Environmental enhancement gone awry: characterization of an artificial reef constructed from waste vehicle tires

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Abstract

In 1967, Broward County, Florida resource managers initiated a project to construct an artificial reef using an estimated two million unballasted waste vehicle tires. These tires were deployed in bundles approximately 1.8km offshore in 21m of water. Over time, the bundle bindings failed and the tires have moved extensively, some displaced kilometers from their original location. The loose tires have physically damaged benthic reef fauna on the natural reef, including corals that have recruited onto individual tires. Due to the biological damage caused by the mobile tires, a large-scale removal plan has been initiated. To assess damage, and to acquire a baseline to evaluate the effectiveness of the tire removal, an examination of existing biota was accomplished. Live corals were absent on the natural substrate of the Middle reef edge buried by tires. However, on tires the abundance of corals is similar to that found on neighboring hardbottom reef tracts. Likewise, fish abundance and richness on the tire reef is similar to bordering natural reef tracts. Significantly higher fish abundance was found along the edge where tires were present, than on control sites. Future monitoring will determine what changes in reef biota resulted from the removal operation and the effectiveness of the attempted restoration.

Keywords: artificial reefs, tires, coral reefs, restoration, fishes, corals.

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1 Introduction

Since the mid-1900's artificial reefs of varied materials have been deployed worldwide to acquire large and diverse fish assemblages to increase recreational and commercial fisheries as well as recreational SCUBA diving. Artificial reefs, originally viewed as a way to enhance local fish populations, were often comprised of waste materials such as automobiles, airplanes, vessel reefs, and dredging debris [1, 2]. As coral reef conservation efforts have come to the forefront of marine research, interest in the materials used for artificial reef construction have come under increasing scrutiny [3–5]. Not all materials have proven equal in standing up to the tests of time and elements.

In 1967, resource managers in Broward County, Florida, initiated a project to construct an artificial reef using waste vehicle tires. Unballasted tires were deployed in bundles of eight, approximately 1.8km offshore, in 21m of water on sandy substrate between two coral reef tracts. By 1973, Raymond [6] estimated one million tires had been deployed in the permitted area named the 'Osborne Tire Reef' with other estimates reaching two million [7] (see Figures 1 and 2).

The tire reef was deployed with two goals in mind. First was to increase the amount of fish habitat in the sandy plain between the two reef tracts for the purpose of increasing local commercial and sport fishes, including snappers (Family: Lutjanidae), jacks (Carangidae) and groupers (Serranidae). Second was to 'constructively' dispose of surplus solid waste by using tires as an economical artificial reef material [7]. Certainly, these goals were well intentioned.

Figure 1: Osborne tire reef with associated biota.

Figure 2: Osborne tire reef with associated biota.

However, the southeast coast of Florida is often exposed to tropical storm events, including hurricanes. The storm forces easily interact with the substrate at the 20-meter depth. Over time, bindings on the bundles failed and the tires were, and continue to be, transported with normal currents and high energy storms. Many individual tires from this reef have been moved onto the public beaches of Broward and neighboring counties during tropical storms or hurricanes. Those tires that have not washed onshore, or been more widely dispersed, are primarily found in an approximately 150,000m^2 area of the seafloor. These mobile tires cause damage to surrounding natural reef by burying or injuring existing coral colonies [7, 8]. Additionally, many of the tires have been piled up against the offshore edge of the Middle reef, an area of high fish abundance and diversity, with tires at individual sites estimated in the 100,000's [7–9]. Further, from an aesthetic viewpoint, the tire reef is a disaster with the appearance of a junkyard in an area frequented by recreational divers [10].

A similar fate befell artificial reefs constructed of tires elsewhere. For example, two artificial reefs constructed of waste vehicle tires bundled together with polypropylene rope and tape were deployed in the Gulf of St. Vincent, South Australia in 1970–1973. Initially, the reefs were reported to attract and retain large fish populations. However, poor construction led to dispersal of tires during storms [5].

Sherman and Spieler [7] examined the feasibility of removing the Osborne Tire Reef. Over the course of eight dive trips 86 volunteer divers bundled 200 tires per dive on 20 lift lines. Commercial divers then raised the bundles to the surface using lift bags. Tires were transported to Port Everglades, removed from the water, rinsed, and finally disposed of by a licensed tire recycler. By the end of this preliminary project, a total of 1,600 tires had been removed leaving a 20m

X 20m area devoid of tires. Part of the project also included monitoring re-incursion of tires into the cleared area. The first monitoring dive two months after removal revealed that the entire site was already re-covered by tires [7].

