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A Professional Jury Report on the Biological Impacts of Submarine Fiber Optic Cables on Shallow Reefs off Hollywood, Florida

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Biological Impacts of Submarine Fiber Optic Cables on Shallow Reefs off Hollywood, Florida

In the summer of 2000, PEER formed a professional jury staffed by two (2) marine biologists, an environmental economist, a marine engineer, and two (2) coral reef regulatory specialists. Their assignment was to conduct a series of research dives down to an existing fiber optic cable conduit off Hollywood, Florida. The resulting study is designed to provide an empirical basis for describing the significant impact federal and State actions have on coral reef ecosystems. Both levels of government — through the Governor of Florida and the Chairman of the Federal Communications Commission (FCC) — are required to approve corporate use of the reefs for infrastructure access by telecommunications cables. To the extent these governments impact the health of the reef, they are responsible for adherence to applicable State and federal environmental laws enacted to protect those nearshore coral reefs.

This issuing of the biological data from the Summer, 2002 dives off the coast of South Florida will be followed by the release of the full Jury report in early 2003.

INTRODUCTION

About fifty-three (53) percent of the US population now lives within 50 miles of the Atlantic and Pacific oceans or the Gulf of Mexico (Helvarg, 2001). Over development of the world's tidal regions has brought about abrupt, considerable degradation to coastal habitats. On the southeast coast of Florida, <u>a direct casualty</u> of <u>poorly controlled coastal development is a scarcity of nearshore coral reef</u> and affiliated, dependent communities such as seagrasses and mangroves. As the population concentrates near the Atlantic Ocean and Gulf of Mexico, the demand for port development and navigation access increases. Dredging navigation channels inland and close to shore destroys bottom vegetation such as seagrasses. Deep water access channels for large commercial vessels such as freighters, tankers, and cruise ships may extend for miles offshore resulting in the direct destruction of coral reefs. Construction of port facilities and docks for smaller recreational vessels destroys fringe vegetation such as mangroves. Commercial and residential developments may be constructed on dynamic shorelines where erosion from ocean waves and currents is severe. Ultimately, this leads to coastal armoring with seawalls or to dredging sand from inlets and offshore to protect property constructed too close to the ocean.

Both indiscriminate routing of submarine telecommunications cables and dredging near coral reefs has and will continue to cause damage to the reefs through direct impact damage and the resettling of suspended sediment and direct contact of the dredge with the reef (Courtenay, *et al.*, 1974; Courtenay, *et al.,* 1975; Courtenay, *et al.,* 1980; Dade County, 1988; Dade County, 1990; Goldberg, 1989; Marzalek, 1981). Nearshore reefs are buried by dredged material deposited on beaches.

Reefs and reef growth

Geologists define a coral reef as a structure built by living organisms locked in a framework with incorporated trapped sediment. Net reef growth relies on accretional, sedimentological and erosional processes all to be at optimal conditions. Bioerosion and calcification are in approximate balance on “normal” reefs; there are many factors that can shift this normal phase toward destructive processes. This delicate balance hinges upon biological (bio-accretion of hermatypic corals and associated calcareous organisms), geological (sediment accumulation and infilling), physical (abrasion) and chemical shifts (shifts in CO_2 and materialization) factors. One can say that “healthy” reefs are undergoing a process of active accretion, while “unhealthy” reefs are undergoing a process of erosion.

Mass mortality or population outbreak of a particular species may cause a complete shift of the coral community. Anthropogenic impacts such as fiber optic cable deployment may change benthic species composition (Done *et al.* 1996) which, in turn, changes the bio-accretional processes. Urchins, herbivorous fishes, sponges, bivalve mollusks and polychaetes have all been known to erode reef structures, while the hermatypic corals and other calcareous organisms such as coralline algae work to build them. Gorgonians may help build reefs by way of baffling, which is the process of catching and trapping sediment that will later be incorporated into the reef structure. Therefore, “health” of a reef may not only be determined by assessment of the live coral communities, but by assessment of reef-building, or carbonate changes.

Ft. Lauderdale Relict Reefs

Coral reefs that exist in Broward County, Florida are considered to be at the latitudinal upper limit of growth of the Florida reef tract, since active reef growth terminates approximately north of Miami (Lighty 1978). These consist of three lines of Holocene and Pleistocene relict reefs. This is due to an event approximately 7,000 years ago, where extensive reef growth was terminated during a period of flooding of the continental shelf (Lighty 1978). This growth was never able to resume in its northern area and the modern reef tract has developed on shallow areas behind the relict reef (Enos 1977). Today the northern Florida reef tract areas have been termed “coral communities” rather than coral reefs due to the fact that these “inactive” structures are not accreting upward as they once were. This can be implied by the absence of *Acropora palmata,* which has historically been proven the main “keep up, catch up” responder species to rapidly rising sea level (Lighty 1978). At present since these communities are believed to be at the threshold for reef growth, it is necessary to protect whatever growth is taking place by hard (framework-building) and soft (baffling) corals, since they are in danger of drowning completely as their ancient ancestors did approximately 7,000 years ago.

Threats to South Florida’s coral communities

South Florida’s coral communities are increasingly stressed by the human-induced causes listed. As commercial and residential development continues to encroach on the coast, infrastructure for road and utility service also increases. Utility services include drainage and sewer facilities that frequently route pollutants directly into nearshore waters, killing and degrading reef habitats.

