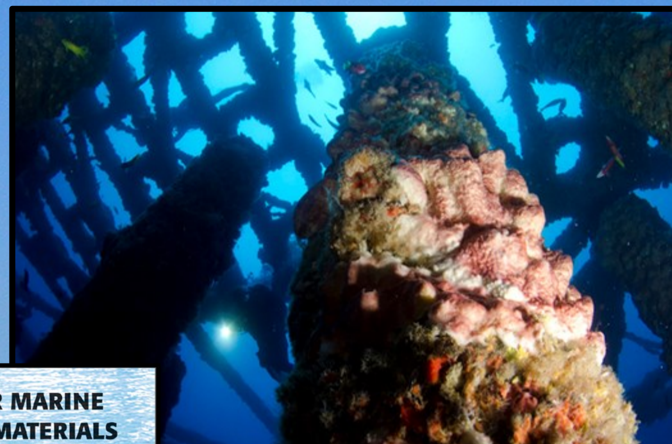
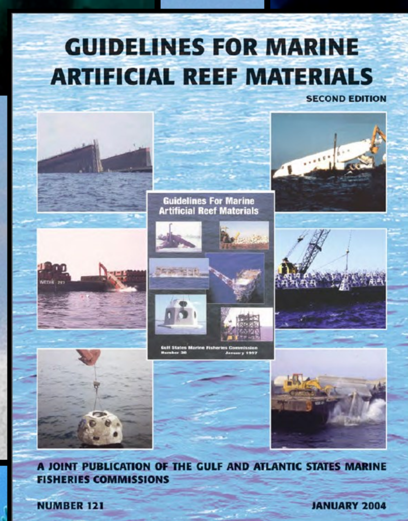
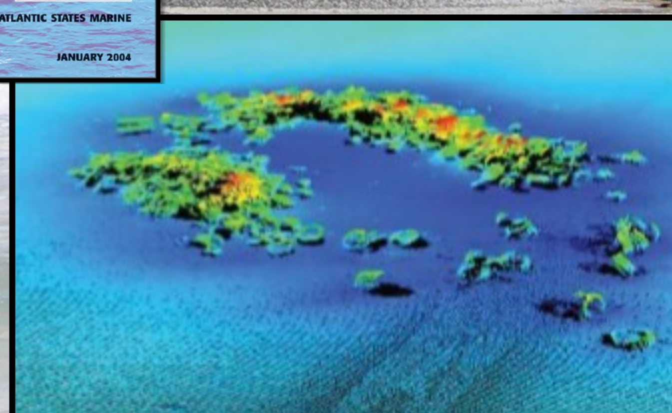
# GUIDELINES FOR MARINE ARTIFICIAL REEF MATERIALS

## THIRD EDITION





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# GUIDELINES FOR MARINE ARTIFICIAL REEF MATERIALS

**Third Edition**

**Compiled by the**

**Artificial Reef Subcommittees**

**of the**

**Atlantic and Gulf States Marine Fisheries Commissions**

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## DEDICATIONS

This edition is dedicated to the memories of Jim Francesconi (Atlantic States Marine Fisheries Commission Artificial Reef Subcommittee Member) and Jimmy Sanders (Gulf States Marine Fisheries Commission Artificial Reef Subcommittee Member).

Jim Francesconi

Jim passed away on July 18th, 2014 after a long and brave battle with leukemia. He began working with the North Carolina Division of Marine Fisheries in 1987 and became the Artificial Reef Coordinator in 2000. Jim's efforts with the Program produced hundreds of enhancements throughout coastal North Carolina, including the creation of one estuarine and two ocean reef sites, the sinking of the USCG SPAR, Tug Titan, The Captain Greg Mickey, Tug Pawtucket, Capt. Charlie, and two USCG Falcon aircraft to name just a few. More importantly Jim made countless friends along the way that will truly miss him.

Jimmy Sanders

July 22, 1973 – May 5, 2018
"Those who knew him, couldn't help but love him."
Whether you knew Jimmy as family, friend, or colleague his kindness was a gravitational force that drew people to him. As the Director of the Mississippi Artificial Reef Bureau, dedicated to creating and restoring habitat for marine life off the coast of Mississippi, Jimmy's work ethic was something to which we should all aspire. No matter how busy he got though, he always made time for his family. Whether it was coaching softball or attending first communion, he never missed the important moments in life. Those important moments are now memories that remain as his legacy. Jimmy will forever be in our hearts as a man that enhanced our lives and the environment. Like everything he touched, he left this world better than he found it. For that we are eternally grateful.

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PREFACE

The purpose of this document is to provide a comprehensive discussion regarding a variety of materials that have been used in the development of marine and estuarine artificial reefs in the United States. This document is a guideline only, and is not, by its nature, regulatory. Our hope is that agencies, organizations, and individuals will find the document useful in the decision-making process regarding the types of materials that are likely to be suitable for use as artificial reefs, including recommendations for optimum application. In that the information in this document represents the opinions and experiences of reef program managers, it should be given serious consideration in decision-making processes. No regulatory agency is bound, however, by any rule to use this document to make decisions about the acceptability of reef materials. In the event a regulatory agency applies the document to its decision-making process, it should do so with the understanding that this document has no legal standing.

The materials discussed in this report do not represent the full range of materials that could be used as artificial reef material, but rather represent the materials that have been used in the development of artificial reefs in marine and estuarine habitats in the United States. References to specific deployments of the selected materials are not intended to be all inclusive, but to provide a general overview and examples of the use of the material. This document is not intended to promote, endorse, or encourage the use of any material over other materials, but to provide background and experiences with the use of selected materials, a listing of benefits and drawbacks associated with using selected materials, and a listing of considerations if the materials are selected for use as artificial reef material. For emphasis, the Benefits and Drawbacks subsections represent perceived benefits and drawbacks contributed by state artificial reef managers as a result of their involvement in artificial reef development over many years. Finally, the Considerations subsection represents practical suggestions by the state artificial reef managers of actions or considerations that should be included in the planning process.

It is anticipated that the adoption of this document, and its distribution, will provide artificial reef programs and prospective artificial reef developers with information that will increase the potential for successful efforts at habitat creation and enhancement. It is not intended to be either anti-artificial reef development, or a promotional publication, but rather a factual reference for those who are tasked with the responsibility for managing, developing, or regulating artificial reef programs, and must consider conservation, fisheries management, environmental protection, recreational, and economic objectives. Materials for artificial reef development will continue to be selected on a case-by-case and program-by-program basis within the permit conditions established by the appropriate state and federal regulatory agencies; however, the ultimate goal of this document is to encourage movement away from the use of questionable materials that have a history of problems, toward the use of materials with a proven track record of success. This is the third revision of a document that was originally published in 1997, and it is expected that this document will continue to be updated and revised periodically. The readers of this document are encouraged to provide additional information regarding positive and negative experiences with specific artificial reef materials, and any recommendations for use of specific materials to either the Gulf States Marine Fisheries Commission, 2404 Government Street, Ocean Springs, Mississippi 39564, (228) 875-5912, or the Atlantic States Marine Fisheries Commission, 1050 N. Highland Street, Suite 200 A-N, Arlington, VA 22201, (703) 842-0740.

# GUIDELINES FOR MARINE ARTIFICIAL REEF MATERIALS

## 1.0 INTRODUCTION

### 1.1 Purpose

The purpose of this document is to provide state and federal agencies and the general public with information related to the history, identification of the benefits, drawbacks, and limitations, and guidelines on the use of selected materials for development of marine artificial reefs.

### 1.2 Background

According to The American Heritage Dictionary, the term "habitat" is defined as "1.) The area or type of environment in which an organism or biological population normally lives or occurs. 2.) The place where a person or thing is most likely to be found." Pennak's Collegiate Dictionary of Zoology generally concurs with this definition, as does Webster's New World Dictionary. So, why be concerned about the definition of the word "habitat" in a document that discusses the use of man-made materials for artificial reef development? Most people think of artificial reefs as mechanisms to facilitate catching fish, but in most cases, artificial reefs constitute habitat for fish and other aquatic organisms. Consequently, regardless of the underlying reason for the development of particular artificial reefs (i.e., create marine life habitat, enhance fishing success, provide SCUBA diving attractions, mitigate for loss of natural reefs, or aquaculture), the end result is the creation of habitat for certain fish species and other organisms that utilize the new habitat for a variety of reasons, including shelter, feeding, and spawning. Indeed, the habitat aspects of artificial reefs are important enough that several Fishery Management Councils have determined that artificial reefs can be designated "essential fish habitat" (EFH) under the definition provided by the Sustainable Fisheries Act amendments to the Magnuson-Stevens Fishery Conservation and Management Act. That definition reads "Essential fish habitat means those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity."

The occurrence of certain species of fish in a given area is largely attributable to the existence of factors on which species depend for survival. Among factors of importance for estuarine and marine species are the presence or absence of topographic relief, substrate composition, temperature, salinity, food availability, and tidal or current movement, along with the absence of hypoxia, excessive turbidity, and toxic algae or chemicals. It is important to know the species of fish that normally inhabit an area and the prevailing environmental factors of an area prior to developing artificial reefs, because these will, to a large extent, dictate the species of fish that will likely be attracted to or found associated with an artificial reef. Also, it is important, in attempting to enhance the occurrence or abundance of fish species in any given area, to know the limiting factors, some of which are beyond the control of the program, including fishing mortality and loss of aquatic vegetation, mangroves, shellfish beds, and salt marshes that serve as juvenile nursery habitat. Those factors will also dictate, to a great extent, what species of fish will be attracted to and flourish on an artificial reef.

Generally, most artificial reefs have been developed in areas that are largely devoid of irregular bottom topography. Portions of the continental shelf along the Atlantic Coast as well as the northern Gulf of Mexico is gently sloping with a mud or sand bottom (Stone et al. 1974). These vast expanses of flat, featureless bottoms provide an excellent opportunity for the application of artificial reefs to alter/enhance the environment, thereby providing habitat for a variety of fish and invertebrate species. If, however, the area in question is an estuary, probably the most limiting factors for the occurrence or lack of occurrence of particular species are temperature and salinity. Typical species that inhabit low salinity, relatively shallow estuarine areas include spotted seatrout, red drum, flounder, Atlantic croaker, and others. These species utilize a variety of habitat components including mud flats, submerged and emergent grass beds, and oyster reefs. The addition of artificial habitat will, in all likelihood, attract these species of fish at various times, but will not be the sole, or even primary, factor in their occurrence. In other words, in the absence of artificial reefs, those species will still be available to fishermen.

In deeper, offshore areas where salinity is generally higher, a variety of species may occur if habitat components are present, but may not occur in the absence of those habitat components. For example, Franks et al. (1972) documented that fish occurrence offshore Mississippi was dominated by the family Sciaenidae, species that are typically not dependent upon irregular bottom topography for survival. The addition of Liberty ship artificial reefs in this area altered the species composition significantly, with the addition of such fish as red snapper, other snapper species, several grouper species, triggerfish, and several species of tropical or subtropical origin. Lukens (1980) calculated an index of similarity comparing the species composition of the flat, featureless bottom with the artificial reef, resulting in a value of 0.32, which indicates little similarity (A value of 1.0 would indicate exactly alike, while a value of 0.0 would be completely dissimilar).

It is important to understand the limiting environmental factors related to the occurrence or lack of occurrence of target species of fish or invertebrates prior to developing an artificial reef so that there will be some understanding regarding the potential performance of that artificial reef. For instance, if someone were to build an artificial reef in the middle of the Mississippi Sound with the intent of attracting snapper and grouper species, the effort would most likely result in failure. If, however, the purpose of the artificial reef was to provide a known location where anglers would have the likelihood of catching spotted seatrout or red drum, the effort would likely be a success, all other factors being equal (i.e., appropriate bottom type, food items, tidal and wave action, etc.).

## 1.3 History

McGurrin et al. (1989) provide an excellent summary of the history of artificial reef development in the United States. This summary will cover some of the high points in that article. The first documented artificial reef in the United States was off South Carolina in the 1830s using log huts. In the Gulf of Mexico, artificial reefs were constructed as early as the 1950s off Alabama. From that time to the present, over 80% of artificial reefs in United States waters have been created using secondary use materials. Secondary use materials include such natural materials as rock, shell, or trees, and such man-made materials as concrete, ships, barges, and oil and gas structures, among others. Most early artificial reef development efforts were accomplished by volunteer groups interested in increasing fishing success. It was widely held that artificial reefs were successful;

consequently, deployment of materials took a higher priority to other activities such as planning, research, and experimentation with various materials, including designed structures (Bohnsack 1987).

Experimentation and small-scale deployment of specifically designed artificial reef structures began in the United States in the late 1970s, and continues to the present. While secondary use materials are still used in the majority of artificial reef construction projects, several coastal states have, in recent years, begun utilizing designed reef structures to carry out artificial reef development objectives. This expanded reliance upon designed reef materials is due, in part, to the development of more readily available, affordable, and seemingly dependable designs, recent increases in funding levels of some artificial reef programs, and the loss of previously relied-upon supplies of certain secondary use materials. Whether using designed materials or secondary use materials, it is likely that artificial reef development will continue at a pace that early activists would not have predicted, a situation that clearly requires examination and oversight.

## 1.4 National Artificial Reef Plan

The National Fishing Enhancement Act (Act) was passed by Congress and signed into law in 1984, and brought attention to artificial reefs in a broader context of planning and responsibility than had previously been embraced. The Act called for, among other things, the development of a long term National Artificial Reef Plan (National Plan, Stone 1985). The National Marine Fisheries Service (NMFS) was given the lead in the development of the National Plan, which was completed and adopted in 1985. One of the most important sections of the National Plan discusses general criteria for materials that are to be used in the development of artificial reefs, including function, compatibility, durability and stability, and availability.

Each of the four criteria described below is vital when considering the use of any material for artificial reef application. Selecting a material because it meets one or two of the criteria will most likely result in a less-than-successful effort. Materials should be selected because they help achieve the primary goal for a reef project, generally creating habitat for marine fish and invertebrate organisms. Taking the below criteria into consideration, cost and availability of materials are also important factors in determining what materials to use. Materials that are available but are not cost-effective are of limited value to a program. Materials that are inexpensive but scarce make artificial reef development difficult. The right combination of availability and affordability is critical for cost-effective artificial reef development and management.

- Function

This criterion is related to how well a specific material functions in attracting and holding aquatic organisms. It is important that a material provide habitat for small organisms, attaching epifauna, and larger species that are important to recreational and commercial fisheries. If it is known that specific materials do not provide suitable habitat for the establishment of marine communities, or do not support the goal for which an artificial reef is being developed, the function of that material should be evaluated and alternatives considered.

- Compatibility

Compatibility of materials with the marine environment is essential to developing a successful artificial reef. When there are documented environmental risks associated with using a specific material, those risks should be known, and steps taken to minimize such risks. If the risks outweigh the other criteria, or minimizing the risks becomes too expensive, alternative materials should be considered. In the case of new materials with unknown risks, it is important that an environmental assessment be performed to determine the risks.

- Durability

The marine environment is, at best, hostile to man-made materials. Therefore, artificial reef materials should be selected for their resistance to the chemical and physical forces that will be in constant action in the marine environment. Durability is specifically related to how long a material will last in the marine environment in a form that will maintain its function and compatibility.

- Stability

Stability is related to a material remaining in its original configuration and on the permitted site. This is especially important when artificial reefs are subjected to strong storm events, such as hurricanes. If a material is not stable, alternative materials should be considered.

### 1.5 Gulf and Atlantic States Marine Fisheries Commissions

The Gulf States Marine Fisheries Commission (GSMFC), and the Atlantic States Marine Fisheries Commission (ASMFC), provide artificial reef coordination for member states. The Commissions' Artificial Reef programs take joint action to establish programs, policies, and recommendations regarding issues related to artificial reefs, marine fisheries and the environment in the Gulf of Mexico and Atlantic Coast. Information on these two Commissions, as well as copies of Commission materials related to artificial reefs, are available from the GSMFC and ASMFC web sites at www.gsmfc.org and www.asmfc.org.