Although the Sherman and Spieler [7] study initially indicated the feasibility of a tire removal project and provided insight into methodology, it clearly demonstrated that a much larger project, with more funding, was required to make a more significant impact than would likely be accomplished with volunteer workers. Removal cost alone has been estimated at upwards of $30 million (USD) based on the initial estimate of 2 million tires at the site (Sherman unpublished). However, the work clearly raised awareness of the problem and a removal of a large portion of the tire reef is scheduled to begin in April 2008.

To remove the tires several agencies on the local, state, and federal levels have developed a partnership. Staff from Broward County's Environmental Protection Department will help coordinate the removal effort with the State of Florida and the U.S. military. The Army's 86th Dive Team and the Navy's Mobile Diving Salvage Unit Two, with Army watercraft support, are scheduled to begin the salvage efforts in April 2008. The project aims to remove approximately 675,000 tires.

Priority for removal will be given to those areas of the tire reef that are considered the greatest threat to the adjacent natural reef, such as areas with the most mobile tires closest to the natural reef. Prior to tire removal, teams of trained divers will remove and transplant coral colonies (>10cm diameter) from tires to a preselected coral nursery site.

Tires deemed to have long-term stability due to their partial burial and/or high coral coverage will not be removed from the site during the planned operation. Collected tires will be transported to Port Everglades in an Army landing craft and brought to a tire processing facility [8]. The U.S. military will not charge for the removal and transport to the processing facility which will dramatically reduce costs.

Prior to this removal, an assessment of current biota is needed to allow a comparison of the tire reef to the natural reef and to provide a baseline for monitoring future impacts the tire removal may have on the surrounding natural environment [9,11,12].

2 Materials and methods

The experimental design consisted of comparing species richness (number of individual species present) and abundance (number of individuals present) of fishes and corals on the Osborne Tire Reef to neighboring natural sites.

2.1 Fish Counts

There are three natural coral reef tracts which run parallel to the shoreline of Broward County, in sequentially deeper water. These tracts are locally called the Inshore, Middle, and Outer reefs (also called the First, Second, and Third reef, respectively [13,14]). The tire reef lies on sandy substrate between the Middle and Outer reefs (Figure 3).

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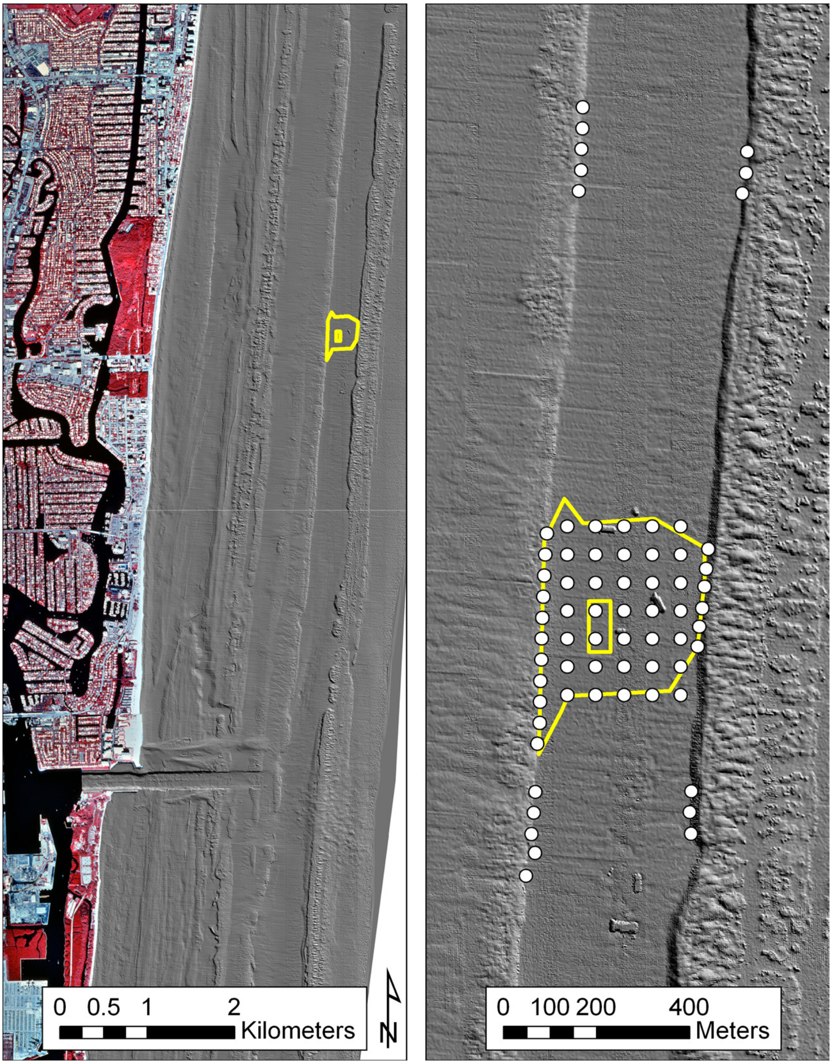