To meet the increasing need for telecommunications capability along South Florida’s coastline, telephone cables have been laid across the reefs causing physical damage to corals, sponges and other sessile organisms. Until recently, telecommunications cables could be laid across the seafloor without environmental review by either the State of Florida’s Department of Environmental Protection, or Federal agencies such as the Army Corps of Engineers and the National Marine Fisheries Service.

The explosion in information technology has created a demand for newer, fiber optic cables that can meet demands for information transfer. Twelve fiber optic cables have been laid across the continental shelf of southeast Florida from Boca Raton, Palm Beach County, to Sunny Isles, Dade County since 1999. Permits for additional cable are currently being processed. Environmental consultants for the corporations installing the fiber optic cable have documented reef damage, primarily to hard corals (Coastal Planning and Engineering 2001a; Coastal Planning and Engineering, 2001b; Coastal Planning and Engineering, 2002a; Coastal Planning and Engineering, 2002b; Mathers Engineering Corporation, 2001a; Mathers Engineering Corporation, 2001b; Mathers Engineering Corporation, 2001c; Post, Buckley, Shuh, and Jernigan, 1999a; Post, Buckley, Shuh, and Jernigan, 1999b; Post, Buckley, Shuh, and Jernigan, 1999c; Post, Buckley, Shuh, and Jernigan, 2000; Post, Buckley, Shuh, and Jernigan, 2001a; Post, Buckley, Shuh, and Jernigan, 2001b; Post, Buckley, Shuh, and Jernigan, 2001c; Post, Buckley, Shuh, and Jernigan, 2001d). The consulting biologists have implemented coral restoration programs for corals damaged during deployment. A key element of each program is reattachment of dislodged corals to the reef substrate. Monitoring of damaged corals has shown that restored corals continue to grow with no additional statistically significant deterioration after restoration compared to undisturbed nearby corals. Some hard corals are damaged beyond repair or are too large to relocate without causing additional damage. Artificial reefs have been constructed as mitigation for these impacts.

Little attention has been paid to damaged organisms other than hard corals. The purpose of this study is to assess the health of the hard corals which remain near the cables and were not relocated as part of the restoration programs and to characterize and quantify some of the damage which has occurred to other taxonomic groups.

MATERIALS AND METHODS

Site Selection

Along with monitoring reports, underwater videotape of the cables after deployment are available as part of the public record. Video tapes of cables crossing the continental shelf and landing at Boca Raton, Palm Beach County, Florida, and cables landing at Hollywood, Broward County, Florida were viewed to select areas where the organisms selected as study subjects would most likely be found. As more reef acreage was crossed close to shore by the American Telephone and Telegraph (AT&T) cable array making landfall at Hollywood, the study was designed to focus on reef impacts in this area (Figure 1). Among the reef lines crossed by the AT&T cables at Hollywood, the second reef was chosen for study because of the shallow depths. Since the reefs are less than 35 feet deep, bottom time is not limited by nitrogen accumulation in the blood of the diver/biologists. In addition, the consultant's reports provided coordinates for coral restoration sites along three of the AT&T cables at Hollywood facilitating location of cables in the area for study. Latitude and longitude of some of coral restoration sites to 1/1,000 of a minute are listed in Appendix A of Post, Buckley, Shuh, and Jernigan (PBS&J) report (1999). Selected locations were navigated to by GPS.

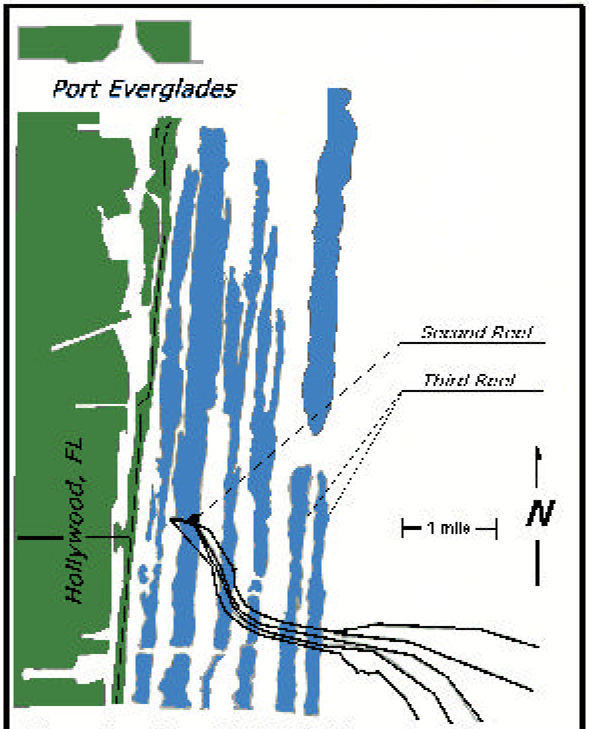

Figure 1. Site of AT&T Cables.

Field Methods

Reef epifauna near cables landing at Hollywood, Broward County, Florida was surveyed for impacts due to the proximity to the cable. Sixteen replicates of two fifty meter belt transects (Dodge *et al.*, 1982) were run using measuring tapes and 1 m^2 PVC quadrats. Each replicate consisted of two consecutive, parallel transects: one centered on the cable and a control transect at least 3 m distant. The 3 m distance for the control was judged sufficient to place the control transect outside of the cable impact area.