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## 2.0 DISCUSSION OF MATERIALS

Beyond the general guidelines that artificial reefs should create no hazard to navigation or the marine environment, materials used to develop artificial reefs should not create the potential to trap divers or marine vertebrates.

### 2.1 CONCRETE

<u>Overview</u>

Concrete, either in fabricated units specifically designed for artificial reefs, imperfect concrete manufactured products such as culvert, or rubble from razed buildings, roadways, or bridges, has a demonstrated high success rate as artificial reef material in both marine and estuarine environments. The primary reasons for this high rate of success are the strong similarity of most concrete to naturally occurring limestone rock, as well as its durability and stability in reef applications.

Concrete is defined as a hard, strong building material made by mixing a cementing material (commonly Portland cement) and a mineral aggregate with sufficient water to cause the material to set and bind. Portland cement is largely made from lime, a component of limestone which, itself, is comprised primarily of calcium carbonate, the substance of which coral reefs are made. Portland cement falls into five classes, as designated by the American Society of Testing Materials in the Designation Standard Specifications for Portland cement. Marine applications of concrete under load-bearing conditions, conditions of repeated wetting and drying, and conditions of periodic freezing and thawing, such as bridge spans, require at least Type II Portland cement. Cement types II-V are resistant to the sulfates and other chemicals in sea water which can attack and break down concrete made with Type I concrete. Although concrete materials of opportunity used for reef building (such as culvert, bridge decking or demolition debris) are often made of Type I concrete, these materials perform very well and have a much longer lifespan as reef materials than might be expected because they are not load-bearing, are not subjected to structural stresses, and are not repeatedly being wetted and dried. Another factor influencing the longevity of Type I concrete in seawater is the ratio of water-to-cement used in the manufacture of the product. If this ratio is low enough, the performance of concrete Types I, II and V in seawater become much more similar because the permeability of the resulting concrete is much lower, and less seawater enters the structure of the concrete. Most culvert and other imperfect manufactured concrete materials are made with Type I concrete, but a very low water-to-cement ratio is used. This produces high early strength of the concrete, an asset in the manufacturing process, and produces an impermeable concrete which will resist chemical attack in use. These characteristics make it resistant to the effects of seawater exposure as well.

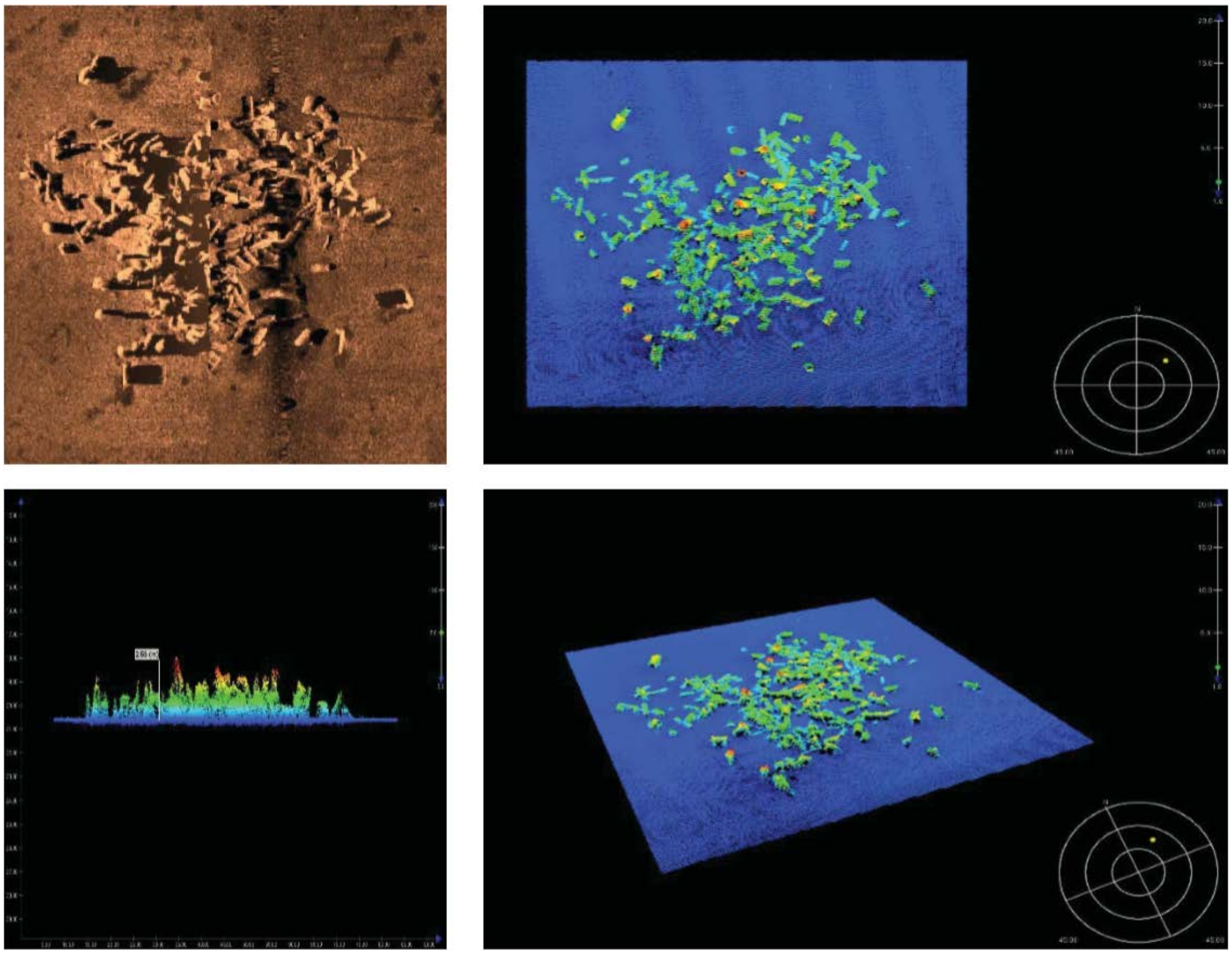
Lime (calcium hydroxide) in "green" or uncured cement may have surface pH levels of 10 to 11, which is significantly more basic than seawater, which has a pH of 8.3. This can make the surface of uncured concrete toxic to invertebrate organisms for 3 to 12 months. Repurposed concrete (carbonated concrete) has a pH of 8.5 which is closer to seawater (Rissman 2018). The majority of concrete used in reef applications, however, is not in the “green” or uncured form. Most imperfect culvert, bridge or road decking or demolition debris has aged and cured for many months or years prior to deployment as reefs, allowing immediate and rapid colonization of epifaunal communities. For example, an estuarine reef in Delaware Bay made from concrete culvert exhibited biomass and species diversity equal to that of the adjacent infaunal community less than two months after deployment.

Research and development studies conducted by the Portland Cement Association have characterized the long-term performance of concrete exposed to seawater (Stark 1995). Where freezing and thawing is not an issue, as is the case with reef materials, the report concludes "Based on the 32 to 34 year performance observations… All concretes exhibited a high level of durability in seawater exposure, regardless of ASTM type of Portland cement. The ratio of water to total cementitious material and quantity of air entrainment and pozzolans appears to be of little or no significance in the observed durability of concrete." Other studies have tested strength of concrete in seawater over a 30-50 year period. In all tests, concrete of various types continued to gain compressive strength which continued to increase over the period of observation (Portland Cement Association, personal communication). This increase in strength is due to the continuing hydration of the cement on a molecular level. The duration of these studies has not been sufficient to measure how long this strengthening process may continue, but estimates range from many decades to hundreds of years.

Concrete materials have been in use as artificial reef structure in the US for over 60 years and are currently used by nearly every state-sponsored artificial reef program. One of the earliest recorded uses of concrete as artificial reef material was by the California Department of Fish and Game, which placed prefabricated concrete box structures as reefs between 1958 and 1960. Surveys during the first two years following deployment found a strong trend for fish to gather around these box reefs (Carlisle, et al. 1964). Concrete rubble has been used repeatedly to build reefs off southern California ever since. One of the largest artificial reefs off the California coastline, the Bolsa Chica Artificial Reef off Orange County, created in 1986, consists of 160,000 tons of concrete rubble, with a footprint of approximately 30 acres. This reef supports much of the commercial passenger fishing boat industry operating out of Los Angeles and Long Beach Harbors during several months of the year (Dennis Bedford, personal communication).

Other early uses of concrete material include the use of concrete culvert pipe off Alabama and Texas beginning in 1962 (Martinez 1964, Walter Tatum, personal communication). Due to the success of these early reefs, both states have continued the use of concrete material for reef building into the present with both successes and failures. Side-scan sonar surveys of reefs constructed of concrete pipe, conducted by a Naval Reserve Mine Sweeping Unit for the Texas Parks and Wildlife Department (TPWD), revealed that some clusters of pipe were visible with a four-foot profile, while others were covered with mud and no longer visible at all (TPWD Unpublished Data, Jan Culbertson, personal communication) illustrating the importance of determining bottom type before placing materials of this size and weight.

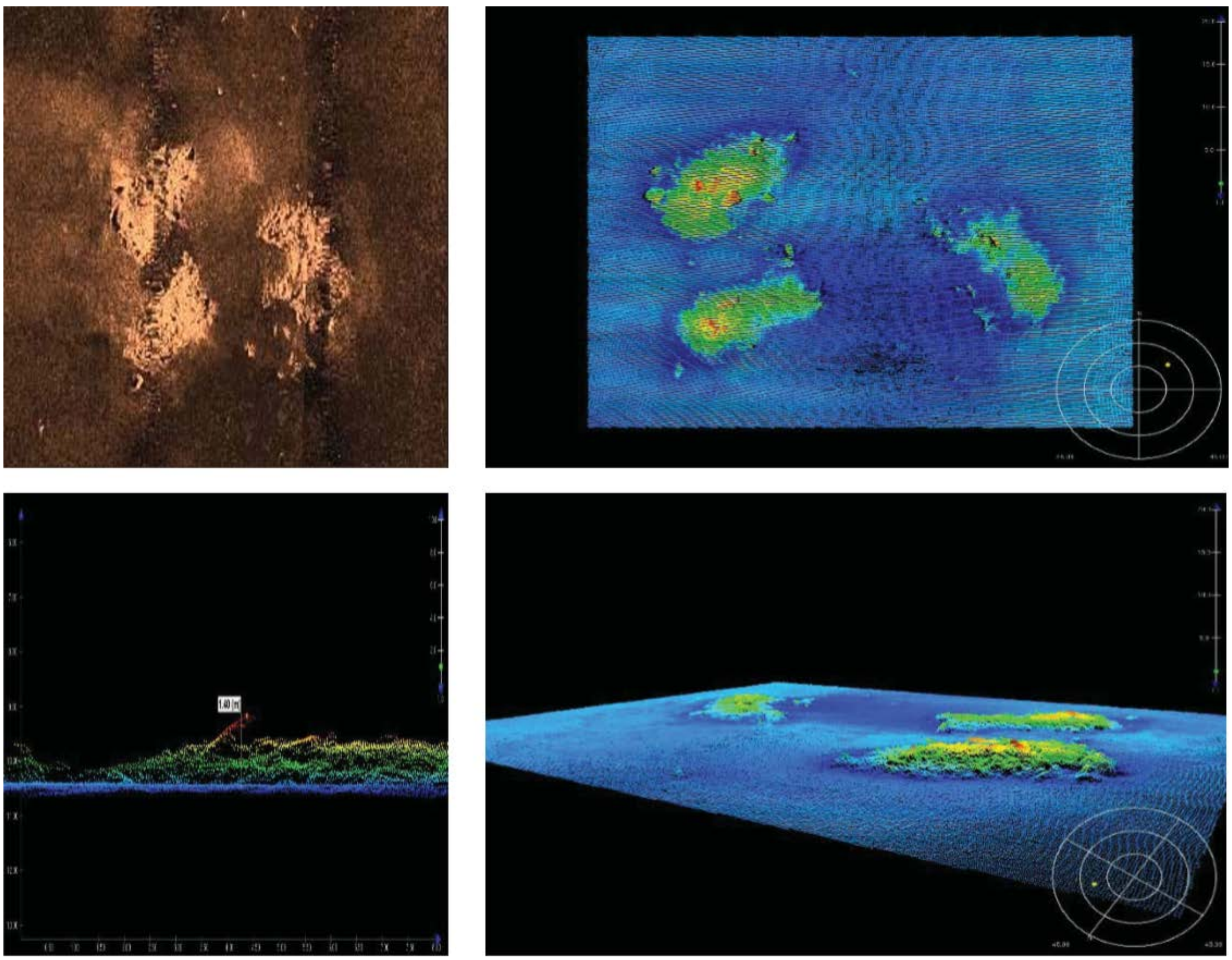
The importance of assessing bottom type when using concrete reef materials has also been demonstrated in Mississippi where concrete rubble has been deployed in over 100 locations since 1988. These deployment sites include nearshore waters 0.25 miles from the mainland in approximately eight feet of water, to sites approximately 30 miles offshore in eighty feet of water. Concrete rubble sizes vary from six inches to ten feet. Side-scan sonar was utilized to evaluate stability of most of the concrete rubble deployments. In most instances, concrete rubble has proven to be a very reliable reef material, with no movement and very little subsidence. However, in 1996, four barge loads of rubble deployed in a near-shore area, which was mined for sand for beach re-nourishment to a depth of fifteen feet, subsided very quickly. Three barge loads of concrete rubble deployed offshore, 3.5 miles south of East Ship Island, could not be detected during a side-scan sonar survey. The bottom on this particular reef site (FH-5) consists of silty clay, and it is assumed that this material also subsided.



Concrete Culverts deployed in 2015 off the coast of Mississippi in 68 feet of water with almost nine-foot profile (David Evans and Associates, Inc. 2016).