Figure 3: Location of survey and control sites (white circles) for the Osborne Tire Reef (outlined) centered at 26º08.422' N; 80º04.867'W.

Fish counts on the tire reef and adjacent reef edges were conducted from August 2007 through December 2007. At The Middle and Outer reef edges of the tire reef and control sites, scuba divers descended down a buoy line on a predetermined GPS point marked by a clump weight. Using a modified Bohnsack and Bannerot [15] point-count method, divers assessed the abundance and species richness of fishes present at 10 sites along the Middle reef (western) edge of the tire reef and at five control sites north and five south of the tire reef.

Six locations along the Outer reef (eastern) edge of the tire reef and three control sites to the north and south were surveyed using point-counts (Figure 3). A diver remained stationary at the center of an imaginary cylinder, 15m in diameter with the center located over the reef edge, and recorded all fish species present from the substrate to the surface for five minutes. After the five minute species count, abundance and size estimates for each species were recorded; followed by a five-minute rover-diver count, simply recording fishes present within the cylinder. The additional five-minute survey compensated for any species in the tires that were not readily visible to the counters when stationary, thus providing a more comprehensive species list.

To evaluate any edge effect, an additional 35 sites were surveyed using the above mentioned point-count technique to assess abundance and species richness of fish strictly within the tire reef (Figure 3).

2.2 Coral transects

Nine coral transects were completed throughout the tire field. A 20-meter belt transect was used and any coral colony greater than 2cm in size, within one meter to either side of the transect mid-line, was measured. Species name and colony length, width, and height were recorded. In addition, notes were taken on any unusual conditions such as apparent bleaching or disease.

2.3 Data analysis

Total fish abundance and species richness were subjected to statistical analyses (Statistica, StatSoft Inc., Tulsa, OK, USA). To meet the assumptions of analysis of variance (ANOVA), abundance data were $\log_{10}(x+1)$ transformed prior to ANOVA and *post-hoc* Newman-Keuls tests. Raw species richness values were used for the same analyses. A p-value of <0.05 was accepted as a significant difference.

An MDS constructed from Bray-Curtis similarity indices, an examination of similarity percentages of particular species (SIMPER), and an analysis of similarity (ANOSIM) were preformed to determine possible differences in fish assemblage structure among sites using Plymouth Routines in Multivariate Ecological Research statistical package (PRIMER v6).

From coral transect data, a species list was compiled and percent coverage calculated.

3 Results and discussion

During this study a total of 158 species (39 families) was recorded for all sites combined. Mean species richness and fish abundance for counts on the tire reef was 19.35±0.90 and 142.35±25.17 (mean±standard error of the mean [SEM]). These numbers are comparable to the populations of fishes recorded in previous studies from the immediate area. Ferro, et al. [9] reported a species richness of 18±0.3 and a species abundance of 144±8.2 on Broward County reef tracts. All fish species recorded on the tire reef were also found on the neighbouring natural reef [9].

The western edge of the field is on the eastern edge of the Middle reef and the eastern edge of the tire reef lies on the western edge of the Outer reef (Figure 3). The predominant movement of the tires is westward and the eastern edge of the Middle reef is much more heavily impacted by the tire reef than the western edge of the Outer reef.