Within each quadrat, sponges, gorgonians, and scleractinian corals were examined for obvious physical damage or developmental

impacts. Impacted animals from each taxonomic group were totaled for each transect. The resulting “cable” and “control” data sets for each taxonomic group and for reef study organisms in general were compared using the Mann-Whitney matched pairs test (Zar 1984). Species were identified to compile a list of species represented within each taxonomic group only.

Obvious physical damage was defined as any immediate and apparent damage to the organism including abrasion marks; shading of the organism combined with obvious signs of bleaching or necropsy; breakage clearly attributable to the cable; and toppling. Developmental impacts were defined as growth interference or alteration of the organism’s growth axis. Potential damage such as shading without physical signs of injury was not included in this category. No organisms were counted in this category if injury or its cause were in doubt.

Photographs were taken along the cable transects to provide visual representation of instances of obvious physical or developmental impacts. The diver/biologist conducting the damage census for a transect placed a small marker near organisms exhibiting specific types of impact. Following behind the diver/biologist, the photographer would photograph each area so marked.

On September 28, 2002, one dive was made at the site of the Sunny Isles mitigation site. The site surveyed is located at 25^{o} 54.463’’ North latitude and 80^{o} 05.377’’ West longitude. Diver/biologists photographed 5 Miami-Dade artificial reef modules and a made a qualitative survey of epifaunal community which has colonized modules.

On September 29, 2002, the two diver/biologists surveyed two reef sites on the third reef platform. The first site surveyed is located at 26^{o} 02.418’’ North latitude and 80^{o} 05.210 West longitude. The diver/biologists took photographs and made qualitative comparisons of the epifauna of the third reef community to that of the artificial reef modules inspected on September 28, the previous day. The diver/biologists also made qualitative comparisons between the epifauna of the third and second reef communities.

RESULTS

During the summer of 2002, eight field trips were conducted at the site of an array of 5 AT&T cables. All cables were laid in 1999 across the seafloor, making landfall at Hollywood, Broward County, Florida (Figure 1). From landfall seaward, the cables were routed through conduit installed by directional drilling under the beach and first reef line. The cables emerge from the bottom west of the second reef line and radiate east and southeastward.

The first cable was found on June 13th using latitude and longitude for coral restoration site M1-R2 in Appendix A. The name of the cable could not be confirmed. On June 27, PBS&J survey marker M2 + 250 was found attached to it, suggesting that it could be the MAC1, MAC 2, or MAYA cable. Replicate 1 was conducted east of this point.

On June 27, the position at M1-R2 was again located and replicate transect 2 run to the west. Concurrently, the cable was followed westward by two other divers to the edge of the second reef. The coordinates were recorded for the point of intersection of the cable and the reef edge and labeled point C20. A second cable was found by following the reef edge approximately 50 feet northward. The coordinates for this point of intersection were recorded and the position named C30. Replicate transects 3 and 4 were run eastward from C20 on the southern cable.

On June 28 replicates 5 and 6 were run east from position C30. PBS&J survey marker "M1 + 1000" was located near the end of cable transect 5, approximately 48 m (157 feet) east of the reef edge. Concurrently, another team of divers located a third cable approximately 100 feet north of C30 at the reef's edge. The coordinates for this point, C40, were recorded and replicates 7 and 8 were run to the east.

On July 16, points north of M1-R2 (see Figure 2) on the northern two cables (presumably Americas II and Columbus III) were recorded and labeled C32 and C42. Replicates 9 and 10 were run east and west, respectively, centered on C32. PBS&J survey marker A1 + 25 was located along transect 10. Replicates 11 and 12 were similarly run from point C42. PBS&J survey marker C1 + 250 was located on cable transect 12 on the northern most cable, just east of PEER named point C32. The survey markers found strongly suggest that the northern cable labeled with marker with prefix "C1" is the Columbus III cable and the cable immediately to the south, with marker prefix "A1" is the Americas II cable. However, the presence of a marker with prefix "M1" (used in Appendix A for MAC I stations) on the second cable to the south makes even this conclusion uncertain.

On July19, a fourth cable was located at PBS&J coral restoration site M3-R1, listed in PBS&J (1999), Appendix A as a point on the MAYA cable. Replicates 13 and 14 were run to the east and west, respectively, of this point. Simultaneously, two divers located the intersection of this cable with the western reef edge. A fix was taken on this point of intersection and the point named C10. The Maya cable was also located at a position within 50 feet of coral restoration area M3-R7. One of the other cables in the array was found approximately 150 feet to the north of this M3-R1. The identity of this cable is unknown. According to PBS&J charts, the southernmost cable is MAYA I. Seemingly contrarily, a plot of the coral restoration sites along each cable shows the MAYA cable to actually lie north of the MAC II cable. To further confuse the issue, both cable were labeled with survey markers with the prefix "M3."

In all, a total of 800 m^2 of reef was examined for damaged epifauna; the transect data is shown in Table 1. Data sets for each taxonomic group were tested for statistically significant differences using the Mann-Whitney Matched Pairs Test. The Mann-Whitney statistics for each taxonomic group are shown in Table 2.