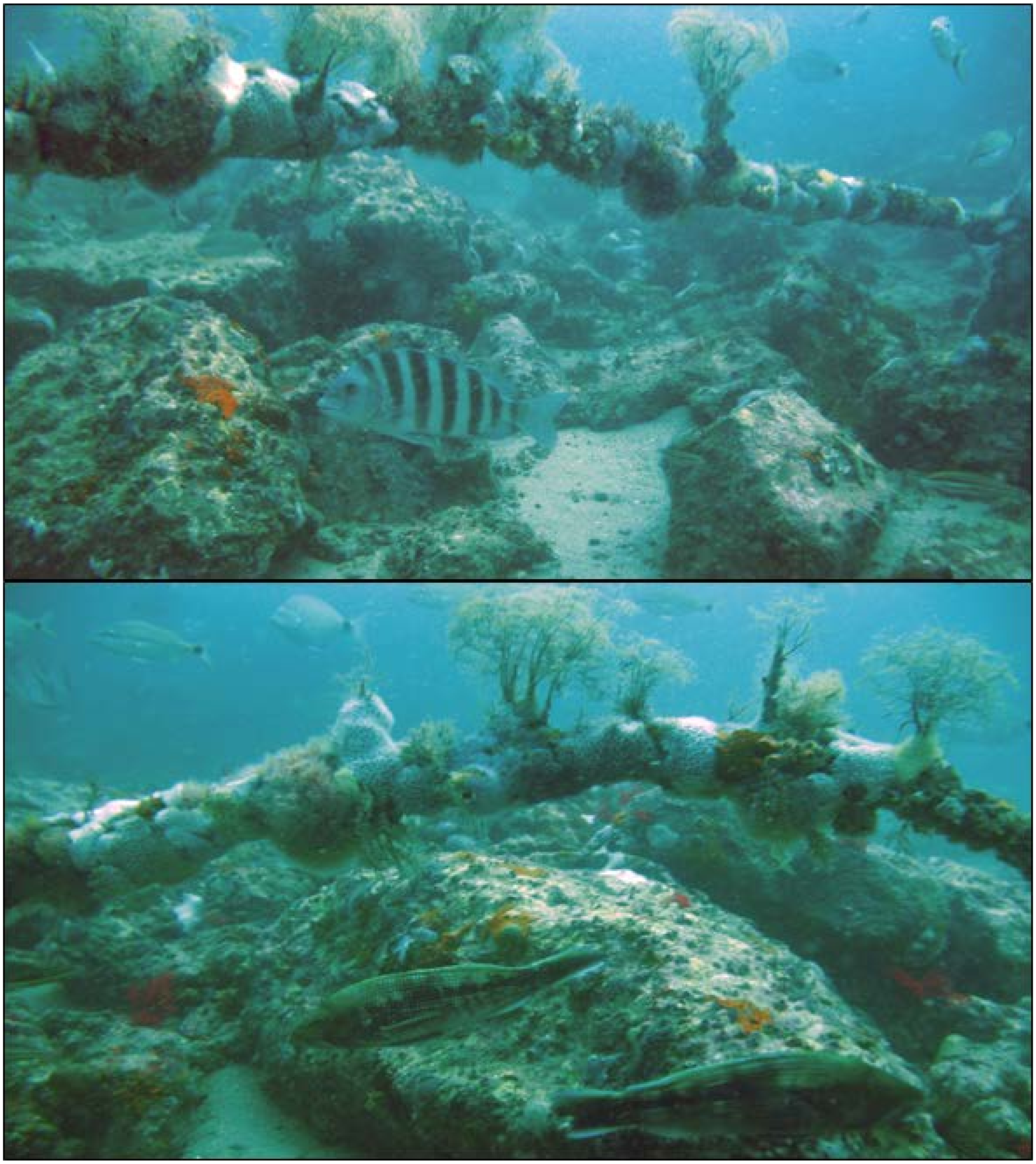
To counter the problem of subsidence, the state of New Jersey has placed many barge loads of concrete rubble at the same location in an attempt to facilitate stacking and increase profile. New Jersey's experience is that concrete provides an effective base for fouling community growth, and an intricate maze of hiding places for fish and large crustaceans. Georgia has also had success increasing reef profiles by stacking concrete rubble, culvert, boxes, and power poles, and decreasing sedimentation on low relief concrete materials by grouping them in clusters versus at single locations.

Concrete piles are the most important reef material for Delaware Bay, with over 90 large patch reefs deployed. Each patch reef is created by pushing approximately 1,000 tons of concrete off an anchored deck barge. The resulting pile of concrete is from 5 to 15 feet in vertical relief. Piling the material inhibits scouring and subsidence. Concrete placed on sand generally settles slightly during the first year and remains stable thereafter. Culvert in piles has excellent complexity and high surface area. Monitoring of Delaware's concrete patch reefs has shown a 50 to 100 fold increase in invertebrate biomass, compared with the natural bottom. Concrete reefs in Delaware support tautog, and provide habitat for juvenile seabass. High profile reefs attract baitfish and species such as weakfish, bluefish, striped bass, and summer flounder.



Concrete rubble deployed off the coast of Mississippi for several years in 35 feet of water still has almost 3.5 feet of profile (David Evans and Associates, Inc. 2016).

One of the largest reef construction projects undertaken in this country utilizing concrete rubble occurred in South Carolina during 2005 and 2006. The demolition of two adjacent highway bridges over the Cooper River in Charleston County generated over 250,000 tons of concrete rubble (Martore, 2003). Using both hopper barges and deck barges, over 50 separate offshore trips placed the material on 12 different reef sites ranging from 30 to 105 feet in depth. Subsequent monitoring at these sites has revealed tremendous invertebrate colonization and growth with diverse and populous fish assemblages in a very natural looking landscape.



Cooper River bridge rubble reefs deployed off the South Carolina coast in 2005 and 2006. Photo Credit SCDNR.

One potential problem with the use of scrap or surplus concrete products is the presence of coal combustion fly ash in many manufactured concrete products (see section 2.11.2, Ash Byproducts). Fly ash is used in concrete production to enhance compressive strength, reduce permeability, increase resistance to sulphate attack, reduce heat of hydration, increase resistance to alkali-silica reactivity, and lower costs (Federal Highway Administration 1995). Fly ash can be used to replace cement in a concrete mix, and serves to combine with an activator such as lime or Portland cement to produce a cementitious material. The coal source of fly ash in concrete products available for reef projects is often unknown. Florida alone, where concrete culvert constitutes the most frequently used concrete material for offshore reefs (Jon Dodrill, personal communication), has several coal-burning plant operations providing a source of fly ash to the construction industry. The hazards of heavy metal leachates from fly ash vary with the coal source and treatment process. For this reason, every effort should be made when using scrap concrete to determine the presence and source of fly ash and avoid coal combustion fly ash when possible.

Concrete manufactured with cement have carbonization qualities that depend on the type and application (Kjellsen et al 2005, Engelsen et al 2005, Bambroo et al 2017, Rissman 2018). Absorption rates of carbon dioxide can vary from 10mm in six months to 60mm in 100 years for untreated concrete in an exposed environment (Rissman 2018). The water to cement ratio is the limiting factor in the carbon dioxide uptake rate (Engelsen 2005). Concrete forms can be expected to have a service life of 40 to 100 years of which carbon dioxide can be absorbed (Kjellsen et al 2005, Rissman 2018). If the concrete is converted to a recycled concrete aggregate the rate of carbon uptake is increased and particles of 1 to 10 mm had the greatest volume of carbonization due to the exposed surface area to volume ratio (Kjellsen et al 2005). The carbonization process is greatly reduced underwater (Kjellsen et al 2005) but repurposing of concrete structures or recycled aggregates as reefs act as carbon sinks. Globally, one third of the cement processing emissions are reabsorbed by the concrete within the first two years and this increases to forty-five percent over two decades.

Over the past 20 years, the use of specially designed, fabricated concrete products has increased exponentially in artificial reef construction nationwide. Concrete habitat modules can now be designed for specific uses, life history stages, or water depths, and allow for the use of specific aggregates or additives. Some of the designs currently in use include balls, boxes, pyramids, cones, tetrahedrons, X-shapes, and Z-shapes. For more information on these products, see section 2.7 Designed Structures.

<u>Benefits</u>

- Artificial reef projects using bridge or roadway rubble can often be financed directly by the state Department of Transportation as a cost-effective way to manage the material.

- Concrete materials are extremely compatible with the marine environment.

- Concrete is highly durable, stable, and readily available.

- The flexibility to cast concrete into a great variety of forms makes the material ideal for developing prefabricated units.

- Concrete provides excellent surfaces and habitat for the settlement and growth of encrusting or fouling organisms, which in turn provide forage and refuge for other invertebrates and fish.

Drawbacks

- A major drawback with the use of concrete material is its heavy weight and the subsequent need for heavy equipment to handle it. This increases costs for landside transportation and loading and transport at sea.

- Deployment of large concrete pieces or prefabricated units requires heavy equipment at sea which is hazardous and expensive. Another drawback related to the weight of concrete materials is the potential for subsidence into the bottom.

Considerations

- Concrete rubble from parking lots, buildings, or other sources may have other materials mixed in with it. Examples include dirt, plastic sheeting (moisture barrier), building materials (wood, fiberglass, etc.), among others. Loads of concrete rubble should be inspected for such associated, undesirable materials prior to deployment.

- To enhance durability, use concrete materials which have Type II or greater Portland cement as the binding agent. Type II concrete is also preferable for designed structures.

- Some scrap concrete may contain fly or other combustion ash, thus ash laden material could be inadvertently deployed.

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## 2.2 STEEL HULLED VESSELS

### Overview

Vessels (or ships) have been used as artificial reef material in marine environments worldwide for years. Ships are durable and stable materials that form complex habitats that enhance marine productivity (NOAA, 2007). With the lack of natural hard substrate in the Gulf of Mexico off shore of Texas, and the steadily increasing popularity of sport diving and fishing, the demand for increased marine habitat make the use of ships as artificial reefs a highly attractive option. Benefits of using ships as artificial reefs include: 1.) social and economic benefits to the local community through the recreational/charter fishing and diving industry; 2.) vessels have life spans as reefs that can exceed 50 years; 3.) vessels attract both pelagic and demersal fishes due to high vertical profiles; 4.) vessels have a heritage of popularity among fishermen and fisheries managers; and 5.) dependent on location, vessels can hold a large biomass of commercially and recreationally important fish species.

In the United States, scrap materials of opportunity, deployed without assembly or much modification, still account for a large portion of reef construction materials. However, vessels have also served as major components of most state artificial reef programs. Where available, and where depth conditions allow for deployment, vessels remain an important reef material to many reef managers, particularly on the Atlantic coast (Grove et al. 1991). The earliest record of intentionally sinking vessels for artificial reef fishing is 1935 when four vessels were sunk by the Cape May Wildwood Party Boat Association (Stone 1974). Dozens of steel-hulled ships sunk in coastal continental shelf waters along the Atlantic and Gulf Coasts during WWII still provide commercial and recreational fishing opportunities and diving enjoyment more than 70 years later.

Vessels intentionally sunk (reefed) by artificial reef programs or diving/fishing groups are numerous and vary in size and complexity. Types of vessels have ranged from small shrimp and pleasure boats, to barges, to large military ships. Table 2.2.1 below provides some insight into vessel usage as reefs by some state governments:

Table 2.2.1. Number of large steel-hulled vessels (> 150ft) for some State Artificial Reef Programs.

| STATE | LARGE VESSELS (>150ft) | ALL VESSELS | MIN LENGTH (ft) (all vessels) | MAX LENGTH (ft) (all vessels) | WATER DEPTH (Range) | REPORTED COST (prep/reefing) |
|---|---|---|---|---|---|---|
| North Carolina | 25 | 83 | 28 | 459 | 13-160 | (6) |
| South Carolina | 12(3) | 313 | 145(4) | 460 | 45-120 | $0-$100,000 |
| Florida (Atlantic) | 139 | 326(1) | 30 | 615 | 15-458 | $870-$8.6m |
| Florida (Gulf) | 26 | 176(2) | 30 | 888 | 12-212 | $2,850-$21m |
| Alabama | 8 | 27(5) | (7) | 270 | 36-127 | $0-$970,000 |
| Mississippi | 13 | 53 | 35 | 408 | 31-136 | (6) |
| Texas | 17 | 27 | 46 | 572 | 38-136 | $5,000-$4m |

Notes: (1) Includes FL 7 wood, 7 concrete, and 2 plastic vessels. (2) Includes FL 1 wood, 5 concrete, and 3 plastic vessels. (3) SC numbers are approximate; they report 300 additional vessels of all sizes up to 300ft in length. (4) From 12 reported large vessels. (5) AL includes 1 concrete and 8 wood vessels, and 2 dry docks. (6) None given. (7) Unknown.

States (and private organizations working through state governments) have obtained vessels in various ways. The U.S. Maritime Administration (MARAD) has a process in which state governments can apply for vessels which have been designated for disposal, and the U.S. Navy has a similar program managed through the Naval Sea Systems Command. Other methods of obtaining vessels include no-cost donations and direct purchase.

This chapter will highlight the reefing of large vessels (ships over 150ft), but the principles of environmental remediation, reef site environment, and socio-economic impacts apply to all vessels regardless of size. The reefing of large vessels requires extensive planning, cleanup operations, hull modifications, technical sinking methods (explosives vs. non-explosives), and other factors that are outside of the scope of this chapter. It is our hope that the information presented here will give the reader a general background on reefing ships by highlighting a few state examples.

The Early Years - Large Military Vessel Procurement through MARAD

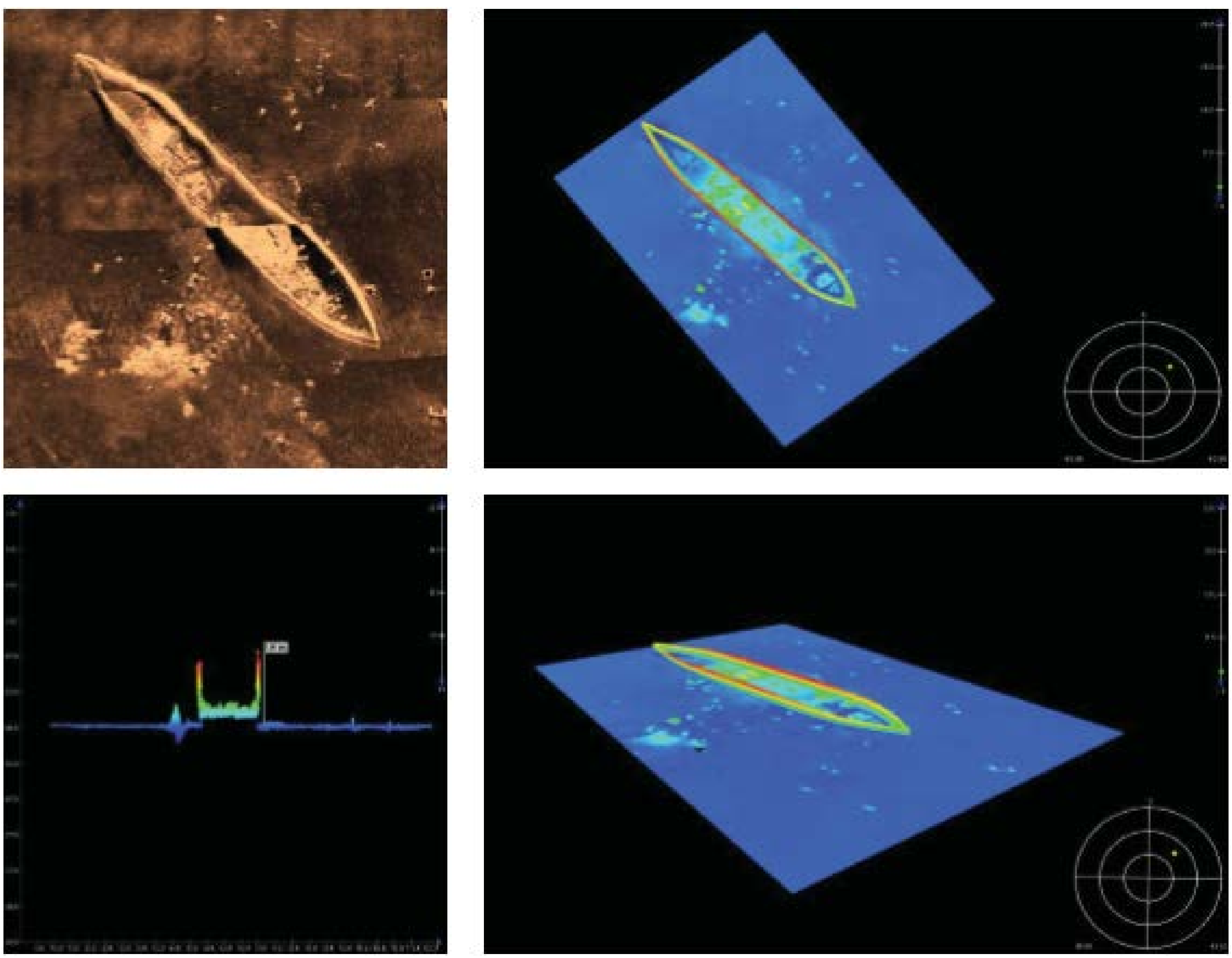
WWII Liberty, Victory, and other USN Ships

The first governmental efforts to provide ships as artificial reefs began with the Liberty Ship Program. Liberty ships were intended to substantially augment the U.S. merchant marine fleets to transport all types of solid cargo to Allied forces worldwide during WWII. There were 2,581 Liberty ships mass-produced in production line fashion from component parts shipped to several shipyards within the U.S. These ships were quickly manufactured (welded, not riveted), inexpensively built, slow moving, lightly armed, and expendable.

