Ecosystem Services of Waste-Material and

Designed Artificial Reefs

By

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CERTIFICATE OF APPROVAL

Honors Thesis

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Artificial reefs in the United States, including the West Florida Shelf (WFS) are often composed of waste-materials used to improve ecosystem services of reef habitats. Recent efforts have been made to extend the use of artificial reefs by designing reefs to mimic natural bottom of the WFS to be used as mitigation sites. The objective of this project is to compare designed and waste-material artificial reefs by assessing benthic cover. The study revealed waste-material and designed artificial reefs had similar benthic assemblages and provide similar ecosystem services. The primary difference, more abundance of sponges on the waste-material and more algae on the designed artificial reefs. These trends are more likely a consequence of the location and depth of the reefs than their design or materials.

Introduction:

The first recorded artificial reefs in the United States were created in the 1860s using fallen trees to increase fishing in South Carolina (Stone, 1974). Artificial reef programs have been implemented by many agencies at the city, county, state and national levels in the past 50 years due to an increase in recreational fishing. Original artificial reefs were created by sinking old automobiles or retired naval ships. The structures oxidized and corroded, causing problems for the marine ecosystems (Hickman, 2001). Other failed reef programs included the sinking of millions of old tires, leading to the rubber leaching petroleum into the waters and preventing any reef growth (Skoloff, 2007). Before the environmental movement of the 1970s, artificial reefs were used for projects related to conservation rather than preservation; the reefs were created with the interest of human needs – such as fishing, boating, or waste disposal (Hickman, 2001). Trial and error has long been the approach to building artificial reefs. With many failures come few successes, but over time, society is learning and implementing successful strategies and technologies.

Artificial reef programs are active in other regions including the Mediterranean Sea and western Pacific. In countries like Italy and Japan, the purpose of their artificial reefs is to enhance fisheries. Specifically in Italy, artificial reefs are seen more as fishery management devices that are used to protect nursery areas or vulnerable habitat from illegal bottom trawling, and improve small-scale fisheries (Manoukian, 2011). Japanese artificial reefs, "*tsukiiso*" meaning construction of reef, began as fish shelters in the 18^{th} century to support the large fishing industry. Since that time, Japan has allocated significant government funds into creating structures specifically designed for reefs (Ino, 1974).

The difference between artificial reefs in the United States and reefs in other countries like Italy and Japan is the material and design used to create a benthic habitat. Reefs in the United States are often seen as sites to dispose of unused or outdated culvert pipes, concrete, metal, ships, infrastructure, or automobiles. Abroad, artificial reefs are specifically designed for single or multiple purposes including fishing, substrate introduction for coral growth, habitat rehabilitation (Clark & Edwards, 1994), or as stress relief on natural reefs (Polovina, 1991).

In 2001, designed artificial reefs were constructed by Gulfstream Natural Gas Systems, L.L.C. (GNGS) on the West Florida Shelf (WFS). These designed reef “modules” were part of a hard bottom mitigation project for a natural gas pipeline deployed from Mississippi traveling into Tampa Bay. Not only were these modules originally designed to be reefs, but also were designed with features to mimic a natural hard bottom commonly found on the WFS. The designed modules (US Patent #5215406) have rectangular dimensions of 1.8 m wide x 2.7m long x 1.8m tall (Figure 1). The modules are located in three sites in 16-17m water depth, located approximately 25km west of Tampa Bay, where 153 modules were deployed in areas of 150m x 150m. These module sites will serve as the designed reef aspect of this project. Dupont (2009) compared bottom cover of the modules with natural ledge (Table 1). Primary differences in results were bare substrate dominated module sites, while macroalgae dominated natural live bottom. Fishery studies showed that natural and artificial reefs in the Gulf of Mexico had similar assemblages, while more commercial fish were found on artificial reefs.

Figure 1. Designed Artificial Reef Modules on WFS (Gulfstream Natural Gas)

Table 1. Results from Benthic Cover of designed artificial reefs and natural live bottom in Gulf of Mexico (Dupont, 2009).