Overall, species richness was significantly higher on the tire reef than natural reef. When examining the edge effects, it appears tires may have added habitat. The Middle reef edge had significantly higher fish abundance with tires present than the control sites on the same reef edge (438.05±77.31 versus 223.1±37.82; $p<0.05$, ANOVA). In contrast, on the eastern side of the tire reef (western Outer reef edge) there was no significant difference in abundance between control sites and the edge that contained tires (90.58±16.79 versus 121.75±41.72; $p>0.05$). This difference appears to be due to the lower density of tires near the edge of the Outer reef, causing these sites to be more similar to the existing natural reef environment. No significant difference was noted for species richness when comparing the edge sites (tires vs. control) for either reef (Middle reef control: 19.00±0.78; Middle reef with tires: 23.80±1.20, Outer reef control: 16.75±1.05, Outer reef with tires: 16.33±0.73;$p>0.05$).

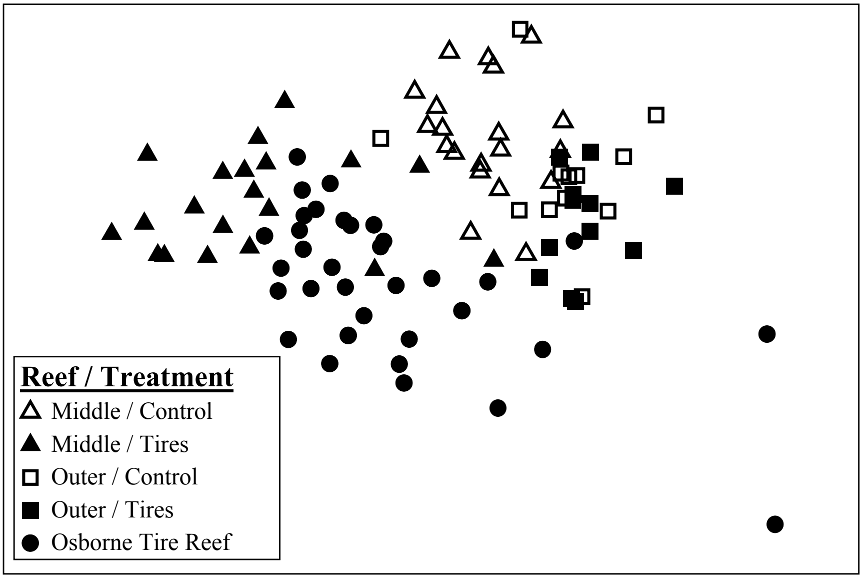

Figure 4: MDS plot of Bray-Curtis similarity indices illustrating assemblage structure differences between reef edges and the presence or absence (control) of tires.

By combining all control sites and comparing them to the tire field itself, no significant difference existed for either species richness or fish abundance (tire

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reef richness and abundance: 19.35±0.90, 142.35±25.17; control site richness and abundance: 18.16±0.64, 185.09±29.27). However, while the actual number of species and individuals did not differ, an MDS plot revealed a difference in assemblage structure (Figure 4).

These findings were further supported by ANOSIM and SIMPER analyses. The average dissimilarity between the tire reef and the natural surrounding reefs was 62.65%. The top 25% of the dissimilarity was due to the following six fish species: *Coryphopterus hyalinus/personatus* (6.44%), *Thalassoma bifasciatum* (3.69%), *Stegastes partitus* (3.28%), *Serranus tortugarum* (3.15%), *Acanthurus bahianus* (2.83%), *Acanthurus chirurgus* (2.82%), and *Haemulon flavolineatum* (2.81%).

A total of 19 species of stony corals was recorded on the tire reef with a mean species richness of 8.76± 2.9. The Osborne Tire Reef is similar in percent coverage to the surrounding natural reef tracts, with a mean percent coral coverage of 1.46%±0.99. On the Middle reef, Gilliam, et al. [12] reported mean percent coral coverage to be 1.63%±0.42. The Outer reef coverage was 1.42%±0.24. The high variability of coral coverage on the tire reef could be due to the variable tire coverage throughout the area. Coral coverage appeared to be highest where tire density was highest.

Despite similarities in coral richness and coverage between the natural and tire reefs, the dominant species differed. *Stephanocoenia intersepta* was the dominant species on the tire reef while *Siderastrea siderea* was the most abundant coral species on the nearby natural reefs [12].