Liberty ship SS *Addie Bagley Daniels* ready for deployment at Georgia's JY reef in 1975. Photo Credit: GADNR.

After the war, many surviving ships were placed in the MARAD Reserve Fleet across the U.S., where they were maintained for future use or sold for scrap metal. The MARAD maintains the National Defense Reserve Fleet as a ready source of ships for use during national emergencies, and assists in fulfilling its traditional role as the nation's fourth arm of defense in logistically supporting the military when needed. As these vessels get older and their use questionable, they are sold as scrap or donated to organizations as museums or artificial reefs. By the 1970s, there were 36 Liberty Ships available in MARAD fleet reserves in Texas, Alabama, Virginia, and California.

On August 22, 1972, the 92nd U.S. Congress passed the Appropriations Authorization-Maritime Programs Bill. With President Richard Nixon’s signature, it became known as the Liberty Ship Act [Public Law (P.L.) 92-402.] The law provided for the transfer of obsolete MARAD WWII-era Liberty Ships to coastal states for use as artificial reefs. Alabama was the first state to reef a Liberty ship under the Act. Most of these ships were reefed from 1974-78, with 26 (72%) of them sunk along the Gulf coast: Alabama (5), Texas (12), Mississippi (5), and Florida (4) (Texas Coastal and Marine Council 1973, Lukens 1993, Gregg and Murphey 1994). Two other Liberty ships were reefed off the Florida east coast during this period. Arnold et. al (1998) provides a detailed history of how 12 Liberty ships were obtained, cleaned, and reefed in Texas Gulf waters.



Liberty ship hull deployed in 1978 off the coast of Mississippi in 45 feet of water with almost nine-foot profile (David Evans and Associates, Inc. 2016).

The use of Liberty ships as artificial reefs provided a number of state artificial reef programs with their earliest exposure to intergovernmental issues related to getting permits through the U.S. Army Corps of Engineers (USACOE), coordination with state regulatory agencies, and the U.S. Environmental Protection Agency (USEPA), as well as addressing navigational issues with the U.S. Coast Guard (USCG).

In 1984, the Liberty Ship Act was amended by P.L. 98-623 to include noncombatant reserve fleet ships other than the Liberty class for artificial reef construction. Initially most of the nearly 650 WWII-era merchant vessels still available in the early 1970s were Victory class ships. However, relatively few of them were ever secured for use as artificial reefs. Like the Liberty ships before them, most of the Victory class component of the inactive reserve fleet was scrapped. Deployment of Liberty ships virtually ceased from 1978 to 1987. Only six (15%) of 42 Liberty ships and 402 other vessels sunk as reefs (outside of Florida waters) were deployed from 1988 through 1992 (Gregg and Murphey 1994). None were deployed from 1993-2001.

Florida Experience

In Florida, under the amended Liberty Ship Act P.L. 98-623, two 327-foot USCG cutters were sunk in 1987 in the Florida Keys (*Bibb* and *Duane*), and two 460-foot transports (*Rankin* and *Muliphen*) were sunk off Martin and St. Lucie Counties (Southeast Florida) in 1988-89 (Virginia Vail, personal communication).

After several years in which MARAD did not release any ships to a state under the Liberty Ship Act, Florida citizens and government coordinated an effort to obtain one. In July 1995, a group of Floridians, along with the Key Largo - Florida Chamber of Commerce and Monroe County government (Florida Keys), requested assistance from the state of Florida to secure the 510-foot ex-navy Landing Ship Dock, USS *Spiegel Grove* (LSD-32). The ship was to be sunk as an artificial reef off Key Largo, Florida within the Florida Keys National Marine Sanctuary.

USS *Spiegel Grove* (LSD-32) Photo Credit: navsource.org.

The title transfer for the ship from MARAD to the state of Florida (and subsequently to Monroe County through Memorandum of Agreement) was delayed for nearly seven years, until May 30, 2001. Delays revolved around environmental, legal, logistical, administrative, contractor and fiscal issues. On June 13, 2001, the USS *Spiegel Grove* was towed from the James

River Reserve Fleet in Fort Eustis, Virginia to a Virginia ship yard for remediation and hull modifications for reefing.

Following delays stemming from the national disaster of September 11, 2001 (9-11) and switching shipyards and contractors, vessel preparation was completed. Final environmental clearances were received from the USCG, USEPA, the Florida Fish and Wildlife Conservation Commission, and the Florida National Marine Sanctuary. The USS *Spiegel Grove* was towed to Key Largo, Florida and sunk on its permitted site on May 17, 2003, then opened to the public for fishing and diving three weeks later.

Texas Experience

- USTS *Texas Clipper* (1997-2007)

The USTS *Texas Clipper* is towed to its reef site on November 6, 2007 after final remediation and hull modifications.

The first large non-Liberty Ship vessel reefed in Texas was the USTS *Texas Clipper* (*Clipper*). It was chosen for use as an artificial reef and dive attraction because of its historical ties to the state of Texas and Texas A&M University. Built in 1944 as a troop transport ship, it was commissioned as the USS *Queens.* After the war, it was converted into one of the World's first fully air-conditioned ocean liners and renamed the S.S. *Excambion*. It was retired in 1959, and by 1965, taken over by Texas A&M University-Galveston as a maritime training vessel and renamed the

USTS *Texas Clipper*. She was again retired to the MARAD fleet in 1996. At 473 feet long, she has a beam of 66 feet, and stands 81 feet tall from the keel to the top of the upper-most deck.

In 1997, the Texas Artificial Reef Advisory Committee (composed of representatives from academia, oil and fishing industry, conservation groups, diving and fishing groups, and state agencies) proposed to create an artificial reef with the *Clipper*. Texas Parks and Wildlife Department (TPWD) submitted its first application for transfer of the *Clipper* to MARAD in 1999. In the same year, TPWD was awarded a U.S. Fish and Wildlife Service (USFWS) grant to compensate for some of the costs for reefing under the Sport Fish Restoration Program. Due to several MARAD administrative snafus, including changes in key personnel and application procedures, and lost application materials, TPWD resubmitted its application for the ship in 2003. During the time of this second application process, the MARAD and USEPA became increasingly concerned about the levels of Polychlorinated biphenyls (PCBs) found on ships in general, and their disposal in the marine environment. A blue ribbon panel of federal agencies was formed to review PCBs and other hazardous materials onboard ships for use as artificial reefs. The end result was the publication in 2006 of *National Guidance: Best Management Practices for Preparing Vessels Intended to Create Artificial Reefs* (BMP). By this time, TPWD had submitted its third application for the ship.

The USEPA issued a *Conditional Liberty Ship Act Certificate Regarding USTS Texas Clipper* in June 2006, which authorized the State to proceed with its remediation plan. The *Clipper* was finally transferred from MARAD to the State of Texas in October 2006, a process that had taken nine years.

Remediation was conducted for all hazardous and non-hazardous wastes onboard the *Clipper.* The remediation goal was to meet or exceed guidelines in the *National Guidance: Best Management Practices for Preparing Vessels Intended to Create Artificial Reefs* (BMP) (U.S. EPA and MARAD 2006). The BMP gives guidance for remediation of hazardous and non-hazardous materials typically found on vessels intended to be used as artificial reefs. The total amounts of materials removed by type as compared to pre-cleanup estimates are presented in Table 2.2.2.

Table 2.2.2. Total amounts of hazardous and non-hazardous materials remediated from the *Texas Clipper* as compared to pre-cleanup estimates.

| Materials Remediated | Pre-Cleanup Estimate | Quantity Remediated |
|---|---|---|
| Hydrocarbons | (see note 1) | 7,000 gals |
| Oil Sludge | (see note 1) | 7,040 lbs |
| Asbestos | 4,079 yd $^3$ (see note 2) | 1,680 yd $^3$ |
| PCBs (solid) | 130,000 lbs | 72,250 lbs |
| PCBs (liquid) | 2,000 lbs | 4,000 lbs |
| PCB-contaminated paint/sand media | 10,000 lbs (see note 3) | 317,020 lbs |
| Debris and floatables | 1,500 yd $^3$ | 1,410 yd $^3$ |
| Non-hazardous liquid wastes (bilge water, etc.) | 400,000 gals | 330,452 gals |
| Hazardous waste, solids | 5,000 lbs | None Found |
| Hazardous waste, liquids | 1,000 gals | None Found |

Note 1: Included in Non-hazardous liquid wastes amount of 400,000 gallons.
Note 2: TPWD over-estimated this amount due to difficulties in converting linear feet measurements into cubic yards. Through negotiation with the contractor, the bid amount was lowered to 1,680 yd $^3$.
Note 3: This amount was included in the PCBs (solids) amount of 130,000 lbs.


The USTS *Texas Clipper* finally touches bottom in the Gulf of Mexico on November 7, 2007, where she rests on her port side.

After 10 months of remediation and hull modifications, final approval for reefing was granted by the USEPA, MARAD, and the U.S. Fish and Wildlife Service in October 2007. By this time, TPWD faced adverse weather conditions for towing the vessel to its reef location, 17nm off South Padre Island. After a week of weather delays, the ship was towed and reefed on November 7, 2007. However, weather conditions interfered with the contractor's sinking plans, which called for a controlled flooding of the ship's holds by releasing water into the ship at strategic points. Valves were opened and closed to allow the water to level out in the holds. As weather worsened, the contractor opened all the valves and vacated the ship. Swells ranged up to 7 feet as workers scrambled to get off the *Clipper*. The ship listed to port, and a strong wind on its starboard side prevented the ship's holds from flooding evenly. With the strong list, flooding of the holds took much longer than anticipated, by which time the ship had drifted about 0.5nm from its designated deployment zone. The *Clipper* sank on its port side, where she lays today. Most of the work that went into clearing the upper decks for divers was compromised, as she now lays 90 degrees over on its port side in 135ft of water. The *Clipper* remains as a good dive but only technical divers venture inside the ship. A more detailed account of how the *Clipper* was transferred to TPWD, its remediation, and reefing is found in the Afterword of Curley (2011).

Use of non-MARAD Vessels as Artificial Reefs

Although MARAD vessels dominate the vessels over 300 feet in length, vessels of this size intentionally placed as artificial reefs, as of 1994, constituted only 9% of vessel reefs on the Atlantic and Gulf Coasts (Gregg and Murphey 1994). By 2002, this percentage had declined even more dramatically. In Florida, as of April 2003, only seven actively fished shipwrecks, and 19 vessels sunk as artificial reefs out of 487 total publicly fished vessels (5.3%) exceeded 300 feet in length.

Smaller non-MARAD and noncombatant military service craft are occasionally made available to states through the Navy's inactive service craft ship disposal program (Ken Trahan, personal communication). In 2001, Florida sank two decommissioned 135-foot Navy dive tenders (YDTs) off Pensacola that were secured through this program and the GSA surplus property process (Jon Dodrill, personal communication).

Vessel sinkings during the last decade have emphasized smaller vessels obtained outside the MARAD program. Common sources have included vessels available through marine salvage and construction companies, private donations, vessels confiscated by the U.S. Coast Guard, or other types of government surplus property transfers. Gregg and Murphey (1994) reported that 77% of all vessels deployed in the Gulf and Atlantic were 150 feet in length or less, with barges (33%) and landing craft (28%) dominating the list. One hundred of 136 landing craft reportedly used as reefs were sunk at one site off Virginia, and comprise most of the 130 vessels, including six Liberty Ships, which that state has deployed (Mike Meier, personal communication). Gregg and Murphey (1994) summarized data on 666 vessels used as artificial reefs, 414 (87%) of which were steel vessels. They stated that vessel use has been largely restricted to Atlantic States (58%) and the state of Florida (34%) with only 8% of the vessels deployed as reefs off Gulf states (excluding Florida). Louisiana, a state with the most comprehensive "Rigs-to-Reefs" program with 391 decommissioned oil and gas structures, as of 2018 had no vessels in its artificial reef program (Gregg and Murphey 1994) until a single vessel was sunk in 2001 (Rick Kasprzak, personal communication). Although Texas also has a comprehensive "Rigs-to-Reefs" program, there are 12 Liberty Ships sunk as reefs at five separate reef sites. Subsequent Texas reef deployments have utilized smaller vessels. In August 1995, Texas sank a tug boat at the Port Isabel/South Padre Island Reef, followed by a 100-foot Navy surplus dive work barge at this same 70-foot-deep site. Both vessels have provided habitat to numerous reef fish species, including Goliath grouper (TPWD unpublished data 2002). A variety of barges and vessels such as tugboats, trawlers, steel hulled vessels, sail and powerboats, and research vessels have been deployed in Georgia's offshore waters (6 nm to 50 nm) to enhance reef habitat (January Murray, personal communication). Vessels deployed in Georgia are typically 110 feet in length or less, while barges tend to be a bit bigger, less than 250 feet in length. From 1973 to 2007, nineteen tugboats were deployed in water depths ranging from 35 to 130 feet on nine of Georgia's 31 offshore reefs, while 36 barges were deployed between 1977 and 2017 on 14 reefs in water depths ranging from 30 to 170 feet (January Murray, personal communication).

From 1959 through mid-April 2003 in Florida alone, 280 miscellaneous boats and ships, and 173 barges (453 vessels total) ranging in overall length from 36 foot to 610 foot, were intentionally sunk in state and federal waters off 28 coastal counties. An additional 34 ships, boats, and barges noted as wrecks lost through acts of war, accident, or storm events since 1926 are also utilized as fishing and diving sites. This total number of 487 vessels represents 24.6% of the 1,938 public artificial reef records in the Florida Fish and Wildlife Conservation Commission artificial reef database as of April 1, 2003. During the period 1988-92, six east coast states, including North Carolina, Georgia, South Carolina, New Jersey, Maryland, and New York, spent a total of $149,000 on vessel preparation and deployment. During that same time period, only one recorded vessel deployment was reported from the Gulf (excluding Florida), with no expenditure of funds on vessels reported from Alabama, Mississippi, Texas, or Louisiana (Gregg and Murphey 1994).

- The TPWD M/V *Kraken* (2016-2017) Project

In March 2016, TPWD contracted with a private company for the acquisition, modification, cleanup, and reefing of the 371-foot M/V *Kraken*, a general cargo carrier tween deck vessel constructed in 1987. In April 2016, the contractor towed the ship from Trinidad to the Port of Brownsville, were remediation was conducted.

Upon berthing at the Port of Brownsville, the *Kraken* underwent assessments for the presence of asbestos containing materials (ACM), poly-chlorinated biphenyls (PCBs), and other hazardous and non-hazardous wastes. The remediation goal was to meet or exceed guidelines in the *National Guidance: Best Management Practices for Preparing Vessels Intended to Create Artificial Reefs* (BMP) (U.S. EPA and MARAD 2006).


Photo of M/V SCM *Fedra* (pre-M/V *Kraken*), a 371-foot general cargo carrier purchased by TPWD through a contractor.

TPWD environmental consultants verified that all tests were conducted to the state of Texas and federal standards. Since this was a much newer ship than the *Clipper* above, no ACM or PCBs were detected. General cleanup of the vessel was then conducted for all other hazardous and non-hazardous wastes onboard under the direct supervision of TPWD and consultants. TPWD performed a final visual inspection of the ship in November 2016. Overall, environmental remediation included abatement of: 125,585 gallons of hydrocarbons (and associated waste water); 390 cubic yards of debris and floatables; and 9,000 pounds of ammonium sulfate (urea) contaminated material that was discovered in the cargo hold and unknown to the contractor.