Table 1. Number of Gorgonians, Sponges, and Hard Corals Showing Obvious Physical Damage Near Fiber Optic Cables Compared to Parallel Control transects 3 m Away.

	Damaged Sponges		Damaged Gorgonians		Damaged Hard Corals	
Replicate	Cable	Control	Cable	Control	Cable	Control
1	5	0	13	4	1	0
2	2	0	26	4	9	0
3	5	0	39	8	5	0
4	5	0	19	14	5	0
5	0	0	11	10	1	0
6	0	0	15	12	1	0
7	1	0	26	6	4	0
8	1	0	28	4	5	0
9	4	0	14	16	3	0
10	5	0	12	22	3	0
11	10	0	19	22	3	0
12	7	0	12	13	5	0
13	2	0	18	28	2	0
14	4	0	22	16	12	0
15	1	0	6	0	2	0
16	11	2	11	1	5	0
Totals	63	2	291	180	66	0

Table 2. Mann Whitney Statistics of Each Taxonomic Group for Cable and Control Transects.

	Damaged Sponges		Damaged Gorgonians		Damaged Hard Corals	
	Cable	Control	Cable	Control	Cable	Control
n	16	16	16	16	16	16
R	371	157	320	208	192	136

	Sponges	Gorgonians	Hard Corals
U’	235	184	256
p	<.0005	<.025	<.0005

Within each category of damaged organism - sponges, gorgonians, and hard corals – as many species were identified as possible within the study’s time constraints. Species from each taxonomic group are listed in Table 3.

Table 3. Species of Sponges, Gorgonians, and Hard Corals Identified as Damaged or Developmentally Impacted.

Sponges	Gorgonians	Hard Corals
Iotrochota birotulata	*Eunicea* sp.	*Millepora alcicornis*
Callyspongia vaginalis	*Briareum abestinum*	*Acropora cervicornis*
Callyspongia vaginalis	*Pseudoplexaura* sp.	*Porites astreoides*
Monanchora unguifera	*Murecea* sp.	*Madracis decactis*
Speciospongia versparium	*Plexaurella* sp.	*Stephanocoenia intercepta*
Holopsamma helwigi	*Pseudopterogorgia* sp.	*Montatstrea annularis*
Ectyoplasia ferox	*Pterogorgia* sp.	*M. cavernosa*
Xestospongia muta	*Gorgonia ventalina*	*M. faveolata*
Iricinia felix	*Erythropodium caribaeorum*	*Solenastrea bournoni*
Aplysina fistularis		*Dichocoenia stokesii*
A. cauliformis		*Favia fragum*
A. fulva		*Siderastrea siderea*
Niphates digitalis		*S. radians*
N. erecta		*Diploria strigosa*
Chondrila nucula		*D. clivosa*
Pseudoceratina crassa		*D. labyrinthiformis*
Verongula rigida		*Meandrina meandrites*
Amphimedon compressa		*Manicina areolata*
Cliona delitrix		*Colpophyllia natans*
		Eusmilia fastigiata
		Agaricia agaricites

Photographs of various types of impacts on the above organisms will be included in Appendix A of the final report. Photographs taken on September 28, 2002, of the Miami-Dade-designed artificial reef modules will be shown in Appendix B. Photographs of the reef community present on the third reef platform will be shown in Appendix C.

DISCUSSION

Hollywood cables, on-site impacts and restoration

Significant differences were found in the number of damaged individuals of each taxonomic group along the cable when compared to control data. Gorgonians are shown to sustain more damage in the control transects than either sponges or hard corals. Although damage to the reefs may come from ***both*** non-human and human actors, the increase in documented damage in the study zone near the cable indicates that human damage ***is compounding the normal level of damage associated with the natural functioning of the reef ecosystems.*** Although gorgonians appear to be the frailest taxonomic group included in the study, this finding is unexpected. Sponges are reported to be preyed upon by sea turtles (Meylan, 1988) and fishes such as the triggerfish (Neudecker, 1977) and butterflyfish (Cox, 1986) prey on hard corals. Little is known about gorgonian predators.

The presence of physically damaged gorgonians and sponges more than three years after cable deployment is surprising, as well. Assumptions within the regulatory community thus far have posited that reef damage due to State and federally-approve actions is primarily the result of installation; ***clearly, the PEER dives indicate that the presence of a telecommunications cable across a reef may be a permanent and continuing source of environmental degradation.*** Swing damage may occur when large storm waves cause a surge on the bottom, moving the cable up and down or from side to side. Cables may come in contact with and damage reef organisms during storms as a result of this movement. Another possible source of continuing impact is anchor fouling. Anchors are known to snag cable laid across the reef surface (Don Deis, personal communication, 2002) and move a portion of the cable a short distance. Movement of a cable segment a few inches could result in coral/cable contact and reef damage. Cable suspended off the bottom was frequently observed. Anchors are even more likely to hook an elevated cable and, as a result, shift its position.

