 m/sec.

The direction of the current typically is within a few degrees of due north. Bottom currents on Oculina Bank generally are not as strong as the surface currents, and usually dissipate below the thermocline. However, in 2001, bottom currents approaching 1.6 m/sec were experienced at a site within Oculina Bank off Sebastian at a depth of 88 m (Author, pers. obs.). On average, bottom currents of 0.5-0.8 m/sec flow through Oculina Bank (Scanlon et al., 1999; Koenig, 2001). Currents at the sediment-water interface are undoubtedly less strong than those observed just above the sea floor, and are most likely on the order of 0.2 m/sec; however, that velocity is sufficient to erode silt and sand (Hollister and Heezen, 1972; Reineck and Singh, 1980).

Frequently, the central eastern Florida coast experiences dramatic upwelling in the summer months. Parcels of cold water move inshore from beyond the OCS edge, resulting in tremendous temperature fluctuations. Commonly, the bottom temperature on Oculina Bank averages 16 °C. However, bottom temperatures can fall to 7 °C during an upwelling event (Reed, 1981).

## DEEP REEF TRACT OF THE NORTHEASTERN GULF OF MEXICO

Topographic prominences form reef-like features along the OCS edge and continental slope of the southeastern United States and Gulf of Mexico (Weaver et al., 2002). In particular, the OCS of the northeastern Gulf of Mexico (NEGOM) is populated with numerous hard-bottom topographical features (Gardner et al., 2000; Sulak et al., 2004). Parker et al. (1983) estimated there was substantially more hard bottom habitat in this area compared to that in the northwestern Gulf of Mexico and along the Atlantic coast.

Early investigations on the distribution of OCS reefs in the NEGOM began in the middle of the 20th century. Ludwick and Walton (1957) mapped the location of OCS reefs along the northern Gulf from the Mississippi Delta to Port St. Joe, Florida. An extensive set of reef features, known as the Pinnacles Reef Tract, occurs off Mississippi and Alabama at depths between 60 and 110 m (Weaver et al., 2002). This tract is apparently part of a sequence of drowned reef complexes along the “40-fathom” shelf edge of the NEGOM (Ludwick and Walton, 1957; Gardner et al., 2000). While numerous studies have mapped this reef tract, information gaps still exist, especially east of DeSoto Canyon and along the west Florida shelf. Furthermore, while the *Lophelia pertusa* deep reef ecosystems (i.e., 300-500 m depth) in the Gulf of Mexico have been the focus of several studies (Schroeder, 2002; Schroeder et al., 2005), little is known about coral communities in more intermediate depths (e.g., 80 m).

The eastern part of the NEGOM region is separated from the western part by the DeSoto Canyon (Figure 3), which forms a physical and hydrographic barrier separating shelf and slope faunas (Shipp and Hopkins, 1978). The bathymetry of DeSoto Canyon also influences local current flow; in particular, eddies originating from the Loop Current (Churchill et al., 2000). The clockwise flow that extends northward into the Gulf of Mexico and eventually re-joins the Yucatan and Florida Currents is known as the Loop Current (Hofmann and Worley, 1986). Variable in position, the Loop Current intrudes into the Gulf of Mexico, forming an intense clockwise flow as far north as 29 °N; occasionally this loop will reach as high as the Mississippi river delta or the Florida OCS (Wiseman and Dinnel, 1988; Molinari and Mayer, 1982; Huh et al., 1981; Vukovich et al., 1979). The Loop Current is constrained from impinging directly onto the Florida shelf by depth related vorticity considerations. However, eddy formation and trapping of Loop Current waters on the shelf break combined with onshore Ekman transports provide a mechanism by which Loop Current waters can be transported onto the shelf.

When the Loop Current intrudes onto the shelf, a strong southward current may be produced along the shelf slope seaward of the intruded water boundary (He and Weisberg, 2003). This current can transport cold, nutrient-rich water from the north, thereby producing anomalous hydrographic features near the shelf break (i.e., 80-m isobath). He and Weisberg (2003) found the shelf-break currents are largely Loop Current controlled, while the shelf currents are largely controlled by the local winds.