	Modules-2005	**Natural Live Bottom-2007**
Bottom Type	**% Cover**	**% Cover**
Bare Substrate	73	69
Macroalgae	10	20
Coral	3	4
Porifera	5	7
Other Live Bottom (OLB)	2	2

Pinellas County Division of Solid Waste developed their artificial reef program in 1975. Rather than disposing of large objects like bridge pilings, concrete conduit, and Army tanks on land, they are placed in waters west of Pinellas County. Prior to deployment, the surfaces were cleaned and vehicles like boats or tanks had any hazardous materials removed, leaving only a steel shell. The purpose of the artificial reef program was two-fold: (1) responsibly dispose of large, impractical, waste objects while creating reef structures west of Pinellas County and (2) attract commerce to Pinellas County in the form of anglers, divers and boaters who would use the sites. The economic impact of the Pinellas County Reef Program was studied in 2009 in collaboration with Pinellas County Sea Grant Extension, Florida Fish & Wildlife Commission (FWC), the University of Florida-Institute of Food and Agricultural Sciences (IFAS), and the National Oceanic and Atmospheric Administration (NOAA). The study reported that boaters and divers spend more than $79M within Pinellas County visiting the artificial reefs; $36.4M of those monies come from non-Florida residents (Florida Sea Grant, 2011).

<u>Ecosystem services:</u>

Ecosystem services are resources that an environment provides and from which humans can benefit from in many ways. Ecosystem services can include resources like clean water, shoreline protection, or habitat for fisheries or corals. Defined by the Millennium Ecosystem Assessment of 2005, ecosystem services are divided into regulating, provisioning, cultural and supporting categories (Table 2). Regulating services include control of adjacent areas including shoreline protection or water quality control. Provisioning includes services including fisheries, medicinal and pharmaceutical use, building, and jewelry. Cultural includes the aspects of eco-tourism, recreation, and aesthetic appreciation. Finally, the supporting category includes nursery habitats, and nutrient cycling (UNEP-WCMC, 2006). All of these categories are benefits to humans, and both natural and artificial reefs provide each of these ecosystem services to some degree. As human populations increase and coastal environments change, the importance of each service category will also change.

Table 2. Ecosystem Services of Coral Reefs (UNEP-WCMC)

Ecosystem services	Coral reefs
REGULATING	Protection of beaches and coastlines from storm surges and waves Reduction of beach erosion Formation of beaches and islands
PROVISIONING	Subsistence and commercial fisheries Fish and invertebrates for the ornamental aquarium trade Pharmaceutical products Building materials Jewellery and other decoration
CULTURAL	Tourism and recreation Spiritual and aesthetic appreciation
SUPPORTING	Cycling of nutrients Nursery habitats

By definition, a ‘reef’ is a submarine ridge of rocks, coral or sand. Coral reefs are created from the calcium carbonate accretion from coral polyps while artificial reefs are man-made structures placed in the ocean. Artificial reefs are an efficient way of introducing new substrate and structure that would normally take hundreds of years to grow naturally. Although coral growth rates and coral cover have declined over the last 25 to 50 years, artificial reefs and man-made structures may provide an adequate sollution for structure requirements of fish and invertebrates.

Even though coral reefs cover less than 1% of the ocean floor, they provide habitat to one-quarter of all marine species (NOAA, 2008). Recent studies show declines of coral cover from averages of 28% to 14% over the past 27 years on the Great Barrier Reef; most of which is attributed to anthropogenic climate change (De’atha et al., 2012). Artificial reefs provide substrate for benthic organisms, including corals to attach and grow Thus, artifical reefs do not necessarily an increase coral cover; if conditions for coral growth are not ideal, the substrate will become colonized by other organisms.

Previous Research:

Previous reports have shown that the design of artificial reefs has a profound effect on the type of uses for that reef. Reefs with large surface areas tend to promote growth of benthic organisms, while reefs with crevasses and gaps promote fisheries by providing shelter (Pinkering & Whitemarsh, 1997). My working hypothesis was that the designed modules would provide more ecosystem services than the waste-material reefs. Fisheries are the most noticeable type of ecosystem service provided by reefs. Dupont (2009) observed more commercially desired fish on artificial reef modules than natural ledges. First, I must determine how benthic habitat data relates to ecosystem services, and what the connection is between benthic cover and human use.