The results show that cable impacts to all three groups are statistically significant. Statistically significant impacts can occur in a small, insignificant areas. A larger question is whether or not the AT&T cable impacts are extensive or severe enough to significantly degrade the second reef community at Hollywood, Florida. The significance of an environmental impact is linked to a defined impact area. For this study the sample area, or defined impact area, was 0.5 m on either side of 400 linear feet of the fiber optic cables. Within this predetermined impact area, damage to reef organisms was found to be statistically significant. Had 4 m^2 quadrants been used and the impact area considered increased to1 m^2 on either side of the cable, the considered impact area would include a greater proportion of undisturbed habitat and the results seemingly less significant. As the impact area included in the study increases in size away from the cables, the measured impacts tend toward insignificance. There exists an impact area (study area) which, once determined, would define the maximum area within which the observed fiber optic cable impacts remain significant.

Gorgonians. Using gorgonian as an example, the mean number of damaged individuals per m^2 is 18.2 ± 4.1, the mean number of damaged gorgonians found in the control quadrats is 11.2 ± 4.1. The ratio of total damaged gorgonians in the pooled samples of cumulative cable impact area compared to the pooled number of damaged individuals within the control area is 291 ÷ 180 or 1.63. In other words, about 63 percent more damaged gorgonians are present in the cable study area. Cable and control sample areas totaled 400 m^2 each. If the study area is doubled in width, the cable impacts found will be diluted by the addition of undisturbed habitat into the study area and the number of incidents of gorgonian damage within the control tansects relative to the cable transects would be would be (291 + 180) ÷ (180 + 180) or 1.31. Rephrased, cable impact areas have 31 percent more damaged gorgonians. If we consider an increase over non-cable impacts of 10 percent or greater to be the threshold of significance, doubling the impact area to 800 m^2 would still yield a finding of significant impact. If the study area considered area is tripled, the ratio would be 1.21; if quadrupled, 1.15; if quintupled, 1.12; and if sextupled, 1.10. By considering impacts spread over areas increased by one increment at a time, in this case by 400 m^2, the significance of the damage tends to be reduced. In conclusion, considering a 10 percent reduction in healthy gorgonians to be smallest significant impact, the area considered must be multiplied by 6 to approach insignificance. Thus, due to the severity of the observed impacts, they must be considered equal to a lesser but significant impact spread over a minimum of 2400 (400×6) m^2.

The second reef is approximately .75 miles wide and is crossed by 5 cables. A total of 3.75 linear miles of cable was laid across the second reef. Using the reasoning above, damages occurred which are sufficient to significantly impact a 6 meter-wide by 3.75 mile-long area. In imperial terms, the impacts could be spread out over a swath 19.7 feet wide by 19,800 feet long, or 8.95 acres, and still be significant.

<u>Sponges.</u> Although fewer sponges than gorgonians were counted as damaged, the ratio of impacted sponges in the cable transects to those counted in the control transect is greater than that for gorgonians. In the control transects, an average of 0.125 ± .24 sponges was found to be impacted by causes unrelated to the nearby cable. On average 3.9 ± 1.6 sponges per transect were determined to be impacted. Pooling the data from control and cable transects, the rate of damage in the cable transects is $63 \div 2$, or 31.50 times the observed rate in the control transects. To reach the 10 percent threshold of significance, the considered area is expanded to encompass ever more non-cable damage until $[63 + 2(n)] \div 2n \leq 1.10$, where *n* is a multiple of the area considered in this study. In this case, *n* must equal 315. Again, distributing the damage over a larger area by expanding the considered 1 m (3.28 feet) wide study area by a multiple of 315 over 3.75 linear miles of cable yields damage sufficient to significantly impact 469 acres of second reef sponge community. This multiple is much larger than that obtained for the gorgonians and is due partially to lesser relative abundance of sponges and the rarity of observed non-cable damage.

<u>Hard corals.</u> Hard corals provide the most extreme example. Since no physically damaged individuals were found outside the cable transects, theoretically the study area can be increased without bound without dilution of cable impacts by non-cable impacts. In other words, the number of hard corals found damaged within the cable study area relative to those found within the control area is infinity ($66 \div 0$). This line of reasoning is presented to illustrate that this and other algorithms used to compute mitigation ratios can break down when the numbers put onto the formula are too large, too small, or irrelevant. From this perspective, because damage to gorgonians is commonplace, the value subtracted from the reef community by additional adverse effects, such as those caused by laying fiber optic cable, is diminished when compared to less abundant taxonomic groups. On the other hand, human induced damage to sponges and hard corals is amplified because of their observed rarity. This is due at least in part to the lower abundance of sponges and hard corals relative to gorgonians.

An ambitious hard coral restoration plan was implemented following cable deployment. Post, Buckley, Shuh, and Jerningan (1999) report that a total of 160 corals were restored (reattached to the bottom) after installation of the five AT&T cables at Hollywood. Dislodged corals were located by divers and cemented to the bottom near their original location. The cable was moved off of hard corals in contact with the cable, but not dislodged**.** The health of reattached corals was monitored and they were determined to be recovering from the disturbance based on insignificant differences in changes in maximum height and width, the percent of old and dead tissue, presence of disease, between the restored corals and reference, undisturbed corals. An artificial reef consisting of 30 reef modules was constructed as mitigation for irreparable coral damage. The modules, of a design conceived by Dade County, were place at the site of the mitigation for reef damage caused by the grounding of the US submarine Memphis.