The suite of reef fish species inhabiting the OCS reefs in the NEGOM represents a fraction of the Caribbean reef-fish fauna (Weaver et al., 2002). Several factors may attribute for this reduced diversity, including depth, temperature, habitat, and/or trophic limitations; Weaver

et al. (2002) surmised the greatest influence on taxonomic structure is the lack of a full range of reef habitats, such as coral and coralline algae dominated communities.

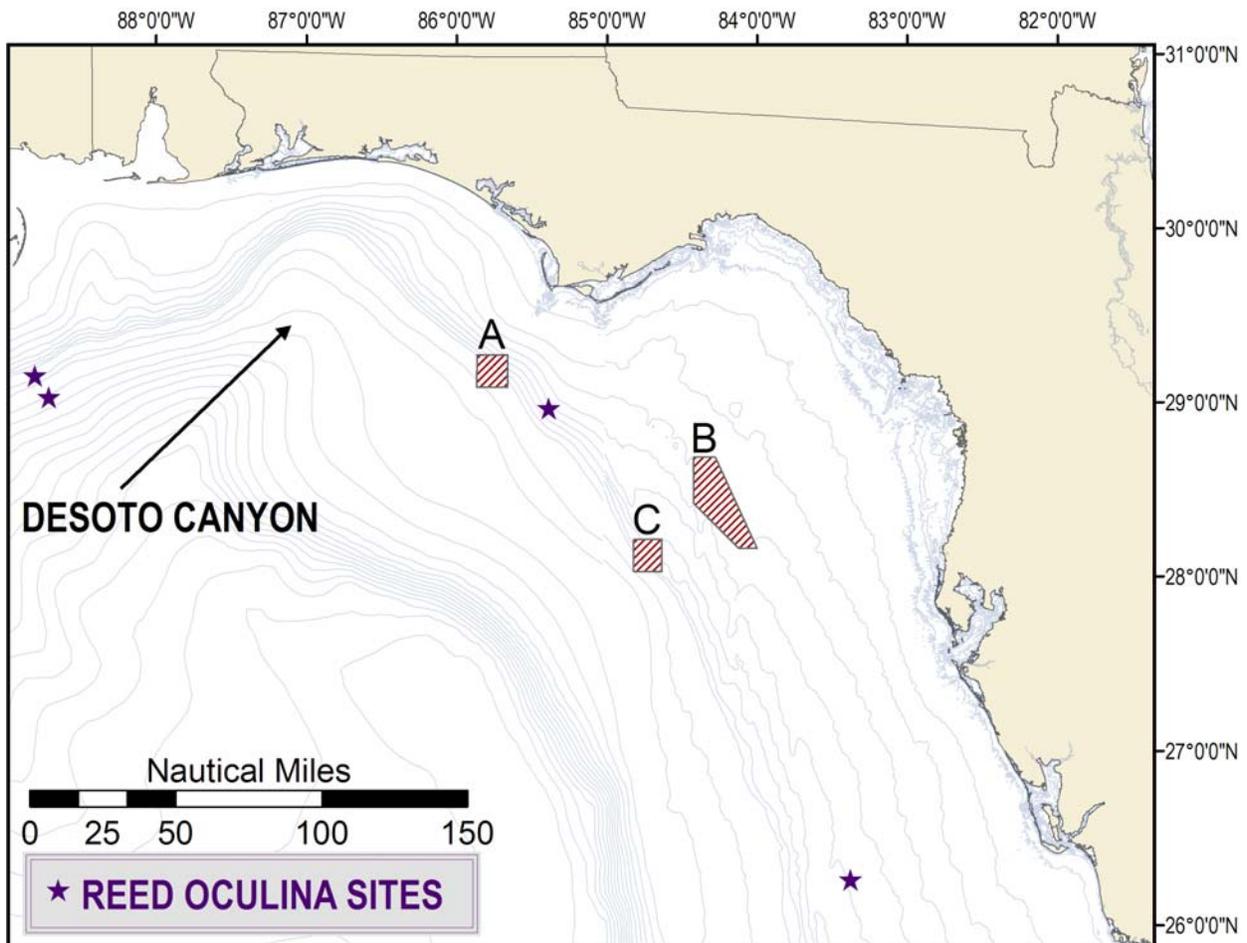


Figure 3. *Oculina varicosa* sites documented by Reed (pers. comm.). A: Madison and Swanson reef fish closed area; B: Florida Middle Grounds Habitat Area of Particular Concern; C: Steamboat Lumps reef fish closed area.