TPWD received final approval from the USEPA to reef the ship on November 21, 2016. As with the *Clipper* above, adverse weather and scheduling prevented TPWD from reefing the ship until January 2017. With fair seas, the *Kraken* was towed to its reef site 70nm offshore of Galveston and reefed on January 20, 2017. The contractor used controlled flooding to bring the ship to the bottom, where it lays upright with no list.


The 371 foot merchant vessel *Kraken* was reefed off the Texas coast on January 20, 2017. Photo credit: TPWD

<u>Current Procurement and Preparation Issues Related to Large Military Vessels</u>

- Hazardous Waste Removal Issues

Today P.L. 92-402, formally known as 16 United States Code (U.S.C.) ' 1220 (a)-(d). ' 1220(a), specifies the terms and conditions under which a coastal state has the authority to accept title to a vessel from the United States government, generally with the vessel in an "as is, where is" condition. This phrase has historically had significant monetary and environmental implications that, until the spring of 2003 resulted in limited progress towards reefing MARAD vessels, as reflected by the slow progress made by MARAD vessel sponsors during the 1990s. A brief history of the hazardous waste issues related to military ships is provided below. The following section is not intended to serve as a detailed guideline for the identification, removal, and handling of hazardous waste materials on vessels, but is intended to highlight some of the environmental preparation considerations when dealing with vessels.

- Polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are mixtures of synthetic organic chemicals with the same basic chemical structure and similar physical properties ranging from oily liquids to waxy solids. Due to their non-flammability, chemical stability, high boiling point and electrical insulating properties PCBs were used in hundreds of industrial and commercial applications including electrical, heat transfer, and hydraulic equipment; as plasticizers in paints, plastics, and rubber products; in pigments, dyes, carbonless copy paper and many other applications. More than 1.5 billion pounds of PCBs were manufactured in the United States prior to cessation of production in 1977. (EPA, website: http:/www.epa.gov/opptintr/pcb/). Concerns over the toxicity, bioaccumulation, and persistence in the environment of PCBs led Congress in 1976 to enact §6(e) of the Toxic Substances Control Act (TSCA) that included among other things, prohibitions on the manufacture, processing, and distribution in commerce of PCBs. TSCA legislated management of PCBs in the United States from initial manufacture to disposal. (EPA, website: http://www.epa.gov/opptintr/pcb/).

Prior to 1989, the issue of the possible presence of PCBs as a hazardous waste on military ships or any other vessel sunk as an artificial reef had not been addressed. In 1989, the Navy discovered high levels of PCBs saturating sound dampening felt material during the scrapping of a submarine on the U.S. west coast. This discovery prompted subsequent sampling of other military vessels. In a series of 3,000 tests conducted by the Navy, PCBs, long-lived, carcinogenic substances, of low solubility were found in wiring insulation, paint, gaskets, caulking, plastic and other nonmetallic materials in nearly all of over 100 naval vessels sampled and in service prior to 1977 (when PCBs were banned from use in the U.S.). PCBs, first developed in the late 1920s were used to enhance fire retardant properties of materials, as well as increase flexibility in materials, and were also used throughout U.S. industry and in commerce, including use on civilian vessels like those in the Seattle ferry system (Dennis Rushworth, personal communication). The ship sampling results prompted concern by the EPA that ocean sinking of vessels violated their 2-parts per million PCB threshold. The Navy voluntarily shut down its operational Sink-Ex program (deepwater ship sinking at depths of 6,000 feet or greater during military target practice exercises). Military specifications requiring the use of PCBs could apply to any number of government vessel types especially prior to the late 1970s. This fact, combined with declining scrap steel prices and concerns about environmental and work conditions in overseas ship breaking facilities, resulted in the curtailing of much of the overseas and local ship scrapping, and use of MARAD ships as artificial reefs in the decade of the 1990s. Meanwhile, the MARAD inactive reserve fleets continued to age and expand. In 1994, the ASMFC's Artificial Reef Advisory Committee (ARAC) drafted a statement addressing the issue of surplus military ships and PCB contamination. In the statement, the committee said, "The future of surplus ships as additional artificial reef material has come under a cloud of uncertainty. In 1989, the U.S. Navy discovered PCBs aboard their surplus vessels in levels high enough to cause concern."

The ASMFC ARAC, in its statement, requested from the EPA an assessment of the potential for PCBs to cause environmental and human harm in the marine environment as a result of being present in military vessels used as artificial reefs. The committee also requested that EPA develop standardized inspection and testing procedures to measure on-board levels of PCBs, and determine what constitutes acceptable levels of PCBs in the marine environment. The ASMFC ARAC's position was that "states should continue to operate their programs in an environmentally responsible manner, using surplus ships until the requested EPA standards are adopted." Regardless of the ASMFC ARAC stance, the position of the EPA in the 1990s was that deployment of vessels containing PCBs violated the Clean Water Act (Gregg and Murphey 1994). The EPA position that disallowed any remnant PCBs on vessels sunk in shallow water, effectively terminated MARAD federal ship donation activity for artificial reefs for the next eight years.

In 1995, The EPA's Office of Pollution Prevention, Pesticides and Toxics prepared a technical policy document entitled "Sampling Ships for PCBs Regulated for Disposal," (EPA 1995) that provided an interim method for determining whether PCBs had to be removed from ships. That document was intended for evaluating vessels destined for scrapping to recover metal. The waste and water programs within EPA believed this policy was not appropriate to use as a guide to PCB removal work on vessels to be sunk in shallow water marine environments as artificial reefs. To help address the PCB concern, the South Carolina Marine Artificial Reef Program initiated a study to examine the levels of PCBs found in organisms collected from ex-military ships which had been sunk as artificial reefs. After confirming the presence of PCB-laden materials, fishes and invertebrates were collected from the ship reefs, as well as from natural hard-bottom control sites. Analyses revealed no significant differences in PCB concentrations between any of the sites. In addition, the levels that were detected were well below concentrations deemed hazardous by the FDA (Martore et al. 1997). In the late 1990s, the Navy conducted an assessment of the potential release of PCBs from Navy ships sunk in deep water through the SINKEX program using the ex-*AGERHOLM* as a case study. That study examined the ecological risks of the ex-*AGERHOLM*, a destroyer (DD-862) sunk in 916 m (2750 ft.) of water about 120 nautical miles off the coast of San Diego, CA, in 1982. The results of the study found no evidence of ecological risk to deep-sea benthic, epibenthic, or pelagic communities associated with PCBs-in solid materials onboard the ex-*AGERHOLM* (SPAWAR 2006).

In 2001, the EPA Office of Pollution Prevention, Pesticides, and Toxics program operating under the TSCA, developed additional guidelines that helped address the situation of the Spiegel Grove project that had been languishing for several years awaiting resolution of the PCB issue. Without allowances for some low level of PCBs to remain on military ships proposed to be sunk as artificial reefs, no vessel could be cost-effectively prepared for sinking. In response to this dilemma, the EPA Office of Pollution, Prevention, Pesticides and Toxics program considered use of a military ship to create an artificial reef a "disposal." That is, the original use for which the vessel was intended has terminated. Because vessels contain PCBs that are not an "authorized use", the only current recourse for EPA short of initiating enforcement discretion was to consider the activity of preparing a ship for sinking as a "disposal", whereby minimum acceptable residual PCB levels can be left on board [at levels less than 50 parts per million (ppm)]. EPA cannot without some type of enforcement discretion allow a "continued use" of materials containing substances like PCBs that are not authorized to be left in place in an ongoing use scenario. However, to complicate the situation, the EPA waste and water programs viewed the ship cleaning and sinking activity as a "continued use". Under the disposal scenario the concentration limits of PCBs in materials are limited to less than 50 ppm (40 CFR 761.60, 761.50, 761.30). Under the "continued use" scenario the PCB limits are 2ppm.

- Asbestos

Asbestos is a naturally occurring group of minerals characterized by long silky fibers. Asbestos is only dangerous to human health if it becomes airborne allowing tiny fiber fragments to be inhaled into the lungs. To be a significant health hazard, asbestos fibers must be inhaled at high concentrations over an extended period of time (Health and Safety Web site: www.dehs.umn.edu/ihsd/asbestos/healtheffect.html). The EPA is chiefly concerned with Regulated Asbestos Containing Material (RACM). RACMs are classified as friable asbestos. Nonfriable Asbestos Containing Materials (ACM) category I or II , may be classified as RACM if they have a high probability of being exposed to sanding, grinding, cutting, or abrading (category I) or have a high probability in the case of category II of becoming crushed, pulverized or reduced to powder by the forces exerted on the material in the course of demolition or renovation. (40 CFR Part 61, Subpart M.).

The approach to asbestos inspections on ships in the 1980s and 90s was varied. A U.S. Coast Guard marine safety officer in Florida required removal of asbestos from a ship in 1994, while another in South Carolina did not. The EPA Region 4 inspection criteria for vessels under P.L. 92-402 was to leave the asbestos in place until more information was available on the impact, if any, of asbestos in the marine environment. Elizabeth Stanley, the EPA Director of the Office of Compliance, in a June 9, 1997 letter to Winston Smith, Director of Air, Pesticides and Toxics Management Division, EPA Region IV, stated that sinking of a ship was most reasonably classified as a demolition of a facility under the asbestos National Emission Standard for Hazardous Air Pollutants (NESHAP). The facility or ship is considered to undergo demolition when some event occurs to make a load supporting structural member no longer capable of supporting the load of the facility, or with respect to a vessel, some modification to the ship occurs in preparation for sinking the vessel or causing the vessel to sink. Elizabeth Stanley said, "The owner/operator would need to remove RACM from the ship that may have a high probability of becoming regulated during or after the demolition. Certain asbestos-containing materials may be left in place during the demolition. Nonfriable asbestos-containing material, such as asbestos-containing gaskets, may generally be left in place during the demolition. Additionally, friable material on a facility component that is encased in concrete or other similarly hard material may also be left in place. For example, asbestos in the bulkheads would be allowed to remain in place as long as the bulkheads are not wrecked and the asbestos is not exposed during the demolition. We believe that it is unlikely that this material would be released into the environment. Pipe lagging that is wrapped in cloth or tin would not be an example of encased material. Any encased asbestos that will be exposed by any of the demolition activities would need to be removed prior to the demolition. Category II asbestos-containing material may or may not be left in place. A case-by-case determination would need to be made for these materials….Where there is a question, EPA or the local delegated agency should use sound judgement concerning the fate of the material in question." The current requirements in Florida for state and federally funded reef projects is that an EPA or Florida Department of Environmental Protection (DEP) air quality specialists, or a designated certified consultant with asbestos experience must conduct an asbestos assessment of a vessel prior to sinking. Federal regulations which deal with asbestos are: 40 CFR Part 61.145 Subpart M, and the OSHA regulations in 29 CFR Part 1915.

- Lead

Concerns about the presence of lead in primer coat paints of steel hulled vessels and metal bridge spans have been expressed by reef managers. Both Florida and South Carolina sought guidance on this issue. In a letter written on August 23, 2000 by Roland E. Ferry, Coastal Programs and Nonpoint Source Section, EPA Region 4, to J. Wayne Hall Assistant Environmental Manager, South Carolina Department of Transportation, Mr. Ferry stated, "The agency [EPA] does not consider the lead in paints used on vessels deployed as artificial reefs a significant environmental or human health risk…The lead in the paint should leach at low rates due to the low solubility of lead in seawater and is not expected to cause a significant adverse impact. In addition, the removal of lead based paints may cause greater potential for risk of adverse impact to the environment or human health than if left in place on the structure." On May 1, 2001, Florida artificial reef administrator, Jon Dodrill, contacted Dr. Joseph Sekerke with the Florida Department of Health, Bureau of Environmental Epidemiology. Dr. Sekerke stated that lead paint in a marine environment would have no adverse human effects and that there was no human health risk. He confirmed that lead has low solubility in seawater, and stated that it did not bioaccumulate in fish. While there may be some effect on invertebrate marine organisms that graze directly on the painted surface, he did not believe toxic effects would be transferred as a risk to humans. However, this should not preclude removal of visible concentrations of lead such as lead ballast, shielding and fittings.

- Fuel and Oil Products

The definition of oil under the Clean Water Act is "oil of any kind or in any form including, but not limited to, petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other than dredged spoil" [Clean Water Act, Section 311(a)(1)]. On vessels, it would be possible to encounter one or more refined petroleum products such as gasoline, kerosene, medium to heavy weight fuel oils, lubricating oils, and greases. Crude unrefined oil, synthetic oils, and used or contaminated oils might also be found.

Hazardous waste cleaning standards which seemed appropriate in the early days of MARAD ship sinking may no longer be appropriate based upon current experience. For example, the EPA in the early 1970s developed ship cleaning criteria for Liberty ships secured under P.L. 92-402. One of these criteria were: "The presence of cosmoline on the walls of fuel tanks can be adequately mitigated by filling the tanks with water, and bolting and welding the tank hatches closed. Any tanks that will be ruptured by the explosive charges used to sink the vessel must be free of cosmoline (Source: EPA Region 4, Atlanta Georgia)." The Liberty ship *Joseph L. Meek*, sunk off Escambia County, Florida in 1976, was found 20 years later to be leaking bunker "C" fuel oil from a small corrosion induced leak in a tank that was thought to have been pumped clean, inspected and sealed. This incident cost the Florida Department of Environmental Protection's Emergency Response section $100,000 to address. (Jon Dodrill, personal communication) Liberty ships sunk off Mississippi were associated with oil slicks for several years post deployment, and in fact, the slicks were used as a means by boaters without navigation equipment to locate some of these reefs (Ron Lukens, personal communication). It requires only a few gallons of residual fuel or other petroleum source to create a noticeable oil slick. This was clearly demonstrated by a leaking five gallon fuel container accidentally left on board the *Spiegel Grove* when it sank prematurely off the Florida Keys in 2002. This resulted in a persistent oil sheen on the surface and a Coast Guard mandated lab testing of the petroleum sheen composition with a follow-up multi-day search requiring scores of dives until the can could be located and recovered (David Score, personal communication). These instances, combined with negative publicity received in the case of both Florida scenarios, emphasize the need to thoroughly clean ships of all petroleum products prior to deployment as an artificial reef. The U.S. Coast Guard has the responsibility to inspect all vessels proposed for deployment as artificial reefs to ensure they are free of petroleum products and floatables prior to vessel deployment.

There are other materials of environmental concern to the EPA, state regulatory agencies, reef managers, and the Coast Guard that may be found on vessels. These include, but are not limited to, antifreeze and coolants, sewage/grey water, batteries, fire extinguishing systems, refrigerants and halons, radioactive materials, products containing mercury, loose miscellaneous debris not securely attached to the vessel, including plastics and floatables. All of these items should be removed from the vessel prior to sinking.

Specific direction for PCBs, asbestos, oil and fuel, and other materials of environmental concern removal are outlined in the *National Guidance: Best Management Practices for Preparing Vessels Intended to Create Artificial Reefs* (2006) which was jointly developed by the EPA and MARAD.

<u>MARAD Navy Vessel Cleaning and Preparation Cost Issues</u>

The implications of sampling for and subsequently dealing with hazardous materials in large complex military vessels, is that hazardous waste removal is more involved, and associated vessel preparation costs are considerably greater than what they were in the 1970s. The original Liberty Ships of the 1970s were scrapped to the second deck, salvage efforts more than recovered the cost of the labor, holes were cut in the sides, and they were sunk as little more than very large bathtubs. Under the original MARAD Liberty Ship program, the vessels were accepted by the states in an “as is/where is” condition, at no cost to the federal government. Weighing 3,400 tons, the original Liberty Ships were 441

USS *Oriskany* – Essex Class Aircraft Carrier sunk as an artificial reef 23 miles off the coast of Pensacola. October 16, 2008, 2.5 years after deployment. Photo credit: Florida FWC.

feet long, 57 feet wide, and 80 feet from the top of the stack to the mold line. States recouped cleaning and towing fees by having the salvors pay them to remove the entire superstructure down to specified levels, along with all other items of salvage value. Although the states realized $30,000 to $40,000 in salvage value from each vessel, there were complaints that the Liberty Ships were stripped down to the point that they were glorified bathtubs, without much complexity (Virginia Vail, personal communication).