The objective of this project is to see how ecosystem services differ on reefs of the WFS depending if the habitat is designed as a reef, or repurposed from waste-material. By observing benthic cover and diversity on both sites, a comparison can be made to understand how structure design affects the benthic community.

Methods:

Seven categories of bottom cover were surveyed on both sites: live coral, macroalgae, sponges, bare substrate or pavement, calcareous algae, anemones, and other. The category of 'other' included mostly *Diadema* among other urchins or marine debris (fishing gear).

Study Area:

Two artificial reef sites were selected to compare the benthic cover of waste-material and designed artificial reefs: the Gulfstream modules, and Treasure Island waste-material artificial reef. The waste-material site included Treasure Island Reef, the designed reef site; both sites are within 30km of the Pinellas County shoreline on the West Florida Shelf.

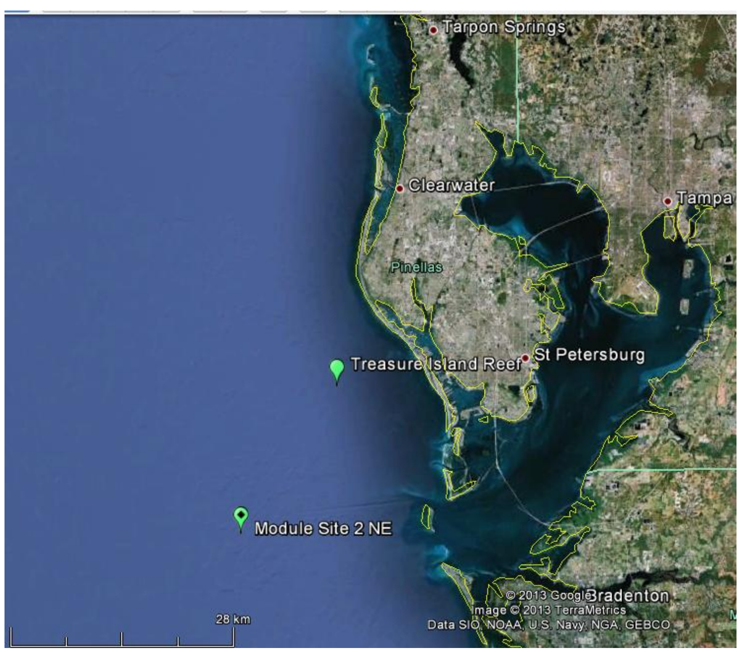


Figure 2. Map of Eastern Gulf of Mexico. The Waste-material Reef (Treasure Island Reef) is located 11km west of Pinellas County in 10m of water; the Designed Reef (Modules 2) is located 25km west of Tampa Bay in 18m of water.

One of these Pinellas County artificial reefs accessible to diving is Treasure Island Reef, located approximately 11km Southwest of Treasure Island in 10m of seawater. Treasure Island Reef was deployed in 2004 and consists of concrete culvert piping (Figure 3) and other unused sewer and drainage project equipment (Pinellas County Utilities, 2011). Treasure Island reef will serve as the waste-material aspect of this project.

Figure 3. Example of Waste-material Artificial Reef on West Florida Shelf

Survey Methods:

Artificial reef sites were surveyed in October 2012 (waste-material reefs only), November 2012 (designed reefs only), and April 2013 (both waste-material and designed reefs) using SCUBA as the primary tool for data collection. Having two collection seasons will also show how seasonal variations affect benthic habitats between fall and spring on the WFS. Each reef site was surveyed using Atlantic and Gulf Rapid Reef Assessment (AGRRA) point count methods. AGRRA is an efficient benthic survey method used widely throughout the Caribbean and Gulf of Mexico. Point counts focus on bottom cover, using codes to designate sponges, macroalgae, turf algae, bare substrate or live coral. Traditionally, the point count consists of a 10m transect divided into 10cm segments; identification of bottom type below each line-point intercept on the transect are recorded. Each AGRRA transect will contain 100 data points with bottom cover data of each point; a complete list of AGRRA protocols can be found on the AGRRA website (Lang et al., 2010). Seven types of bottom were recorded on each transect: live coral, macroalgae, pavement or bare substrate, sponge, calcareous algae, anemone and other.