### OBSERVATIONS OF OCULINA HABITAT IN THE NORTHEASTERN GULF OF MEXICO

*Oculina varicosa* grows in shallow water in the Gulf of Mexico at depths from 2-45 m (Reed, 2002). The deep-water variety (i.e., >45 m) of *O. varicosa* has only been previously observed in the Gulf of Mexico at four sites (Figure 3). Reed (pers. comm.) collected *O. varicosa* from a site in 59 m of water on the west Florida shelf, approximately 160 km offshore Naples. Reed documented three other video observations of *O. varicosa*: two on oil rigs off the Mississippi River delta in 102 and 83 m of water, respectively, and one on the west Florida shelf south of Cape San Blas in 65 m of water. It was unclear in the video footage whether the coral observed was *Oculina* or *Madracis* (Reed, pers. comm.). Regardless, abundance of *O. varicosa* in these observations was noted as sparse to rare, and were only found in small colonies. Observed colonies measured 20-30 cm maximum diameter (Reed, pers. comm.). However, dives conducted in August 2005 revealed significant *O. varicosa* habitat on the 40-fathom break south of Cape San Blas, in an area known as Twin Ridges (Figures 4-6).

The Twin Ridges dive site (Figure 4) is within 2 km of where *O. varicosa* was previously observed in video (Reed, pers. comm.). However, the previous observation noted only a small colony at a depth of 65 m. In contrast, the author noted abundant *O. varicosa* at depths from 66-75 m. This may be a function of *O. varicosa*'s preference for high relief topography, which may facilitate feeding.

Divers employed open-circuit SCUBA and breathed a helium-rich gas at depth to displace both nitrogen (to avoid narcosis) and oxygen (to avoid toxicity issues) levels common to compressed air. Decompression gasses of 50% enriched-air nitrox and 100% oxygen were used on ascent. Observations on the 30-minute dive were documented by underwater video. Depth to the top of the ledge was 66 m, while the bottom of the nearly vertical ledge was located at 75 m. Surface temperature was 29 °C, bottom temperature was 23 °C, and current was negligible.