Off-site mitigation for irreparable impacts to hard corals

Habitat Equivalency Analysis (HEA) is used to determine on-site restoration and off-site mitigation required to offset habitat impacts due to engineering projects. HEA was developed by the National Oceanographic and Atmospheric Administration (NOAA) and was employed to calculate artificial reef area needed to mitigate project impacts. The prerequisites for HEA are outlined in NOAA Technical Paper 95-1 (1997). One condition necessary for HEA applicability is that a common indicator (or metric) can be defined that captures the level of services (*e.g.* contribution of shelter from predatory fishes) provided by the habitat. Metric declines must be closely correlated with reductions in the quantity and quality of those services caused by an injury to that habitat. The indicator must also capture differences in the services provided by replacement habitats. Once a metric is defined, the sum of the indicated percentage of services lost per year until full recovery is calculated. For example, suppose 100 % of the services contributed by one acre of estuarine bottom vegetation are lost due to a project impact. Further suppose that recovery is linear and 100 percent recovery will in five years, the replacement habitat, including the recovered habitat, should equal 1 + (1-20%) + (1 – 40%) + (1 – 60%) + (1- 80%) or 3 acres. Thus, ignoring temporal lag in restoration, an additional 2 acres of the habitat is needed for full compensation.

HEA also imposes a 3 percent per year addition to mitigation requirements if there is a delay in constructing the mitigation or if there is a lag between construction and development of the constructed habitat to full function as determined by the common metric. In the simple example above, the 3 acres required for full compensation would take 5 years to mature to the point of providing 100% of habitat services. The 3 percent charge would be added to each year's unpaid balance in services provided until the mitigation project is fully functioning.

Fonseca *et.al* (2000) provide an example in which HEA was used to calculate mitigation requirements for injured sea grass (turtle grass) beds. HEA applies well to seagrass mitigation because such cases meet the three criteria defined by NOAA and have been upheld by the US District Court (United States of America vs. Melvin A. Fisher *et al*. 1997) for HEA use. The criterion are: (1) lost on-site services are biological functions and not services which provide values for human use; (2) it is feasible to conduct restoration projects which provide the same type and quantity of services lost;

(3) sufficient data exists or is obtainable for input into the HEA model. Seagrass shoot density is the metric used for input into an HEA for turtle grass beds. This parameter captures the level of services provided by turtle grass because the grass is predominant in the habitat and nearly all other organisms depend on it for food or shelter. Moreover, the provision of these services is directly linked to shoot density, an easily obtainable metric.

The third criterion listed above, obtaining data for input into the HEA, presents difficulty in applying HEA to the second reef community off Hollywood. Field data collection for this study was limited in focus to three taxonomic groups, which represent the most abundant species occupying the substrate. No data was collected on many other groups (echinoderms, holothuroidians, bryozoans, *etc.*) observed on the reef. The subject reef community is more diverse than the data presented implies. Gorgonians are most abundant, yet no single species or taxonomic group dominates the substrate providing services (food and shelter) to the preponderance, or even a majority, of reef inhabitants. Definition of a common metric is illusive in the complex web of interrelationships among species associated with three predominant groups on the reef. In the first step of applying HEA to the second reef community of Hollywood, determining the level of services lost due to cable impacts, a metric must be defined which captures the ecological services lost due to impacts to a diverse assemblage of codominant taxonomic groups comprising many species. The metric data must already be available or easily obtainable and must capture the type and the quantity of services added by the off-site replacement habitat.

All three taxonomic groups provide biological services to the reef community. Sponges provide shelter for small crustaceans, polychaetes, and fishes (Jaap 2000). The larger the sponge, the larger the fish which may take refuge behind or inside it. Mature reef butteflyfish (*Chaetodipterus sedentarius*) and honeycomb cowfish (*Acanthostracion polygonius*) have been seen (personal observation) inside barrel sponges (*Xestospongia muta*). Barrel sponges may take as long as one hundred years to reach full size (Humann, unpublished data). Jaap (2000) stated that coral reef restoration cannot be successful without salvage of corals *and* sponges. Sponges provide food for the hawksbill sea turtle (Meylan, 1988), fishes (Pawlic, personal communication, July 7, 2002) and, perhaps, others. Some fishes seek shelter in the form of concealment among gorgonians from predatory fish. As in sponges, size is important as larger specimens are able to conceal larger fishes. Polychaetes and gastropods graze on octocoral branches (Kim and Lasker 1997). Some fishes feed either on the soft gorgonian polyps or epiphytic algae which grows on soft coral branches (personal observation). The data gathered suggests that the gorgonians are the most numerous organisms on the second reef. This group necessarily provides substantial biological services, many of which are, as yet, undetermined. Hard corals, hundreds of years old (see Dodge, 1987) are known to provide shelter for fishes and invertebrates including the Florida lobster. They are also a food source for fishes able to bite through their hard coral skeleton.

To determine appropriate mitigation type and quantity, a metric which captures all of the service provided by the dominant groups on the Hollywood reefs must, at a minimum, take into account the population densities, relative abundance, and size distribution for each of these three groups. Then the percentage of these services lost in a predefined study area can be calculated. Data for these parameters would have to be fed into a mathematical model which gives appropriate weight to each. To our knowledge, no such model yet exists. Further, the poor state of our knowledge of coral reef ecology precludes the development of such a model in the near future.