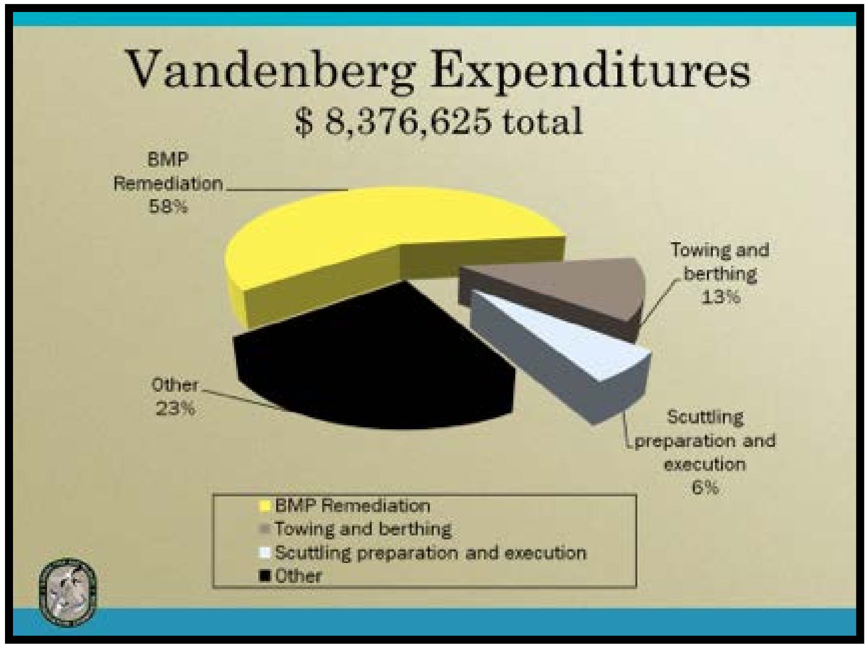
Fifteen years after the last Liberty Ships were deployed, the cost to secure, clean, tow, and sink the 460-foot military transport *Muliphen* off St. Lucie County, Florida, in a largely structurally intact condition, was $118,000 (Stan Blum, personal communication). Salvors involved complained to the Department of Defense about not being able to benefit from the more complete stripping of the vessel (Virginia Vail, personal communication).


USS *Arthur W. Radford* in the Mediterranean Sea, circa November 27, 2002. Military.wikia.com. The Radford was sunk off the coast of Delaware on August 10, 2011 as an artificial reef.

Today's large military and civilian vessels have cleaning and preparation requirements which need to be evaluated in a cost-benefit analysis of their use as artificial reefs. Additionally, there is increased demand on the part of the diving industry to leave vessels externally intact in physical appearance to the extent possible. Estimates to cover all costs associated with hiring consultants, securing, permits, yard space, cleaning, hazardous waste removal and disposal, towing, sinking, for a military vessel over 500 feet long in 2018 range from 1-23.6 million dollars per vessel. For example, the USS *Spiegel Grove* as only one component of its cleaning process had 102 diesel, aviation fuel, lubricant, ballast, and sewage tanks which had to be individually cleaned, inspected and temporarily resealed. During the four months of cleaning, more than a dozen inspections by the U.S. Coast Guard Marine Safety Officer were required (Jason Walker, personal communication).

The EPA mandated that all wiring from the USS *Spiegel Grove* be removed due to concerns about PCBs in the insulation. The wiring alone removed from the ship exceeded 100,000 pounds, though the removal, temporary storage, and shipment to a hazardous waste disposal site accounted for only about 4% of the overall vessel cleanup and preparation cost, and precluded having to conduct an extensive amount of PCB sampling in a cable and wiring system thousands of yards long (Tim Mullane, personal communication). Even though an agency may receive a ship from the U.S.

Maritime Administration for free, the subsequent individual ship cost estimates as projected in 2018 substantially exceed the annual operating budget of a typical state artificial reef program. Without major private, local government financing, fund raising efforts as occurred with the *Spiegel Grove* and *Hoyt Vandenberg*, or a federal plan to subsidize artificial reef deployments of federal ships, the expense involved in start-to-finish environmentally-friendly cleanup and deployment of large military vessels will be prohibitively expensive for most state reef programs.




Breakdown of the *Hoyt Vandenberg* reefing expenditures. (Florida FWC).

As of 2001, the Navy and MARAD presided over a fleet of approximately 450 retired naval combatant and MARAD noncombatant ships. An estimated 358 of these ships will have to be disposed of by means other than donations as museums, in military sinking exercises (Sink-Ex), or overseas sales, or leases. The remaining inactive ships constituted of a diverse range of vessel classes. They included merchant ships (145), auxiliary vessels (74), amphibious ships (31), surface combatants (71), mine warfare vessels (7), miscellaneous ships (19), submarines (3) and even aircraft carriers (8) (Hess et al. 2001). A cost analysis and feasibility study prepared for the Navy by the Rand Corporation (Hess et al. 2001) recommended disposal via "reefing" (sinking ships on artificial reef sites) off of U.S. coasts as a viable, but previously unexplored, cost-effective alternative to subsidized shore-based stateside scrapping and recycling or long-term storage. Both the Navy and MARAD were interested in this approach, and contracted with the Rand Corporation to determine what legislative and procedural initiatives needed to be identified to make this a viable option.

By 2001, the Navy and MARAD recognized the impediments of making "as is/where is" vessel transfers to state artificial reef programs contingent upon no cost to the federal government. After Congress made the decision not to lift the moratorium on transfer of vessels overseas for scrapping purposes. In March 2003, MARAD announced to the coastal state artificial reef programs and the interstate marine fisheries

| | |
|---|---|
| Ship remediation (BMP-related) | $8.28M |
| Flight deck remediation (BMP-related) | $3.61M |
| PCB model and risk assessment development (BMP-related) | $3.74M |
| Towing and berthing | $3.07M |
| Scuttling preparation and execution | $4.90M |
| Ship clean-up time | 12 months |
| Project duration | 3 years (FY03 through FY06) |

Ex-USS *Oriskany* total project costs. EPA & MARAD 2006 commissions that it had been able to secure legislative authority in 2002 to provide limited federal funding in the form of grants to states to assist them with the cleaning, preparation, towing, and sinking of requested MARAD vessels for artificial reefs.


USS *Oriskany* – Essex Class Aircraft Carrier being sunk as an artificial reef 23 miles off the coast of Pensacola, November 19, 2009, 3.5 years after deployment. Photo credit: Florida FWC.

16 USC 1220c-1(a) states: "The Secretary, subject to the availability of appropriations, may provide, to any state to which an obsolete ship is transferred under this Act, financial assistance to prepare the ship for use as an artificial reef, including for: (1) environmental remediation; (2) towing; and (3) sinking." Subsidized domestic scrapping of MARAD vessels would also continue, and expectations were that MARAD grants to assist the preparation of vessels as artificial reefs would be less than the cost to MARAD to scrap the vessel. MARAD also expressed a commitment to coordinate with other federal agencies to streamline the vessel donation process for artificial reefs (Kurt Michanczyk and Elizabeth Frese, personal communications).

In April 2003, the Naval Sea Services Command, in cooperation with MARAD, announced that an 820-foot long, 34,881 ton Korean War/Viet Nam-era ex-Navy aircraft carrier, USS *Oriskany* (CVA 34) would be available as an artificial reef pilot project through a turnkey operation where MARAD received and processed the project application, and the Navy covered the financial costs of all aspects of cleaning, preparation, towing, and sinking at a permitted site designated by the selected state. Federal funds set aside for this project were approximately 2.5 million dollars (Ken Trahan, personal communication).

Hazardous Materials Remediation and Vessel Modifications

The hazardous materials encountered, and vessel modifications needed to properly prepare a ship for reefing will vary greatly from one ship to another. However, regardless of the vessel selected, it should always be the goal of the reefing project to meet or exceed the standards established in the BMPs (U.S. EPA and MARAD 2006). To help increase the awareness of reef program managers about the types of waste streams that can be encountered during a ship reefing project, one specific ship project carried out by the state of Texas is outlined below as an example.

The scope of the project was to clean, prepare, and sink the 473-foot ship *Texas Clipper* to provide a new artificial reef to enhance fishery resources in the Gulf of Mexico offshore of Texas. The ship was cleaned of debris, loose items, and hazardous materials to a level that met or exceeded BMP guidelines, and complies with health and safety statutes and regulations as set forth by the USEPA, MARAD, and the State of Texas.

The Texas Artificial Reef Program was responsible for preparing the ship in accordance with the BMP for remediation of materials including, but not limited to: fuels and oil, asbestos, polychlorinated biphenyls (PCBs), paints, other materials of environmental concern (e.g., mercury, refrigerants), and debris (e.g., vessel debris, floatable, introduced material).

All loose paint was removed. All asbestos and electrical wiring were removed. All machinery, nonferrous materials of salvageable quality, and pollutants were removed or cleaned, and left in place. The following waste streams were tested, abated and remediated:

- Oils, Fuels and Greases;
- Chromate Ballast Water;
- Waste Water Collection;
- Asbestos;
- Polychlorinated Biphenyls including:
    - All liquid PCB-containing components
    - All solid PCB-containing materials
    - All paint and/or painted surfaces which tested positive for PCBs in concentrations $\geq$ 50 ppm;
- Paints including:
    - All loose paint from walls, bulkheads, decks and hull
    - Sweep and dispose of loose paint on deck surfaces;
- Other Hazardous Materials:
    - Batteries
    - Refrigerants
    - Halons
    - Mercury
    - Antifreeze
    - Coolants
    - Fire extinguishing agents
    - Black and gray water from tanks and piping;
- Solids/Debris/Floatables

(Any loose items and materials which may float or be transported into the water column at sinking including, but not limited to):

- Trash
- Wood scraps
- Light bulbs
- Floor tiles
- Carpet and padding
- A/C equipment
- Furniture
- Ductwork
- Wood paneling
- Ceiling tiles
- Plate glass
- Machinery
- Items left from remediation

Socio-economic Impacts of Vessels

The steadily increasing popularity of sport diving over the past 25 years, combined with the increase in dive charter operations to meet demand, has been a major driving force in some local communities behind the procurement of vessels to sink as artificial reefs. Murray and Betz (1991), in a survey of 721 divers, commercial fishermen, sport fishermen, and environmentalists in Texas, North Carolina, and Florida, reported that 54.2% of all diving trips were to artificial reefs (with emphasis on vessels), versus only 15.5% of all recreational fishing trips. Additionally, 66.7% of all respondents identified as divers stated a preference for ships and barges over other artificial reef sites. The southeast Florida counties of Miami-Dade, Broward, Palm Beach and Monroe have the highest concentration of vessels sunk as artificial reefs on the U.S. east coast or Gulf of Mexico. Off these counties, 9.81 million diving and fishing days were spent on or around artificial reefs in 2001, with vessels comprising an important component of the sites visited (Hazen and Sawyer Associates, 2001).

The value of vessels as dive sites to some individual charter dive boat operators is substantial. In Beaufort, North Carolina, a single, multiple-boat dive charter operation reported an annual gross of $250,000 from trips targeting shipwrecks (Kurtis Gregg, personal communication). In April 1995, the cost to move a re-floated 150-foot dredge barge, cleaned and towed from South Carolina to southeast Florida and sunk as an artificial reef, was $100,000 (Ken Banks, personal communication). However, the annual value of a single ship sunk as a reef to the diving community in Broward County, Florida in 1995 was estimated at $144,000 (Ken Banks, personal communication). In Broward County alone, the economic contribution in sales from 107 artificial reefs comprised of 18 barges and 52 boats and ships, was an estimated $961 million in 2001 (Hazen and Sawyer Associates 2001). Data from post card respondents in a 1990 diving survey relating to South Carolina dive sites indicated that of 2,406 dives reported, 1,294 were on naturally occurring shipwrecks (54%), and 921 (38%) were on artificial reefs, which included some intentionally placed shipwrecks. Only 8% of the reported dives were on live bottom areas or rock jetties (Rhodes et al. 1992).

Utilization of vessels as diver attractants, a recreational activity that has some associated level of risk, should be carefully evaluated by managers. A reef program manager cannot control the human variables of physical condition of the diver, training level and experience, the diver's realistic assessment of his personal limitations, operating status of dive gear, prior dives during the day, competency of top-side support, and proper pre-dive planning. In planning a vessel sinking project to maximize diver safety, the program manager should assess the expected physical factors anticipated to be encountered with a prospective ship reefing site. Water temperature, sea state, current velocity , depth, visibility, vessel orientation, potential for wreck penetration, and distance from shore may all play an interactive role in impacting the challenge level/safety of a dive. Injuries and fatalities on wrecks are low in relation to the number of divers visiting these sites.

Recreational fishing effort, in contrast to diving operations north of the Florida Keys, appears to depend less heavily on artificial reefs using vessels. Generally, vessels represent the minority of numerous natural and artificial reef sites available to saltwater fishermen. In the southeastern U.S., natural reef habitat constitutes 23% of the available habitat on the continental shelf (Parker et al. 1983). In South Carolina, in a 1991 recreational fishing survey, 5% of all fishing days were spent on shipwrecks, and 17.3% were spent on artificial reefs, which includes some intentionally placed wrecks. Greater time was spent fishing inshore in bays and estuaries (36.2% of the fishing days), followed by days fished on rock jetties (17.2%), open ocean (13.5%), and on live bottom (10.8%) (Rhodes et al. 1994). An earlier assessment of Texas Liberty Ship usage indicated that while the vessels played a role in extending the charter fishing season, their actual accessibility was limited to local vessels 20 foot long or greater, operating out of the nearest inlet. The ships were seen as one of numerous possible fishing sites (Ditton et al. 1979).

Storm Impacts on Steel-hulled Vessels

The sea is a harsh environment for artificial reef materials. In addition to physical abrasion by sand in shallow water conditions, metal materials such as steel hulled vessels are subject to corrosion of metallic components. Corrosion rates can be influenced by both factors associated with the metal, and factors associated with the environment. For example, the chemical and physical uniformity of the metal, the electrode potential of the metal in seawater, and the metal's ability to form an insoluble protective film would be examples of metal related corrosion factors. Environmental factors impacting corrosion rates would include, but not be limited to, temperature, mechanical stresses, proximity of dissimilar materials, the nature and concentration of fouling organisms, flow rate of seawater past the metal, acidity, and dissolved oxygen levels (Horne 1969). All vessels deployed as artificial reefs in shallow water marine environments experience varying rates and degrees of degradation over time. Exposure to major storm events can exacerbate this process.

High vertical profile and the trend towards placing vessels at depths accessible to divers makes steel-hulled vessels vulnerable to major storm systems, especially hurricanes of category 4 and 5 intensities. Table 2.2.3 provides a summary of known damage to artificial reefs using steel-hulled vessels as a result of Hurricane Andrew, a category 5 storm which hit the Dade County, Florida area on August 22, 1992. Most vessels, which were in 65 to 125 feet of water and in the direct path of the hurricane, experienced structural damage. Maximum movement of 700 yards was noted for a concrete-loaded steel barge, and up to 100 yards for a steel freighter. Scouring of fouling organisms from hulls, removal of wheel houses and stern sections, and hull subsidence into scour depressions were common hurricane effects when the eye of the hurricane passed nearby. To the north of Dade County in Broward County, Florida, 80 miles from the hurricane's eye, at least one vessel was moved offsite, four were laid over on their sides, and wrecks in water as deep as 180 feet experienced hull damage. The hulls of the steel freighters *Mercedes* (250 feet in length in 97 feet of water) and the *Noula Express* (220 feet in length in 90 feet of water) were both broken in three places. A light gauge metal yacht in 65 feet of water was reduced to rubble. There was evidence that shipwreck reefs were literally bounced up and down against the bottom (Ken Banks, personal communication). Hurricane Hugo (1989), like Hurricane Andrew, which had sustained winds exceeding 150 miles per hour, bounced a 450-foot long troop ship, sunk off South Carolina 700 feet laterally across the bottom. The vessel, which originally was in 130 feet of water, sat in a scour depression at 140 feet after the hurricane passed (Bell and Hall 1994 and Mel Bell, personal communication). Off North Carolina, Hurricane Hugo also heavily damaged a large barge serving as an artificial reef (Steve Murphey, personal communication).