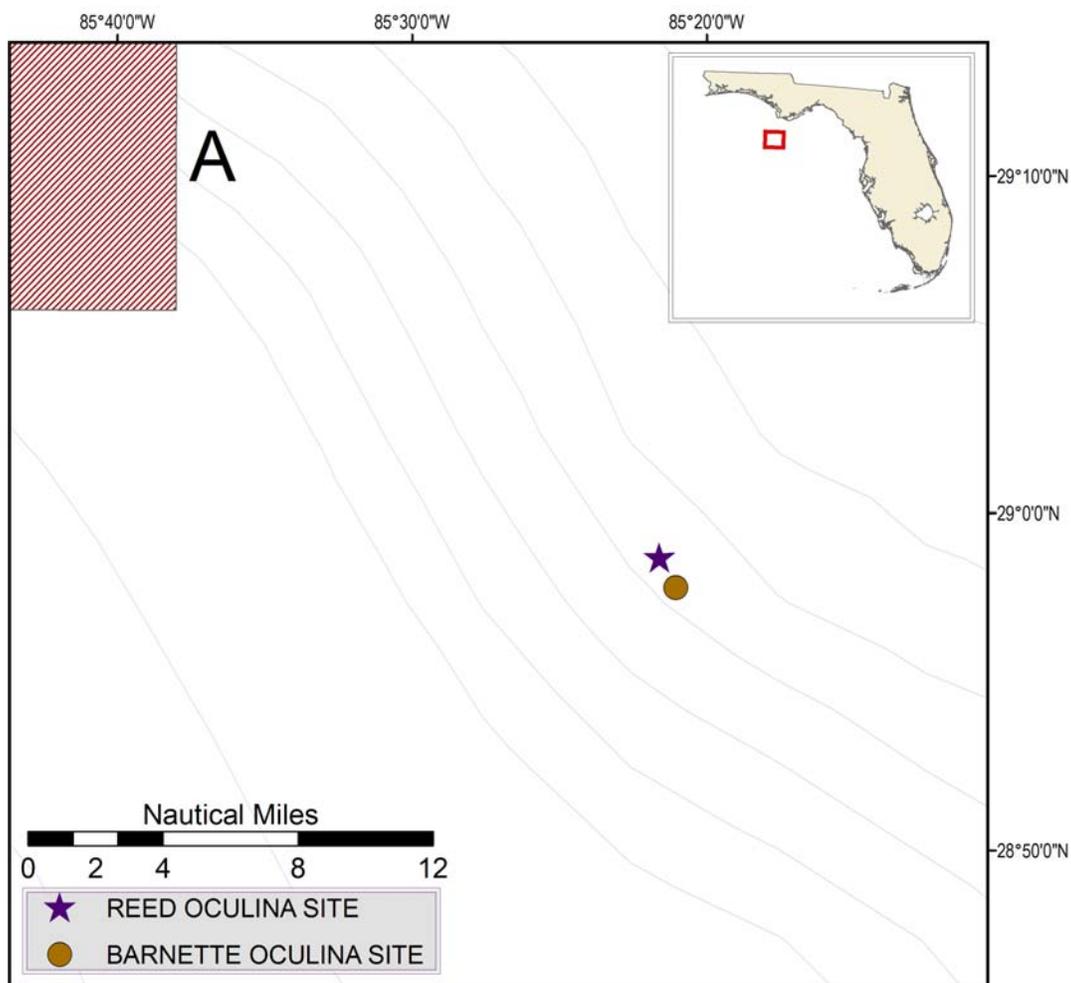


Figure 4. Twin Ridges area illustrating *Oculina varicosa* site observed by the author and its proximity to the historical site documented by Reed (pers. comm.). A: Madison and Swanson reef fish closed area.

The dive occurred on a portion of the 40-fathom break consisting of a 10 m-high ledge with numerous offset pinnacles and undercuts. Colonies of *O. varicosa* were largely found randomly distributed on the vertical face of the ledge and on most surfaces of the offset pinnacles. *Oculina varicosa* rubble was observed around the base of the ledge and

pinnacles, most likely the product of natural succession. In many of these areas growth was extensive, and colonies 1 m in diameter were very common (Figures 5-8). Because the colonies were neither linear in shape, nor formed massive thickets as found in discrete areas off the central eastern Florida coast, the growth pattern most closely resembled the first category described by Reed (1980). However, colonies were not always spherical, and sometimes – particularly on the top of the offset pinnacles – individual coral colonies appeared to merge, resulting in coral cover over most of the available surface. *Oculina varicosa* in the NEGOM may not form massive thickets due to the relative stability of the deep reef tract, in contrast to the highly dynamic environmental conditions that impact Oculina Bank off the central eastern Florida coast, which includes significant variances in temperature, current, and turbidity. Furthermore, the presence of extensive suitable habitat for coral settlement along the NEGOM OCS deep reef tract may not require a highly competitive growth pattern that results in the thicket formation found on Oculina Bank. Reed (1981) calculated growth of shallow- and deep-water specimens (6 and 80 m, respectively) of *O. varicosa* in the Atlantic Ocean as 11.3 and 16.1 mm/yr, respectively. The deep-water variety of *O. varicosa* in the Gulf of Mexico is likely exposed to a higher average temperature as compared to coral on Oculina Bank due to the absence of upwelling events, and it is not regularly exposed to significant current velocities as coral found off the central eastern Florida coast subjected to the influence of the Gulf Stream, two factors that should have a positive effect on coral growth. However, growth estimates of *O. varicosa* in the Gulf of Mexico are not possible without further investigation.



Figure 5.



Figure 6.