Percent coverage of the bottom by hard corals was used as the metric to calculate the acreage of artificial reef needed at the replacement site to mitigate for the Hollywood AT&T cable impacts. Impacts were classified into five categories: (1) cable over coral; (2) cable touching coral; (3) cable abrading coral; (4) coral abraded but not in contact with cable; (5) coral dislodged. Questions arise: do fish, gorgonian, sponge and other invertebrate populations within a subtropical reef community increase with increasing percentage hard coral coverage? Since hard coral coverage of the reef near the AT&T cables landing at Hollywood is 7.8 percent, what proportion of biological services available on the reef do the hard corals provide? Does this metric capture *all* of these services?

Other questions regarding the ability of the mitigation to offset project impacts also arise:

(1) Will the sponges, gorgonians, and hard corals grow in the same relative abundance on the artificial reef as on the impacted natural reef?

Steve Blair (personal communication, August 27, 2002) of Dade County Department of Environmental Resources Management and G.M. Selby and Associates (1995), have monitored Dade County designed artificial reef modules installed as mitigation for beach project-related reef damage in 1991. As of 1993, corals had settled on the modules but larger gorgonians (*Eunicea palmeri* and *Pseudopterogorgia* sp.) and sponges such as the barrel sponge had not established colonies. Blair attributes this to a lack of sufficient level substrate. In support of this impression, barrel sponges and gorgonians appeared to be less abundant on the angular slopes of the second reef's west edge, the terminus of three transects censused for this study (personal observation) but quantitative study is needed to confirm this. Goldberg (1973) reported that barrel sponges and soft corals were present on a reef platform off shore of Boca Raton, but these species were not listed among the fauna inhabiting the vertical faces of the reef ledge. In another study (Yoshioka and Yoshioka, 1989) it was shown that irregularities as small as a few centimeters can strongly influence gorgonian community structure. Vertical substrate held few gorgonian species, while flat substrata favored lush growth. Soft corals were more abundant in relatively lower relief habitat.

During a scuba dive on September 28, 2002, the reef community which has colonized 7 of the Miami-Dade artificial reef modules was examined. Each module has a surface area of approximately 7.4 m^2. The total area examined was approximately 50

m^2. One gorgonian and no barrel sponges were found on this surface area. Within the 1600 m^2 area on the second reef sampled for this study, 471 *impacted* gorgonians were counted; unimpacted gorgonians were not counted. Thus, gorgonian density within the second reef study area exceeds 0.3 (471 ÷ 1600) gorgonians per m^2. If the community structure on the artificial reef modules is to simulate that of the impacted second reef community, an average of 15+ (0.3 × 50) gorgonians should be present per 50 m^2 of Miami-Dade artificial reef surface area. Further, if the two communities are similar, it is unlikely that the 50 m^2 area randomly selected in this survey would be occupied by only one gorgonian. This is evidence that the present artificial reef community is very dissimilar from the impacted second reef community.

The evidence also indicates that the abundance of giant barrel sponges differs between the mitigation and the third reef impact area. On September 29, 2 scuba dives were conducted on the third reef east of the Hollywood. The giant barrel sponge was found to be more abundant, we estimate, than on the second reef platform. Six cables encountered were laid haphazardly across the reef and impacted a barrel sponges were photographed (see Appendix C). To determine the likelihood that barrel sponges are colonizing the Miami-Dade modules with a population density similar to that of the impacted third reef, as for gorgonians we first estimate the population density of barrel sponges on the third reef. Although barrel sponge population density was not measured during this study, it is possible to estimated their density on the third reef from data provided by Mathers Engineering (2001a). Mathers Engineering listed 14 barrel sponges impacted by the BICS cable which lies across 700 (213 m) feet of third reef (65 foot depth) community offshore of Boca Raton, Palm Beach County, Florida. Assuming that a one meter swath centered on the cable would not include additional barrel sponges, consider the 213 linear feet of cable to represent an area equivalent to a 213 m^2 sample area. Barrel sponge density within this sample area would equal 0.06 (14 ÷ 213) sponges per m^2 or 3.3 barrel sponges per 50 m^2. As with the gorgonians, if the two communities are similar, it is improbable that sponges would be absent from the 50 m^2 area randomly selected during this survey. Although further study is warranted, this is also evidence that the present artificial reef community is dissimilar from the impacted second reef community.

(2) Will the sponges, gorgonians, and hard corals that colonize the artificial reef modules be of sufficient size to provide the same shelter and other services as those on the natural reef?

Published literature indicates that gorgonian growth rate is rapid enough to reach full size within the 35 year project life defined by PBS&J (Kim and Lasker, 1997; Opresko, 1974; Mitchel, 1993). In this same time frame, the slower growth rates for some species of corals and sponges would preclude their reaching the size of larger individuals damaged by the cable (Dodge, 1987; Humann, 1992; Humann, unpublished data).

The structure of the climax community which will, in time, occupy the surface of limestone boulders placed on the seafloor as mitigation for natural reef damages is currently unknown. John Dodrell (personal communication) who heads Florida DEP's artificial reef program stated that the earliest known deployment of boulder modules as mitigation was in 1991 for the Sunny Isles beach project mitigation. This is insufficient time to allow us to speculate on the structure of the climax community which will occupy the substrate of such modules within the 35 year lifetime of the AT&T cable project as defined by PBS&J. The information necessary for resource management decisions dealing with the trade-offs between natural coral community impacts and artificial reef community mitigation is not yet available. Current evidence provided in this report suggests that, in its present state of development, the community on the artificial reef modules is dissimilar from the impacted resource.