Thus, the Osborne Tire Reef is clearly not the same as the natural reef despite similar species richness and abundance of fishes and corals. This is not a surprising finding as the associated biota on artificial reefs and neighboring natural reefs invariably differ in some degree [7, 11, 16]. Removal of the tire reef, while a worthwhile restoration effort, will likely impact existing fish and coral populations, which are extensive in the area of the tire reef as well as neighboring reef tracts. Data in this study should provide a baseline with which to evaluate direction of change and effectiveness of the restoration efforts.

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Appendix

Table 1: Fish species observed at different sites with tires present, at the control sites and the tire reef.

Scientific Name	Tires Present	Control Sites	Tire Reef
UROLOPHIDAE			
Urobatis jamaicensis	x		x
MURAENIDAE			
Gymnothorax funebris	x		x
Gymnothorax moringa	x		
Gymnothorax vicinus		x	
CONGRIDAE			
Heteroconger longissimus		x	
SYNODONTIDAE			
Synodus foetens	x		x
Synodus intermedius	x		x
Synodus saurus	x		
Lizardfish spp.	x		x
HOLOCENTRIDAE			
Holocentrus adscensionis	x	x	x
Holocentrus rufus	x	x	x
Myripristis jacobus	x		x
Sargocentron coruscum	x		x
AULOSTOMIDAE			
Aulostomus maculatus	x	x	x
SCORPAENIDAE			
Scorpaena plumieri	x	x	
SERRANIDAE			
Cephalopholis cruentata	x	x	x
Cephalopholis fulva	x		x
Diplectrum formosum	x	x	x
Epinephelus adscensionis	x		x
Epinephelus guttatus	x		x
Hypoplectrus gemma	x		x
Hypoplectrus guttavarius	x		x
Hypoplectrus indigo	x		
Hypoplectrus nigricans	x		x
Hypoplectrus puella	x		x
Hypoplectrus unicolor	x	x	x
Hypoplectrus sp.	x		x
Mycteroperca bonaci	x		
Mycteroperca microlepis	x		x

Table 1: Continued.

Scientific Name	Tires Present	Control Sites	Tire Reef
SERRANIDAE			
Mycteroperca phenax	x	x	
Rypticus saponaceus		x	
Serranus annularis		x	
SERRANIDAE			
Serranus baldwini	x	x	
Serranus phoebe		x	
Serranus tabacarius	x	x	x
Serranus tigrinus	x	x	x
Serranus tortugarum	x	x	x
OPISTOGNATHIDAE			
Opistognathus aurifrons	x	x	
PRIACANTHIDAE			
Heteropriacanthus cruentatus	x		
Priacanthus arenatus		x	
APOGONIDAE			
Apogon maculatus		x	
Apogon townsendi	x	x	
MALACANTHIDAE			
Malacanthus plumieri	x	x	x
ECHENEIDAE			
Echeneis naucrates		x	
CARANGIDAE			
Carangoides bartholomaei	x		x
Carangoides ruber	x	x	x
Caranx crysos	x	x	x
Seriola rivoliana	x		x
LUTJANIDAE			
Lutjanus analis	x	x	x
Lutjanus buccanella	x		x
Lutjanus campechanus	x		x
Lutjanus griseus	x		x
Lutjanus jocu	x		
Lutjanus mahogoni	x		x
Lutjanus synagris	x		x
Ocyurus chrysurus	x		x
HAEMULIDAE			
Anisotremus surnamensis	x		
Anisotremus virginicus	x	x	x
Haemulon album	x	x	x

Table 1: Continued.

Scientific Name	Tires Present	Control Sites	Tire Reef
HAEMULIDAE			
Haemulon aurolineatum	x		x
Haemulon carbonarium	x		x
Haemulon chrysargyreum	x		x
Haemulon flavolineatum	x		x
Haemulon macrostomum	x		
Haemulon melanurum	x		x
Haemulon parra	x	x	
Haemulon plumierii	x	x	x
Haemulon sciurus	x		x
Haemulon striatum		x	
Haemulon spp.	x	x	x
INERMIIDAE			
Inermia vittata	x		
SPARIDAE			
Calamus calamus	x	x	x
Calamus penna	x		x
Calamus pennatula		x	
Calamus proridens	x		x
SCIAENIDAE			
Equetus punctatus	x		x
Pareques acuminatus	x		x
MULLIDAE			
Mulloidichthys martinicus	x		
Pseudupeneus maculatus	x	x	x
KYPHOSIDAE			
Kyphosus incisor/sectator	x		x
CHAETODONTIDAE			
Chaetodon capistratus	x	x	x
Chaetodon ocellatus	x	x	x
Chaetodon sedentarius	x	x	x
POMACANTHIDAE			
Centropyge argi	x		x
Holacanthus bermudensis	x	x	x
Holacanthus cilaris	x	x	x
Holacanthus tricolor	x	x	x
Holacanthus spp.	x	x	
Pomacanthus arcuatus	x	x	x
Pomacanthus paru	x	x	x