The extensive *O. varicosa* colonies likely help support the abundant fish populations observed at the Twin Ridges dive site. *Oculina varicosa* coral colonies increase overall habitat complexity, provide shelter, and may be a source of food for some fish species (Reed et al., 1982). There was an abundance of fish at the Twin Ridges dive site, yet the diversity of observed fish species was less than that typically found at shallower (e.g., 30 m) reef sites, most likely due to the aforementioned factors discussed by Weaver et al. (2002). While a comprehensive fish census was not conducted, fish species observed included greater amberjack (*Seriola dumerili*), scamp (*Mycteroperca phenax*), gag (*Mycteroperca microlepis*), spotfin hogfish (*Bodianus pulchellus*), and French angel (*Pomacanthus paru*). It should be noted that coral thickets on Oculina Bank off the central eastern Florida coast support more than 70 fish and 380 invertebrate species (Reed, 2002). Aside from the fish

species observed at the Twin Ridges dive site, numerous other coral and invertebrate species were documented. In particular, gorgonians, echinoderms (i.e., crinoids), and octocorallians were found along with *O. varicosa* colonies. In contrast, *O. varicosa* communities off the central eastern Florida coast are largely monospecific, with only random whip corals typically observed. This disparity is likely due to the dynamic environmental conditions present on Oculina Bank, while the NEGOM OCS deep reef tract is more environmentally stable.

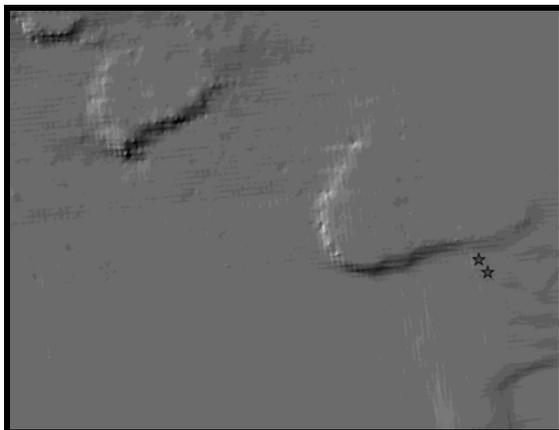


Figure 7.

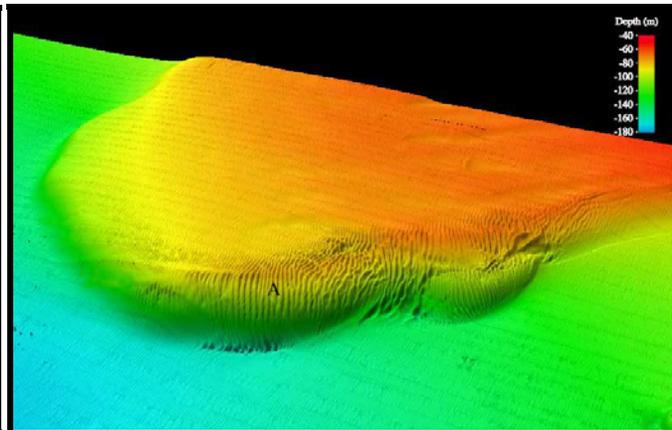


Figure 8.

Both commercial and recreational fishermen target the NEGOM OCS. Entangled, abandoned, and overgrown longline gear was observed in several places along the ledge. The Twin Ridges dive site is approximately 31 km from the southeast corner of the Madison and Swanson reef fish closed area, a marine protected area measuring approximately 394 km<sup>2</sup> established by the Gulf of Mexico Fishery Management Council in June 2000 to provide protection for gag spawning aggregations.



LEFT: Figure 9. National Geophysical Data Center bathymetry of the Twin Ridges area (Image courtesy of Doug Weaver, NOAA).



RIGHT: Figure 10. Perspective view looking north over Twin Ridges. Bedforms, some with 2 m of relief and 120m crest-to-crest labeled at "A" can be seen along the south facing slope. The distance across the bottom of the image is approximately 10.5 km. The vertical exaggeration of this image is 20x (Gardner et al., 2001).