A modified version of the AGRRA point count was used to study both artificial reef types. Rather than surveying a 10m transect covering modules, but also the sand between them, a transect was placed on the designed reef, diagonal to the rectangular shape. Because the modules' dimensions are 1.8m x 2.7m and sparsely scattered on the bottom, a 10m transect survey would survey a majority of sand and non-reef structure. These diagonal transects averaged 4.15m in length and surveyed the sides and tops of the modules. The survey included both vertical and horizontal substrates; statistical analysis was indifferent of the orientation of bottom cover. An additional transect was taken on the same module, however in the opposite diagonal direction as the first transect. The method used to survey the benthic habitat on Treasure Island reef more closely followed the true AGRRA methods of a 10m, 100-point survey. When analyzing the data of Treasure Island reef, insignificant points like sand and non-structure bottom were deleted for improved comparison between the module site method and waste-material sites.

Transects of both reefs were recorded using a SONY Handycam 12.0 megapixel HD video camera and Light & Motion Bluefin CX520 housing. The housing was attached to a PVC pipe at a distance of 40cm tip to lens. The video transects were reviewed using standard media viewing software and point-line intercepts were placed into an Excel spreadsheet.

Statistical Analysis:

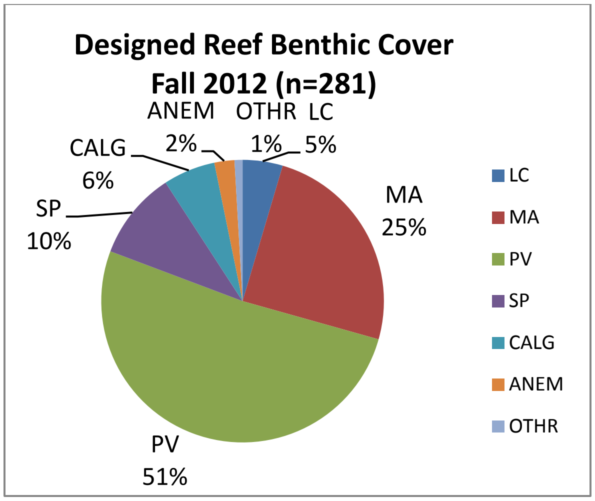
Pretreatment of the video data included removal of insignificant points like sand or non-structure bottom; these points were more common on Treasure Island reef because of the haphazard deployment of the reef. To compare data sets t-tests were performed on bottom types between waste-material and designed artificial reefs. The null-hypothesis on each benthic type t-test was that there is no significant (α=0.05) difference between benthic cover between the reefs. A t-test was also performed to identify significant difference in benthic cover between fall and spring on the designed modules.

Multivariate analyses will be conducted using the Primer-E^{TM} (Clarke & Warwick, 1994) package of non-parametric software applications. Point count results will initially be square root transformed to normalize the data. Bray Curtis dissimilarity will be performed to show how individual transects compare on a scale from 0 (not similar) to 1.0 (exactly the same). Multidimensional scaling (MDS) analysis will graphically show how individual transects compare both between and within dive sites.

Results:

The fall 2012 data sets included AGRRA point counts on 7 designed modules and 3 point counts on Treasure Island Reef (using data from SCUBAnauts Intl.-St. Petersburg). The lack of replicate data on Treasure Island reef makes direct comparison between designed and waste-material sites difficult for Fall 2012. The spring 2013 data set included AGRRA 7 point count transects on designed reefs, and 6 transects on waste-material reefs. Seasonal variation between fall 2012 and spring 2013 can be determined using the 7 transects taken each season. The 14 modules surveyed represented approximately 9% (14 of 153) of the total modules deployed by GNGS in 2001.