Table 1: Continued.

Scientific Name	Tires Present	Control Sites	Tire Reef
CIRRHITIDAE			
Amblycirrhitus pinos	x		x
POMACENTRIDAE			
Abudefduf saxatilis	x		x
Chromis cyanea	x	x	x
Chromis enchrysura	x		
Chromis insolata	x	x	x
Chromis multilineata	x	x	x
Chromis scotti	x	x	x
Microspathodon chrysurus	x		x
Stegastes adustus	x		x
Stegastes leucostictus	x	x	x
Stegastes partitus	x	x	x
Stegastes variabilis	x	x	x
LABRIDAE			
Bodianus rufus	x	x	x
Clepticus parrae	x	x	x
Halichoeres bivittatus	x	x	x
Halichoeres cyanocephalus		x	
Halichoeres garnoti	x	x	x
Halichoeres maculipinna	x	x	x
Halichoeres pictus		x	
Halichoeres poeyi	x		x
Lachnolaimus maximus	x	x	x
Thalassoma bifasciatum	x	x	x
Xyrichtys martinicensis	x	x	
Xyrichtys splendens		x	
SCARIDAE			
Cryptotomus roseus	x	x	
Scarus coeruleus	x		x
Scarus guacamaia	x		
Scarus iseri	x	x	x
Scarus taeniopterus	x	x	x
Scarus vetula	x		x
Sparisoma atomarium	x	x	x
Sparisoma aurofrenatum	x	x	x
Sparisoma chrysopterum	x	x	x
Sparisoma radians	x	x	x
Sparisoma rubripinne	x	x	x
Sparisoma viride	x	x	x

Table 1: Continued.

Scientific Name	Tires Present	Control Sites	Tire Reef
LABRISOMIDAE			
Malcoctenus macropus	x		
Malcoctenus triangulatus		x	
CHAENOPSIDAE			
Emblemaria pandionis	x		
GOBIIDAE			
Coryphopterus glaucofraenum	x	x	x
Coryphopterus hyalinus/personatus	x	x	x
Ctenogobius saepepallens	x		x
Elacatinus oceanops	x		x
Gnatholepis thompsoni	x	x	x
Microgobius carri		x	
Risor ruber	x		
PTERELEOTRIDAE			
Ptereleotris calliura	x	x	x
Ptereleotris helenae	x	x	x
ACANTHURIDAE			
Acanthurus bahianus	x	x	x
Acanthurus chirurgus	x	x	x
Acanthurus coeruleus	x	x	x
SPHYRAENIDAE			
Sphyraena barracuda	x		
SCOMBRIDAE			
Scomberomorus maculatus		x	
Scomberomoros regalis		x	
BALISTIDAE			
Balistes capriscus	x	x	x
MONACANTHIDAE			
Aluterus monoceros		x	
Aluterus scriptus	x	x	x
Cantherhines pullus		x	
Monacanthus tuckeri	x	x	
Stephanolepis hispidus	x	x	
OSTRACIIDAE			
Acanthostracion polygonius		x	
Acanthostracion quadricornis	x	x	x
Lactophrys trigonus		x	
Lactophrys triqueter	x	x	x

Table 1: Continued.

Scientific Name	Tires Present	Control Sites	Tire Reef
TETRAODONTIDAE			
Canthigaster rostrata	x	x	x
Sphoeroides spengleri	x	x	
DIODONTIDAE			
Diodon holocanthus	x	x	x
Diodon hystrix	x	x	
Total species observed:	137	97	108

Table 2: Stony coral species observed on the tire reef and their percent coverage.