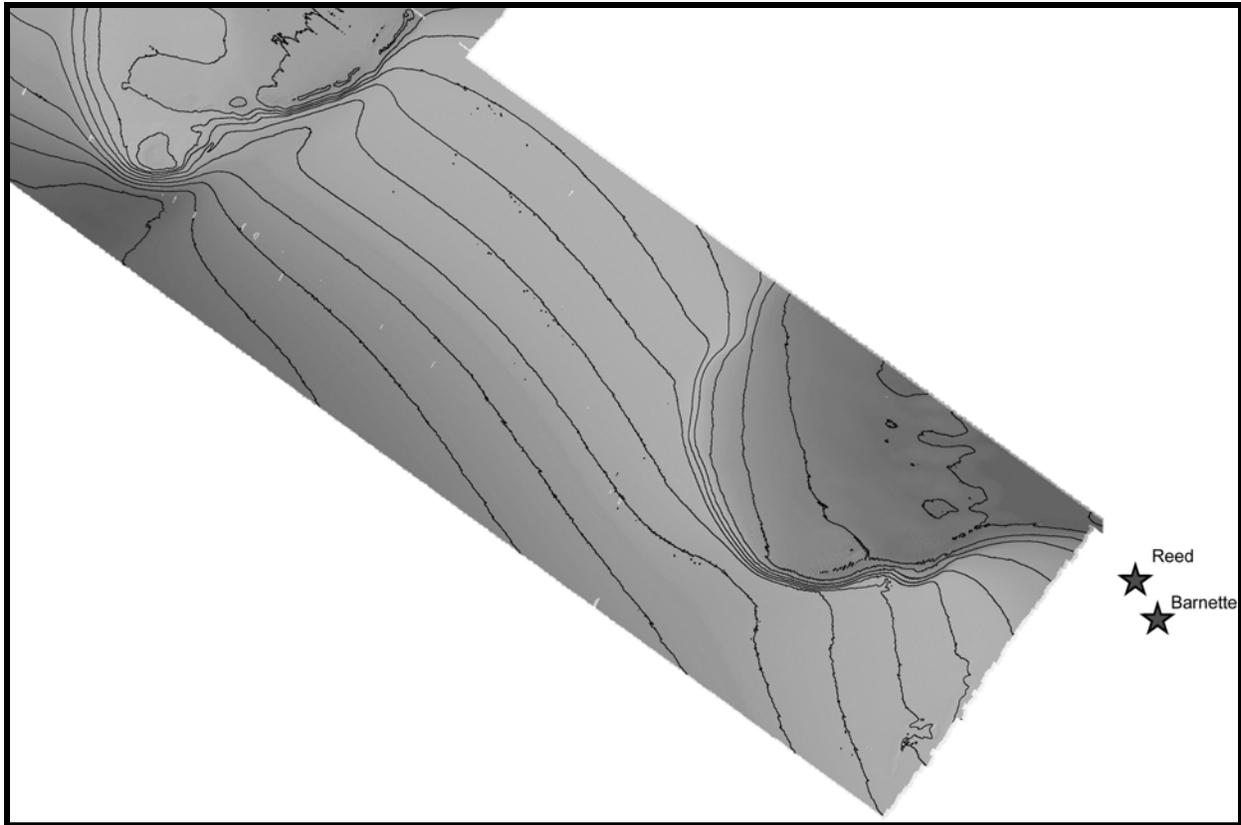


Figure 11. Multi-beam sonar mosaic of the Twin Ridges area (From Gardner et al., 2001; image courtesy of Doug Weaver, NOAA).

As illustrated in Figures 9-11, an extensive high-relief ledge system is located just west of the documented dive site. While unconfirmed, it is probable additional *O. varicosa* habitat exists along this tract. Anecdotal information from commercial fishermen indicates *O. varicosa* is fairly common in the vicinity of Twin Ridges (Figure 10). Given the planktonic larval period of *O. varicosa* ranging from 21 to 27 days or longer (Brooke and Young, 2003; Brooke and Young, 2005), deep reef habitat in the NEGOM OCS likely contributes to the recruitment of both deep- and shallow-water populations of *O. varicosa* in the Gulf of Mexico. Furthermore, given the influence of the Loop and Florida Currents, it is conceivable *O. varicosa* larvae from the NEGOM OCS could settle in the Atlantic Ocean off Florida. Aside from the documented thickets and coral habitat on Oculina Bank, *O. varicosa* has also been observed by the author on several artificial reefs off Broward County that were deployed only in the late 1980s and early 1990s. More research should be conducted to fully evaluate the abundance of *O. varicosa* along the NEGOM OCS, and determine its genetic relationship to populations of *O. varicosa* found off the central eastern Florida coast.

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