Seasonal Variation:



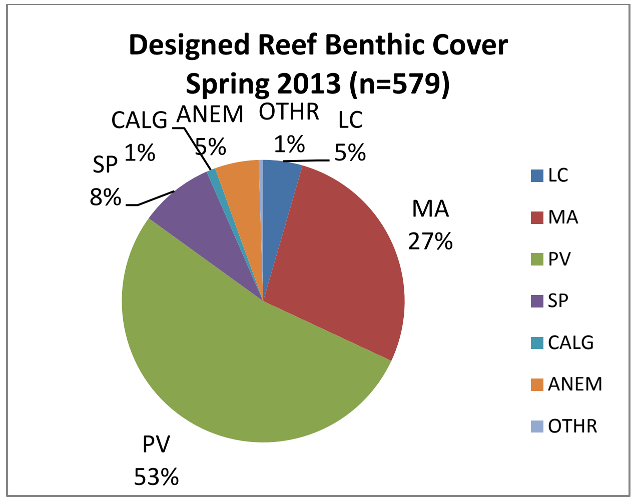
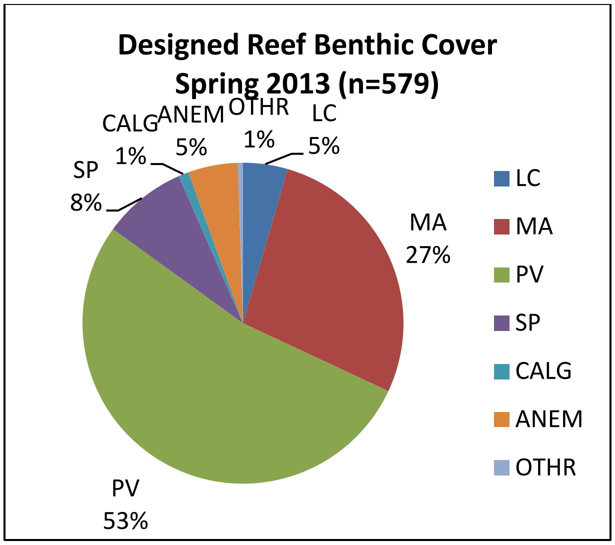


Figure 4. Seasonal Variation of bottom cover between fall 2012 and spring 2013 on designed artificial reefs. T-tests show no significant difference of bottom cover between seasons.

Designed and Waste-Material Reef:

Table 3. Total count of bottom type on Waste-material (WM) and Designed (DS) reefs by individual transect number. AGGRA codes for the seven benthic types are: LC-Live Coral, MA-Macroalgae, PV-Pavement/Bare Substrate, SP-Sponge, CALG-Calcareous Algae, ANEM-Anemone, and OTHR-Other.

Transect #	LC		MA		PV		SP		CALG		ANEM		OTHR	
	WM	DS	WM	DS	WM	DS	WM	DS	WM	DS	WM	DS	WM	DS
1	1	2	8	26	36	42	32	8	0	2	0	5	2	0
2	0	5	10	27	42	44	20	8	0	0	0	1	1	0
3	5	10	12	15	29	51	30	8	0	0	0	4	1	0
4	3	2	8	22	21	42	23	7	0	1	0	4	0	1
5	3	2	9	23	24	42	17	9	0	0	0	4	0	0
6	0	1	11	23	13	44	10	4	0	2	0	5	4	0
7		4		23		44		5		1		6		2