Coral Species on Tire Reef	Percent Coverage
Stephanocoenia intersepta	19.38
Porites astreoides	16.85
Madracis decactis	16.22
Siderastrea siderea	12.22
Diploria strigosa	11.30
Montastraea cavernosa	6.59
Agaricia agaricites	5.62
Montastraea faveolata	3.79
Diploria clivosa	3.39
Colpophyllia natans	1.42
Diploria labyrinthiformis	0.90
Scolymia spp.	0.81
Meandrina meandrites	0.39
Solenastrea bournoni	0.33
Agaricia fragilis	0.27
Montastraea annularis	0.20
Agaricia lamarcki	0.11
Dichocoenia stokesii	0.11
Mycetophyllia spp.	0.09

References

[1] Baine, M., Artificial reefs: a review of their design, application, management and performance, *Ocean and Coastal Management.* **44**: pp.241–259, 2001.

[2] Pollard, D.A., Artificial habitats for fisheries enhancement in the Australian region, *Marine Fisheries Review*. **51**: pp.11–26, 1989.
[3] Bohnsack, J.A. &. Sutherland, D.L., Artificial reef research: a review with recommendations for future priorities*, Bulletin of Marine Science*. **37**, pp.11–39, 1985.
[4] Bohnsack, J.A., Johnson D.L, & Ambrose R.F., Ecology of artificial reef habitats and fishes, IN: Seaman, W. Jr. and L.M. Sprauge eds. *Artificial habitats for marine and freshwater fisheries,* Academic Press; San Diego, Ca. pp. 61–107, 1991.
[5] Branden, K.L., Pollard, D.A., & Reimers, H.A., A review of recent artificial reef developments in Australia, *Bulletin of Marine Science.* **55**, pp.982–994, 1994.
[6] Raymond B., Underwater photogrammetric survey of a tire reef, *Proceedings of the Conference on Artificial Reefs, Florida Sea Grant. Daytona Beach, FL, 13 September.* pp.211–218, 1979.
[7] Sherman, R.L. & Spieler R.E.. Tires: unstable materials for artificial reef construction, *Proceedings of Environmental Problems in Coastal Regions Including Oil Spill Studies*. pp.215–223. 2006.
[8] Nuckols, W.H. & Gray T.A., A plan for the recovery of the artificial tire reef in Ft. Lauderdale, Florida, *NOAA Marine Fisheries Report, December 26th 2006*
[9] Ferro, F., Jordan L.K.B, & Spieler R.E., The marine fishes of Broward County, Florida: final report of 1998-2002 survey results, *NOAA Technical Memorandum NMFS* SEFSC-532. 2005.
[10] Johns, G.M., Leeworthy, V.R., Bell F.W., & Bonn M.A., Socioeconomic Study of Reefs in Southeast Florida: Final Report. Oct. 2001. 348 pp.
[11] Arena, P.T., Jordan L.K.B., & Spieler R.E., Fish assemblages on sunken vessels and natural reefs in southeast Florida, USA. *Hydrobiologia.* **580**, pp.157–171, 2007.
[12] Gilliam, D.S., Dodge, R.E., Spieler, R.E., Jordan, L.K.B., & Walczak, J.C., Marine biological monitoring in Broward County, Florida: year 7 annual report*, Broward County Board of County Commissioners Technical Report EPD 06-XX*. pp.1–95. 2007.
[13] Moyer, R.P., Rielg, B., Banks, K., & Dodge, R.E., Spatial patterns and ecology of benthic communities on a high-latitude South Florida (Broward County, USA) reef system. *Coral Reefs.* **22**: pp.447–464. 2003
[14] Banks, K.W., Riegl, B.M, Shinn, E.A., Piller, W.E., and Dodge, R.E., Geomorphology of the Southeast Florida continental reef tract (Miami-Dade, Broward, and Palm Beach Counties, USA). *Coral Reefs.* **26**: pp.617–633. 2007.
[15] Bohnsack, J.A. & Bannerot S. P., A stationary visual census technique for quantitatively assessing community structure of coral reef fishes, *NOAA Technical Report NMFS.* **41**: pp.1–15, 1986.
[16] Perkol-Finkel, S., Shashar, N., & Benayahu, Y., Can artificial reefs mimic natural reef communities? The role of structural features and age. *Marine Environmental Research.* **61**: pp.121–135. 2006.