During Hurricane Gordon (August 1994), a 600-foot long vessel loaded with concrete and sunk off Bimini, Bahamas in 80 to 100 feet of water, was moved several hundred feet shoreward and plowed across live bottom (Todd Barber, personal communication). The M/V Antares, a 387-foot coastal freighter which was sunk intact on its port side in 125 feet of water off Pensacola, Florida on September 27, 1995, was subjected to the Category 3 forces of Hurricane Opal on October 4, 1995. The stern and bow sections of the ship separated from the center portion, where cargo holds also sustained damage. The pieces remain on site and continue to attract fish, but the damaged vessel is now somewhat disorienting to divers (Tom Maher, personal communication).

Smaller vessels such as tugs that are affected by major storm events are most frequently impacted by the loss or damage of the wheelhouse or superstructure while the hull remains intact. Superstructures with wooden siding or roofs, or that had add-on extensions or components reattached to the original structure appear to be more vulnerable to damage (Jon Dodrill, personal communication). One of the oldest tugs in the Florida reef system, the *Paul Main*, deployed off Jacksonville, FL in 70 feet of water in 1968 still remains a popular dive site in 2003, although its superstructure has been torn away.

Some vessels not operationally designed to withstand heavy sea conditions, and further weakened through age and deterioration, if deployed as artificial reefs, may not withstand normal sea/current conditions, let alone a major storm event. As an example, a triple deck 340-foot, 60-year-old car ferry whose lower deck sat under water for 12 years prior to salvage was sunk in a .75-1.5 knot current environment off Palm Beach County, Florida in 110 feet of water on May 23, 1993 at a cost of $55,000. Following the arrival of the first winter weather seven months later, the lowest deck had collapsed, and the upper two decks had been wrenched sideways, resulting in the creation of jagged sheets of metal and other hanging debris, and forming a potential diving hazard. Salvage procedures, use of explosives, and impact of the vessel with hard bottom upon sinking, may also have contributed to the ship's initial deterioration (Jim Vaughn, personal communication). Continued monitoring of the vessel showed that the superstructure was eventually completely sheared off, and lies on the seabed west of the vessel. Nine years after sinking, the superstructure and the ship proper are experiencing structural collapse. The starboard side of the hull continues to deteriorate, and is splitting away from the remainder of the hull (Palm Beach County Reef

Research Team, 2002). In contrast, the sturdy 110-foot North Atlantic trawler, *Steanne D'Auray*, sunk in March 1986 as a reef off Dade County, Florida in 68 feet of water, withstood Hurricane Andrew intact (Table 2.2.3 and Jon Dodrill, personal communication).

Table 2.2.3. Damage Sustained by Dade County, Florida Steel Hulled Vessels Used as Artificial Reefs During Hurricane Andrew (August 22, 1992).*

| **Vessel Name** | **Type** | **Length (ft)** | **Water Depth (ft)** | **Damage/Movement** |
|---|---|---|---|---|
| *Almirante* | freighter | 210 | 125 | Ship turned upside down; 17 years of coral growth scoured off. |
| *Andro* | freighter | 165 | 105 | Stack damaged, cargo area collapsed; stern section torn off. |
| *Belcher Barge* | barge | 195 | 57 | Several steel plates torn off barge. |
| *Belzona One* | tug | 80 | 73 | Wheelhouse ripped off. |
| *Biscayne* | freighter | 120 | 60 | Stern section partially separated from main hull by adjacent wreck. |
| *Blue Fire* | freighter | 175 | 110 | Part of hull and superstructure separated, moved 10 yards, listing. |
| *C-One* | Navy tug | 120 | 65 | Hull listing in 10-foot deep scour hole. |
| *Concepcion* | freighter | 150 | 68 | Mid cargo area collapsed; stern section separated from hull. |
| *Deep Freeze* | freighter | 210 | 135 | 35 feet of stern section separated from hull. |
| *Doc De Milly* | freighter | 287 | 150 | No damage. |
| *Miracle Express* | freighter | 100 | 60 | Pushed on top of *Biscayne*; hull broken into pieces. |
| *Narwhal* | freighter | 137 | 115 | 90% of structure collapsed; many areas reduced to steel plates on sand. |
| *Orion* | tug | 118 | 95 | Pilot house ripped from hull. |
| *Police Barge* | barge | 75 | 55 | Moved 75 yards into concrete reef material; hull has opened up. |
| *Proteus* | freighter | 220 | 72 | Stern ripped off; remainder of wreck moved 100 yards and is broken up. |
| *Rio Miami* | tug | 105 | 63 | Settled 20 feet into sand depression. |
| *Shamrock* | Navy LCI | 120 | 46 | Coral scoured from hull; position and condition unchanged. |
| *Sheri Lyn* | freighter | 235 | 95 | 50 feet of stern broken off and moved into 105 feet of water. |
| *South Seas* | yacht | 175 | 65 | Stern broke off; vessel moved 50 feet. |
| *Steanne D'Auray* | trawler | 110 | 68 | Intact, unchanged. |
| *Star Trek* | freighter | 200 | 210 | Some steel plates torn off, largely intact, same position. |
| *Tarpoon* | grain carrier | 175 | 71 | Moved inshore 75 yards; pushed up against natural reefs, hull broke into three pieces. |
| *Ultrafreeze* | freighter | 195 | 118 | Starboard side of hull ripped open, vessel bent amidships at 90-degree angle, pilot house torn from hull. |

*Information provided by Ben Mostkoff, Dade County Artificial Reef Coordinator. Printed by Joel Auerbach as "Hurricane Andrew Update" in Dive Miami.

Vessels require a significant amount of care to ensure that they not only reach the designated reef site but are properly placed at the site in the desired orientation. Vessels, other than government vessels, are often available as reefs because they have become a major liability to their owners. Most are unseaworthy, some may already have sunk, been raised and kept afloat with pumps, been stripped, or been structurally weakened by salvage operations. Physical preparation of the vessel (cutting holes in it and patching with temporary patches) may increase the unseaworthy state of the vessel and necessitate deployment in calm weather conditions. These factors, combined with poor judgement on the part of contractors who attempt to deploy vessels under adverse sea conditions, have resulted in vessels sinking offsite and outside permitted areas.

Vessel Complications during Towing and Reefing

The majority of vessels used in artificial reef programs have been sunk at their designated sites with no major problems. For the benefit of increasing awareness among reef managers and planners, the following representative examples are provided that highlight potential problems to be aware of. These examples illustrate the necessity for great care to be exercised on the part of contractors or other involved parties to ensure the condition of vessels under tow, and to operate when the sea state allows for safe arrival on site.

Off Franklin County, Florida, a steel shrimp trawler, One More Time, was under tow in very choppy sea conditions. Waves knocked out the wooden boards sealing previously cut holes in the hull, and the vessel sank more than six miles from the permitted site (Bill Horn, personal communication). Off southwest Florida, a contractor, towing two barges in weather too rough for the operation, cut both vessels loose miles from the permitted site when they began taking on water. One of the barges has yet to be located (Steve Boutelle, personal communication). Off Texas in late October 1976, the twelfth and final Liberty Ship of the Texas reef program became one of the first artificial reef lighted buoy maintenance undertakings. The S.S. *George Vancouver* under tow to the Freeport permit site was caught in heavy seas. The tug could not get the Liberty Ship back to port. The tug and ship moved into shallower water to the southeast, but a 3,000-pound anchor broke loose from the S.S. *George Vancouver* and accidentally deployed. In gale force winds, the ship dragged the anchor along the coast until the vessel sank miles from its permitted site in 60 feet of water, nine miles south of Freeport Texas. Rather than attempt to move the vessel, the Army Corps of Engineers issued a new permit for the site. Because there was only 33 feet of clearance, the Coast Guard required the placement of a light and sound buoy (Arnold et al. 1998). This buoy had to be continuously maintained at a cost of thousands of dollars per year until 1998 when it was replaced by an unlighted buoy, following authorization by NOAA in cooperation with the USCG (Jan Culbertson, personal communication). On March 25, 2000, a small leaking barge, uninspected by the Coast Guard, was under tow offshore for placement at an Okaloosa County (NW Florida) reef site by a private citizen. The vessel sank at the edge of the channel in Destin Pass even before it reached open water. The U.S. Coast Guard and the Army Corps of Engineers deemed the county liable. Salvage and shore side disposal of the barge cost the county reef program $47,500, nearly their entire annual artificial reef budget (Cindy Halsey, personal communication).

Once the vessel arrives on site, care must be taken to ensure that it is properly anchored and sinks on the site in its intended orientation. Off Palm Beach County, the 340-foot long car ferry, *Princess Anne*, sunk as an artificial reef on the edge of the Gulf Stream in marginal sea conditions, drifted a quarter mile before it came to rest on live bottom outside the permitted area in 110 feet of water (Bill Horn, personal communication). Off Jacksonville Florida, a 327-foot long Landing Ship (LST), the Casablanca, sunk as an artificial reef, dropped beneath the surface as anticipated, but due to entrapment of air did not stabilize on the bottom. The vessel moved and was reported lost for a time. It was finally relocated nearly 10 miles down current from the original sinking location

(Ed Kalakauskis, personal communication). While it may be possible to control the position of small unanchored vessels in low current environments when a tug is present while they sink, larger vessels sunk in stronger current situations must be anchored by an anchor system appropriate to maintain the vessel position as it sinks.

The use of explosives in sinking vessels has been popular with reef coordinators in southeast Florida and elsewhere, due chiefly to the public and media attention created by the audio-visual spectacle of an exploding ship. Such vessels are generally sunk by military units or police bomb squads. In southeast Florida, sealed buckets of gasoline and ether, or some other highly flammable liquids, are typically placed on the main deck, wrapped with primacord and tied in to the network of main charges for special fireball effect. Estimates are that over 50 vessels have been sunk with the use of explosives in three southeast Florida counties alone (Jon Dodrill, personal communication).

USS *Oriskany* – Essex Class aircraft carrier being sunk as an artificial reef 23 miles off the coast of Pensacola in May 2006. Photo Credit: Florida FWC.

The perceived advantages of using explosives are public entertainment, program publicity, expediency in sinking, and training opportunities for agencies tasked with explosives use or disposal. Additionally, by leaving the hull as intact as possible while enroute to the deployment site, there is less danger of the vessel sinking prematurely. Another perceived benefit is that vessels sunk with properly placed explosives can sink rapidly, thus shortening the time spent on station during a ship sinking. One hundred foot and 165-foot vessels can be sunk in less than one minute and four minutes, respectively, with as little as 40 pounds of dynamite (Ben Mostkoff, personal communication). Unfortunately, excessive amounts (200 to 400 pounds or more) of explosives have been used in the past. At least one vessel was blown to pieces. Photos of dynamited ships off Florida, dating from the late 1970s and 1980s, show, at the time of detonation, airborne debris, plumes of airborne pollutants, and in at least one instance, superstructure damage from the blast

(Berg and Berg 1991). Off North Carolina during the deployment of a barge, an accidentally delayed charge went off as the barge's bow lifted clear of the water. Metal plates were blown half a mile, landing within 600 feet of an observation boat (Kurtis Gregg, personal communication).

It is not necessary to use explosives to properly deploy vessels less than 150-200 feet long (i.e., tugs, auxiliary vessels, coastal freighters) that do not have the complexity of large numbers of water-tight compartments and other voids as artificial reefs. Other methods may be less showy and slower paced, but avoid having to procure demolitions experts, explosives, and consider other safety and resource protection issues. Cargo ships as large as 460 feet have sunk in 45 minutes without the use of explosives. Opening sea cocks and the use of portable pumps to systematically flood the vessels, and the use of cutting torches to cut holes in the hulls and flood compartments are alternatives to explosives, which have produced fish kills in the past (Jim Bohnsak, personal communication), and have required extra safety measures to be taken for protection of both observers and personnel involved in the sinking.

Situations where explosives use is warranted would be in the sinking of a large (greater than 1,500 tons or 300-foot long) military non-cargo auxiliary or combatant vessel. These vessels are built to resist sinking, and have scores of water tight compartments on multiple decks. To sink them requires the controlled movement into the vessel of hundreds of tons of water and a means for trapped air to escape rapidly. In such situations, in the interest of safety of personnel involved in flooding the ship, and to help ensure the vessel sinks in its proper orientation, demolition experts working in conjunction with marine engineers utilizing vessel stability information, should develop a demolitions/sinking plan that determines the type, poundage and proper placement of charges. Aerial surveys should be flown over the ship beginning 45 minutes before detonation to ensure there are no visible marine turtles or marine mammals noted within ½ mile of the vessel. A security perimeter should be maintained by the Coast Guard or local law enforcement agencies no closer than a five hundred yard radius from the vessel. The perimeter should be maintained until the vessel to be sunk is on the bottom, and has been checked by diving demolition professionals to ensure that all charges have detonated.

A number of forces are at work on the vessel during the sinking process. In high current situations, the force of water and any accompanying wind activity acting on a large hull and superstructure with extensive surface area creates lateral forces which act upon a vessel as it moves through a brief period of instability during the sinking process. Removal of heavy equipment such as engines, generators, etc. can affect a vessel's center of gravity and righting ability. Additional vector forces from anchor lines, abrupt shifts in water movement from one side of a vessel to the other as it lists, catastrophic failure during flooding of ballast tank walls, patches, bulkheads, and insufficient venting of entrapped air from the hull, all create circumstance where a large vessel, as it moves through the sinking process and becomes unstable, may become prone to roll over on its side and fail to sink upright. A few such examples have been a 160-foot yard oiler (South Carolina- sank upside down in the 1980s) (Mel Bell, personal communication), the 387-foot freighter *Antares* (sank on its side off NW Florida, 1995), 460-foot troop ship *Mullephin* (sank on its side off SE Florida in 1988); the 327-foot coast guard cutter *Bibb* (sank on its side off Key Largo Florida, 1987); the 510 foot ex-Navy LSD *Spiegel Grove* (rolled upside down with bow protruding from water off Key Largo Florida in 2002)(George Garrett, personal communication); a barge off Jacksonville, sank on its side in the early 1990s (Ed Kalakauskis, personal communication). In the case of the *Spiegel Grove* and the barge, their orientation created a navigation hazard. In both cases, an extra tug and commercial divers had to be called in to engage in salvage operations to reorient the vessels to acceptable navigational clearance. In the case of the *Spiegel Grove*, the additional salvage expense was approximately $300,000 (George Garrett and Ed Kalakauskis, personal communications).