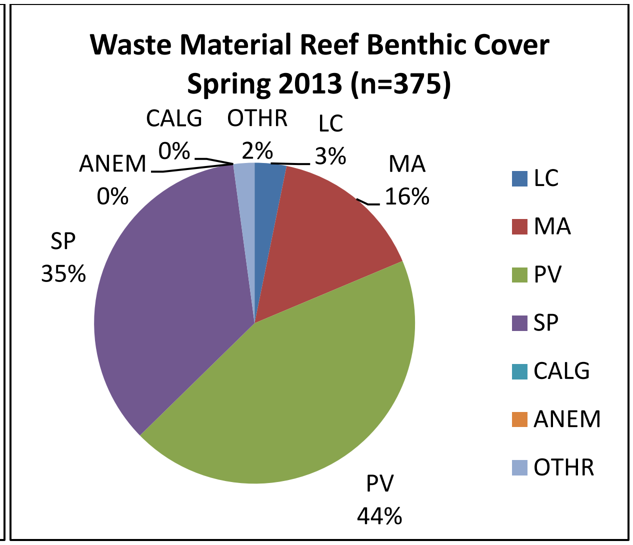


Figure 5. Comparison of Designed and Waste-material Artificial Reef Benthic Cover taken 17 April, 2013. LC-Live Coral; MA-Macroalgae; PV-Pavement or Bare Substrate; SP-Sponge; CALG-Calcareous algae (*Halimeda sp*.); ANEM-Anemone; OTHR-Other (*Diadema*, fishing gear)

Table 4. T-test results (α=0.05) of bottom cover differences between Waste-material (WM) and Designed (DS) artificial reefs

	Waste-material	Designed	P-value (α=0.05)	Accept/Reject null-hypothesis
Live Coral (LC)				
Mean	2	3.714	0.129	Accept null
Variance	4	9.571		
Macroalgae (MA)				
Mean	9.667	22.714	$1.93X10^{-5}$	Reject null
Variance	2.667	14.904		
Pavement/Bare Substrate (PV)				
Mean	27.5	44.143	0.00479	Reject null
Variance	109.9	10.143		
Sponge (SP)				
Mean	22	7	0.00359	Reject null
Variance	67.6	3.333		
Calcareous Algae (CALG)-*Halimeda*				
Mean	0	0.857	0.0226	Reject null
Variance	0	0.809		
Anemone (ANEM)				
Mean	0	4.143	0.000217	Reject null
Variance	0	2.476		
Other (OTHR)-*Diadema*, fishing gear				
Mean	1.333	0.429	0.113	Accept null
Variance	2.267	0.619		

Seasonal Variation:

The temperature range in the Gulf of Mexico can reach maximums of 32°C in summer and minimums of 15°C in winter. This temperature range of 17°C causes large swings of bottom cover like macroalgae throughout the year. The sampling times of fall 2012 and spring 2013 show similar bottom cover percentages in macroalgae (±20%) and live coral cover (<1%) between seasons (Dupont, 2009). During both research dives, the bottom temperatures were within 2°C of another; Fall 2012-20.0°C, Spring 2013-21.1°C. Even though the temperatures were similar at the time (Figure 5), the transition of winter to summer (spring reefs), and summer to winter (fall reefs) may cause variations in bottom cover percentage of macroalgae and coral. Bottom cover between fall and spring designed reefs did not show significant difference through a single factor t-test (α=0.05).

Designed and Waste-material Reefs:

To test for significant difference between reef types, a one-tailed t-test (α=0.05) was performed between each of the seven bottom types between reefs. The null-hypothesis that there was no significant difference between bottom type of waste-material and designed artificial reefs was tested to determine significant bottom cover differences between the reefs (Table 3). The results of the t-test show that only two of the seven benthic categories were not significantly different, live coral cover and other. All other benthic covers: macroalgae, pavement/bare substrate, sponge, calcareous algae, and anemones showed significant differences between the reef types.

ANOVA test was applied to each spring 2013 data set to determine variability among individual transects taken of each reef. The results of the ANOVA tests showed no significant difference (α=0.05) with transect on either the modules or Treasure Island reef with *p*-values of 0.999 and 0.943, respectively.

Multidimensional scaling (MDS) is a multivariate analysis used to represent each sample (transect on the reef) and rank the distance away from one another based on their dissimilarities; points close to one another are more similar to ones farther away. Figure 6 shows the results of

MDS with the 2D stress level of 0.01. In order to show accurate MDS results, WM-6 was removed due to an outlier result in a previous MDS graph. WM-6 was taken as the final transect on Treasure Island reef on freestanding structure away from the main reef. The similarity between the waste-material and designed reef show very close grouping among transect dissimilar from the other reef type.

Figure 6. Multidimensional scaling (MDS) of Waste Material (WM 1-5) and Designed (DS 1-7) Artificial Reefs. Closer proximity of points shows higher similarity between transect sites.