Boca Raton cables, Palm Beach County, Florida

The Atlantica 1 system, cables 1 and 2, were installed at Boca Raton on November 15, 2000 and November 18, respectively. They crossed 1,600 and 1,150 feet of coral community respectively. HEA was not used to determine the mitigation ratio. .A limestone boulder reef of approximately 2,400 square feet was constructed for mitigation Impacts to hard corals only were quantified in post-deployment surveys. The five same types of impacts to hard corals were identified. Fifty-two hard corals were impacted: twenty-seven were impacted by cable 1 and twenty-five were impacted bu cable2. After 6 months, Coastal Planning and Engineering (2001b) reported that cable 1 had shifted 8-10 inches, causing additional impacts to nine hard corals. The cable movement was attributed to a boat anchor fouling. Cable 1 shifted again 2-4 inches between the 6 months and one year monitoring. Seven new hard coral impacts were reported (Coastal Planning and Engineering (2001c). Again the movement was attributed to fouling by a boat anchor. The top of one giant barrel sponge was reported to have been sheered off by this incident.

On January 31, 2001, a single cable for the Bahamas Internet Fiber Optic Cable System (BICS) was laid across 500 feet of reef offshore of Boca Raton. Damaged sponges, gorgonians, and hard corals are listed and the types of impact noted according to the standard 5 classes previously mentioned. One hundred seventy-six gorgonians, fifty-seven sponges and twenty hard corals were reported as impacted. An 1162 square foot limestone boulder artificial reef was constructed for mitigation. The final, 6 months monitoring report (Mathers Engineering Corp., 2001b) repeats the damages found during the post-installation survey.

Sunny Isles cables, Miami-Dade County, Florida

Two cables were laid (date as yet unknown) for ARCOS-1 at Sunny Isles, Miami-Dade County and surveyed for biological damage on April 9, 2001. The northern cable crossed 5050 feet of coral community reef; the southern cable crossed 5,633 feet of reef. Five types of damage to hard corals were recorded; damage to other taxonomic groups were not. ***Hundreds of hard corals were damaged***. The same HEA techniques used to quantify damage and mitigation for the AT&T array at Hollywood were used to calculate artificial reef acreage requirements. For mitigation, a limestone boulder reef of 1,620 square feet was constructed.

CONCLUSIONS

The adverse affects of laying fiber optic cables across coral communities are severe, albeit restricted to the narrow area along each cable. Reports of cable movement (Coastal Planning and Engineering 2001b; 2002a) caused by recreational boat anchor fouling indicate that reef damage continues after the cable is laid. These impacts will continue for as long as the cables remain on the sea floor. The loss incurred by these impacts is amplified by the longevity of hard corals and barrel sponges. The larger of these, which are damaged beyond recovery, cannot be replaced in this generation. Thus, HEA projections based on a thirty-five year project life and impact recovery period is short of the actual duration of impacts.

Routing cables through breaks in the reef such as gaps and trenches for sewer outfalls could minimize reef damages, but the a critical question must be answered: (1) how is environmental damage reduced and mitigated during and immediately after installation, and (2) how does one engineer the anchoring the cable so as to reduce long term, continued degradation of the reef.

Measures could be taken during deployment across reef lines to reduce the amount of damage to reef epifauna: (1) routing the cable around ancient, irreplaceable corals and long-lived barrel sponges; (2) anchoring the cable to prevent movement by surge and currents; (3) fastening the cable to the bottom to avoid anchor fouling and cable movement.

The use of HEA to determine the percentage of biological services lost due to on-site damage is not feasible because of our current lack of understanding of the interrelationships between dominant sessile reef taxa and other members of the reef community. Specifically, identification of a common metric that captures all the biological services provided by the second reef is complicated by community diversity and the lack of a single dominant species. Further, the community present on the third reef, across which cable was also laid differs from the second reef community.

Deep reefs beyond the reach of scuba divers are present far offshore of some areas of Florida. One example is the *Oculina varicosa* reef which lie in 120 to 300 feet offshore of east-central Florida (Reed, 1980). The HEA metric used to develop the mitigation for impacts to the second and third reef communities would not likely apply to deep unknown reefs which may have been damaged by the AT&T cables. Reduced ambient light and cooler temperatures would certainly result in these reefs having a very different epifaunal community from those for which the mitigation was designed. These reefs are fragile and would be damaged if cable is laid over them. Most of the sea floor has not been mapped for civilian use. Reef resources which may lie of the seafloor in depths beyond 100 feet is virtually unknown (Perkins *et.* al, 1997). Cable corridors out to the federal 10-mile limit should be mapped prior to laying cable.

The use of limestone boulders as artificial reef substrate for mitigation may not lead to development of a community as diverse as the one adversely impacted by the AT&T cable. Gorgonians and large barrel sponges are unlikely to colonize the sloping and vertical surfaces of the structure that exist in greater proportion on the artificial reefs compared to the natural reefs.

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