<u>Discussion:</u>

Live coral cover is the most significant bottom cover when observing the state of the reefs. Although artificial reefs may not require much coral cover to be considered productive, coral cover provides a baseline when comparing other reefs across the globe. Studies reporting reef ecology generally look towards percent coral cover to show the health of the reef and predictions of the future. Only three coral species were seen on the modules in 2005 through 2007: *Cladocora arbuscula*, *Phyllangia americana*, and *Siderastrea radians* (Dupont, 2009). In

2012, a genus not previously seen on the modules, *Oculina*, was observed on the GNGS modules. *Oculina* sp. is a branching coral that has been found on natural reef sites on the WFS. A large colony of *Oculina* was observed on Treasure Island reef in Spring 2013.

When evaluating the ecosystem services of artificial reefs using bottom cover data, it is important to understand which types of cover provide for higher trophic levels. Trophic structure on reefs may be the most important service provided by benthic cover of macroalgae. A human eating the fish, eating smaller fish, eating algae and other smaller species is the common way trophic levels are imagined. The major ecosystem service provided by artificial reefs is support of fisheries in areas there would not typically be one. An artificial reef with abundant macroalgae cover could serve the needs of many herbivorous fish, and those herbivorous fish serving the needs of other carnivorous animals; this connection was not studied in this project, but the data displayed could lay a base for future designed artificial reef studies.

The macroalgal cover was significantly different between designed and waste-material reefs. Macroalgal cover could be the most significant factor when determining the ecosystem services of artificial reefs. Macroalgae provide food for grazing fish, and have faster growth rates than corals and cover bare substrate areas (Hughes, 1994). Macroalgae has also shown to affect the resiliency of reefs, which suffer when there is a shift from coral-dominant cover to that of macroalgae-dominate cover. Macroalgal species shows more seasonal variation than coral species, affecting the renewal of coral reefs and their subsequent ecosystem services (Done, 1992).

Through personal observation during dives on the waste-material and designed artificial reefs, the designed reefs appear to have a more diverse fish population compared to that of waste-material reefs. Classes like *Serranidae*, *Haemulidae*, *Labridae*, and *Gobidae* were found in abundance on the module site. The sizes of these fish at the modules were much larger than those seen at near-shore artificial reefs like Treasure Island.

However, differences between the two reefs, regardless of design, are too great to establish a conclusion. Major factors like distance from shore (11km vs. 25km), depth (10m vs. 18m) weigh heavily on the accessibility of the reefs to pole fishing and spear fishing. Water clarity between both reefs varied greatly; visibility 25km offshore was 3 times greater than that found 11km offshore. Water clarity, based on plankton abundance may be a cause for abundant sponges found on Treasure Island reef. Peterson et al. (2006) showed that sponges could reduce the concentration of chlorophyll a from 0.55 μg/L to 0.15 μg/L in a two hour period. With water clarity observations a result of plankton concentration, one could conclude that abundance of sponges on Treasure Island reef were results of water clarity.

An additional factor influencing fish population on the two reefs is public knowledge of GPS coordinates. Lat/long locations of Treasure Island reef and others within the Pinellas County reef program are open to the public; this was clear based on the abundance of fishing gear (monofilament line, hooks) and trash found around Treasure Island reef. The GNGS module sites have been kept private since their deployment; there was evidence of fishing on the module sites, but much less than on Treasure Island reef.

The dynamic relationship between fish and anglers has opened debate about the role of artificial reefs as producing more fish species, or only attracting them to particular areas. Pinkering & Whitemarsh (1997) reviewed the ‘Attraction vs. Production’ debate to show which literature favor an attraction reef compared to a production reef. Crevices, gaps, and holes in artificial reefs favor the development of fish from juvenile to adult life stages. Design of a reef that allows protection of both juvenile and adult fish species increases production on that reef.

Future Research:

As mentioned in the discussion, fish surveys between waste material, designed, and natural reefs at similar depth and distance from shore could provide a more direct link between ecosystem services and reef features or design. Data of this type could shed light on which designs favor an attraction or production artificial reef.

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