Vessels as Fish Habitat

The value of vessels as fishing habitat from a management perspective seems to be a double-edged sword, especially regarding recreationally important, demersal fish populations, which may remain on wrecks for a period of time. Recognizing that improved catch and positive economic impact depend on people being able to reach and use sunken ships and other artificial reefs. It is also apparent that accessibility can generate so much pressure that the value of a vessel or any natural reef as a fishing site is seriously compromised with unregulated pressure. Ditton et al. (1979) stated that Texas Liberty ships "appear to constitute a significant and competitive attraction to offshore fishermen." Alabama Liberty ships are easy to locate and readily accessible but receive such heavy fishing pressure that size of fish and level of landings are reduced (Skip Lazauski, personal communication). In Broward County, Florida, despite the fact that half of the 71 reef sites are sunken vessels, nearly all within two miles of shore, recreational hook and line and spear fishing pressure for demersal species has been so intense (with over 42,000 locally registered boaters) that the local commercial finfish fishery has seriously declined, along with recreational bottom fishing. In that area, vessel reefs provide the greatest social and economic return through the diving industry (Ken Banks, personal communication). Milon (1988) reported that anglers prefer sites with higher than average yields and greater variation in yield. Easily accessible, large wreck sites often do not fit the bill for greater variation in yield and higher yield because they tend to be over-exploited, both by hook-and-line fishermen and spear fishermen using SCUBA. Shipwrecks, like some other artificial reefs, redistribute exploitable biomass of recreationally and commercially preferred species. Although concentrations may exceed levels at natural sites in surrounding areas, a more rapid reduction in the amount of exploitable biomass occurs if fishing is not restricted (Polovina 1991). This underscores the need for equal management across all habitat types with an understanding that artificial reefs may affect fishing pressure and population dynamics.

Some Atlantic Coast deepwater wrecks (300 to 800 feet) south of Cape Hatteras have for years held populations of slow-growing, long-lived (25 to 50 years), deepwater groupers, until these sites were located and intensively fished in the early 1980s (Epperly and Dodrill 1995). In another example, a single commercial vessel, fishing over a short period of time, harvested four to six thousand pounds of snowy grouper a week from an 800-foot deep wreck off Fort Pierce of southeast Florida (Grant Gilmore, personal communication). A single wreck south of Cape Hatteras, North Carolina in 600 feet of water was reputed to have produced $100,000 in deepwater grouper landings over a two year period in the early 1980s (Jon Dodrill, personal communication). A previously unexploited shipwreck off Australia resulted in the harvest of over a ton of snapper species per day, once it was discovered, until the government stepped in and designated it a sanctuary and historic site (Branden et al. 1994).

Despite the popularity of some vessel types such as barges, which are readily available through salvagers and marine construction companies, the lack of structural complexity of these vessels may render them of lesser value to recreationally and commercially important demersal fish species, as well as other reef obligate marine life (Ecklund 1994). On deck barges, snapper and grouper appear to have limited shelter opportunities, which chiefly occur in scour depression holes along the base of the barge, under raked bow overhangs, and in areas of the hull where there are multiple openings close together, instead of a single-entry point (Jon Dodrill, personal communication). Chandler (1983), in a 1979-80 study of two identical barges sunk at the same time in 1964 in 65 feet of water, and 220 yards apart off Panama City, Florida, showed that the barge having the greater degree of surface area complexity (due to more rapid deterioration of the deck and opening up of the barge interior) had a higher fish species diversity and richness. Barges loaded with material which may increase complexity can create greater fish habitat possibilities, and result in holding greater fish populations than the empty barge itself. Combining increased complexity with appropriate placement and a reduction or elimination of fishing pressure can result in a site holding dense concentrations of fish. In January of 1986 during a cold front, a barge carrying 7,000 tons of crushed granite enroute from Savannah, GA to Nassau, Bahamas sank in heavy weather in 80 feet of water off Cape Canaveral. When the Space Shuttle *Challenger* blew up over the Atlantic shortly after takeoff several days later, the area in which the barge was sunk was sealed off while search, salvage, and recovery operations for the shuttle wreckage were undertaken. Because of these search and recovery operations associated with the Challenger, the barge was not accessible to the owner or fishermen for over a year. When the barge owner was finally able to return to the barge and dive on it, he said the sheer numbers of fish extending from the barge through the water column to the surface created a very intimidating diving experience (Joe Ferrell, personal communication).

Seasonal aggregations of now-protected adult Goliath grouper, believed to be engaged in spawning activity, have been reported from shipwrecks off southwest Florida. These shipwrecks represent some of the only known extant spawning aggregation sites of this species off either Florida Coast. (Dr. Chris Koenig, personal communication).

Extensive interior voids in the hulls of barges and ships where water circulation, light levels, and numbers of entry and exit holes are low, limit the use of that space by fish and fouling organisms. Baynes et al. (1989) reported that highest fouling species diversity and greatest amount of living cover on a ship were on vertical surfaces exposed to high velocity, laminar flow, and less subject to sedimentation and diver impact than horizontal deck surfaces.

The vertical profile of ships produces an interruption of the bottom currents, and creates vortex currents (shed eddies), which attract migratory pelagic fishes such as mackerels and jacks. Vessels can serve as eddy generators, and produce modified currents around the vessels, which cause low frequency vibrations, which may act as stimuli for fish lateral line systems (Lindquist and Pietrafesa 1989).

Benefits

- Vessels make interesting diving locations for both recreational divers and technical deep-diving mixed-gas users. Vessels are also regularly utilized as angling sites by recreational fishermen and the charter fishing industry.

- Vessels used as artificial reefs, can, alone, or in conjunction with other types of artificial reefs, generate reef-related economic contributions to coastal counties. Economic contributions from artificial reef systems can be as high as $0.6-$1.5 billion per year in areas such as Miami-Dade and Broward counties in southeast Florida, where ships comprise an important element of the artificial reef system (Hazen and Sawyer Associates 2001).

- Steel-hulled vessels, when selected for sound hull integrity, are considered durable artificial reef material when placed at depths and orientations that ensure stability in major storm events. Large vessels have life spans as artificial reefs that may exceed 60 years, depending on vessel type, physical condition, location of deployment, and storm severity.

- Reuse of large steel-hulled vessels as artificial reefs may be more economical than scrapping the vessels domestically.

- Vessels, due to high vertical profile, attract both pelagic and demersal fishes. Vertical surfaces produce upwelling conditions, current shadows, and other current speed and direction alterations that are attractive to schooling forage fishes, which in turn attract species of commercial and recreational importance, resulting in increased catch rates for fishermen.

- Vessels, like other artificial reef material, can augment benthic structure which locally increases shelter opportunities and reef fish carrying capacity in locations where natural structure is sparse, or create structure which is more preferable or attractive to certain fish species than locally less complex hard bottom (Barnette 2001).

- Steel-hulled vessel reefs that are not well publicized, located far offshore, or otherwise difficult to access for fishing and diving because of depth and currents may, if properly sited, provide important refuge for reef fish species. Such vessels can provide important aggregation, shelter, and residence sites for reef fish species that have been traditionally overfished such as warsaw grouper, black grouper, goliath grouper, red snapper, amberjack, and others.

- Vessels under certain conditions may provide habitat for spawning aggregations of some managed reef fishes [e.g. greater amberjacks on wrecks off Broward County (SE Florida], goliath grouper on wrecks off SW Florida.

- Vessels may provide extensive surface area for epibenthic colonization. This colonization results in the enhancement of lower trophic level biomass at the vessel site.

- Under some circumstances, depending on location and season, some vessels may hold greater abundances and higher biomass of fish species, including some recreationally important species (i.e. gray snapper), than nearby natural reefs (Spieler 2001, Palm Beach County DERM 2001).

- Vessels may reduce anchor damage and other physical damage by directing a proportion of the reef users away from nearby natural reefs. In Southeast Florida, about 1/3 of the fishing use is on artificial reefs, with many of these reefs vessels; 2/3 of the reef use is on natural reefs (Hazen and Sawyer Associates 2001). Similarly, vessels provide diving alternatives to natural reef sites where physical damage to natural reefs through anchor damage, grounding, handling, crawling on, specimen collecting, and spear fishing have accelerated deterioration of natural reefs and their associated fauna.

- Sinking a vessel often creates a media event, providing reef managers with promotional opportunities for their reef programs.

- Sinking steel-hulled vessels as artificial reefs, properly cleaned and under appropriate conditions, may assist other agencies and programs (permanent removal of drug seized vessels from the drug trade, elimination of derelict vessels that have become navigation or safety hazards, etc.).

Drawbacks

- Providing accessibility to both diving and fishing groups while still maintaining adequate navigational clearance above vessels often limits placement of vessels (particularly large ships) within a relatively narrow depth range (80 to 120 feet), and may result in substantial superstructure reduction and loss of complexity to meet Coast Guard clearance requirements. Good water clarity is also preferred, primarily to enhance diver observations, and this may further limit vessel placement.

- Vessel stability during hurricanes is variable. Movement ranges from no movement, to on-site changes in hull orientation, to horizontal movement of several hundred meters. Susceptibility to movement or resistance to movement is dependent upon a combination of stability factors which consider depth, extent of vessel surface area exposed to wave energy, vessel orientation with respect to storm direction, wave height, friction forces resisting horizontal movement, forces like the weight of the vessel resisting vertical lift, vertical profile, and localized storm-generated current and surge conditions. Those vessels placed in shallow depths (less than 50 m) are more susceptible to movement during major storm events, such as Category 3-5 hurricanes, than vessels placed at greater depths (Bell and Hall 1994, Blair et al. 1994.) Movement of vessels of up to 100-700 m has been documented during such storm events.

- Damage to the structural integrity of vessels sunk as artificial reefs can also occur from hurricanes. However, it should be noted that natural reefs and some other less durable types of artificial reef structures have also experienced storm damage. Some vessels that may resist significant hull movement in a storm can still experience substantial structural damage (pilot houses ripped off, hulls fractured, etc.). Loss of structural integrity can increase hazards to divers on artificial reefs by creating a disorienting environment or increasing potential for snagging equipment or for physical injury from jagged metal, etc. (Blair et al. 1994, Bell and

Hall 1994). The extent of measurable storm damage across the entire fleet of U.S. vessels sunk as artificial reefs has not been quantified.

- Durability may be compromised by salvage operations during the cleaning process and/or by the explosives sometimes used to sink these vessels (Myatt and Myatt 1992, Gregg and Murphey 1994).

- Vessels were originally designed and utilized for purposes other than artificial reef construction. They can be contaminated with pollutants, including: PCBs, radioactive control dials, petroleum products, lead, mercury, zinc, and asbestos. Hazardous wastes and other pollutants are difficult and expensive to remove from ships (Gregg and Murphey 1994, Gregg 1995). There are specific federal standards related to the disposal of certain materials that must be addressed. For example, PCBs are regulated under the Toxic Substances Control Act (TSCA, 15 USC 2601-2692). Vessels built prior to 1977 that may potentially have this long-lived material on board must be tested. Hazardous material itself, once removed, must be disposed of under proper guidelines. The USCG requires that other materials, not necessarily classified as hazardous wastes, but which may pose environmental or safety problems such as floatable materials (wood, styrofoam) and plastics, must be removed (tire bumpers, white goods, toilets, etc.).

- The combined fishing pressure from both anglers and spear fishermen on large, easily located and accessible vessels (and other public artificial reefs) may remove more upper trophic level biomass (i.e. recreationally important fish) than is produced by the artificial habitat, thereby adversely affecting some local fish stocks (Bohnsak 1989, Polovina and Sakai 1989, Low and Waltz 1991, Barnette 2001, Lindberg and Loftin 1998). Additionally, over fishing at these sites may result in the decline of catch rates of legal-sized fish, particularly among some grouper and snapper species where there is a degree of site fidelity (Lindberg 1999, Strelcheck 2001).

- Vessels typically provide proportionately less shelter for demersal fishes and invertebrates than other materials of comparable total volume. This is because the large hull and deck surfaces provide few, if any, holes and crevices. This lack of shelter from predation greatly reduces the usefulness of a ship as nursery for the production of fishes and invertebrates. Also, while a high vertical profile can be attractive to pelagic fish species, unless a vessel hull is extensively modified to allow for access, water circulation and light penetration, most of the interior of the vessel is not utilized by marine fishes and macroinvertebrates (Myatt and Myatt 1992).

- Use of vessels for artificial reef can result in conflicts between divers and fishermen (Myatt and Myatt 1992). Although such conflicts can occur on natural reefs, there is often preferential use of vessels by divers resulting in domination of some vessel reef sites by diving user groups. This is particularly true in areas with large tourist and resident diving populations that are selectively attracted to vessels sunk in shallow, clear, warm water environments such as South Florida.

- The surface of a steel hull is a less ideal surface for colonization by epibenthos than rocks or concrete. Sloughing of steel, due to corrosion, results in loss of epibenthic animals (Gregg 1995).

- Removal of hazardous materials, pollutants, and other material not authorized for artificial reef disposal under the permit require additional expense, time, and in some cases, special equipment and expertise. The cost to safely place a vessel in the ocean as an artificial reef increases as the size of the vessel, number of compartments, and overall complexity increases. Large vessels in particular are costly and time consuming to clean, tow, and properly sink on a designated site. Other materials may be cleaner and less problematic to secure and handle. These other materials may also accomplish the same recreational fishing objectives at a lesser expense.

- Potential liability and responsibility issues listed in artificial reef planning documents include: damage to private and public property during cleaning operations or subsequent towing, vessels sinking outside of the designated site creating hazards to navigation, and ships damaging natural habitats due to improper deployment or subsequent movement. Unlike smaller individual artificial reef modules or materials, a large vessel, once sunk, would be difficult and expensive to move if improperly placed (upside down, for example, or outside the permitted area, or on natural hard bottom habitat), or if a greater priority for alternative use of the sea floor became necessary at the reef site in the future. Additional liability includes danger to divers if hatches and doors are not removed during cleaning, chemical or noxious gas exposure of workers cleaning the vessels, insurance issues surrounding use of volunteers in preparing vessels for sinking, etc. (Myatt and Myatt 1992, GSMFC 1998).

- Due to high vertical profile of vessels, some Coast Guard districts have requirements for buoy systems where navigation clearance is less than 85 feet. While waivers may be granted in some situations (vessel charted) in some regions, buoys indicating an obstruction may be required. Lighted buoy systems in particular are expensive to maintain over a multi-year period.

- High vertical profile may render some vessels more prone to movement and/or structural damage due to ocean current and wave surge generated by severe storm conditions.

- Vessels have an alternate value as recyclable steel.

- Use of explosives to sink vessels, while popular with some programs, may cause unnecessary structural weakening, scatter loose debris, cause short-term air pollution problems, and potentially create a hazard to marine life, especially if an excessive amount of explosives are used. However, in situations involving large complex military vessels with scores of voids, many compartments on multiple deck levels and requirements of thousands of tons of water to enter the vessel in a controlled manner in a short period of time in order to control sinking orientation, placement of multiple charges of small explosives, use of cutting explosives, and coordination of demolitions experts with marine architect and stability engineers may be necessary.

- Procurement of large government-owned vessels through bureaucratic channels (MARAD or federal surplus property) may take years from initial paperwork application and fund raising to final deployment, exceeding the time-frame in which some funding may be available and thereby hampering reef construction planning efforts.

- Vessels with high vertical profile and maximum clearance requirements may end up being placed so far offshore of coasts with shallow seabed gradients that only a limited segment of the private recreational fishing community can reach these wrecks.

<u>Considerations</u>

- Several Gulf coast states and Florida coastal counties have demonstrated that it is possible to have a viable artificial reef program without vessels. It is important for managers to assess their objectives when securing a vessel, since cleaning and towing costs, especially when interstate transport is involved, can be prohibitive.

- With the rapid increase in recreational sport diving activities in some areas, ship deployment in certain areas may have greater value to the diving industry than to the recreational hook-and-line fishery. Vessels deployed in shallow water (60 to 100 feet) are especially attractive to recreational SCUBA divers. If the funding source is fishing license revenues, and the site is dominated by divers, this issue should be considered.

- If the intent of developing an artificial reef is to provide recreational fishing opportunities with some level of fishing success, while at the same time avoiding user conflict, the combined effect of spear fishing and hook-and-line harvest and liability associated with diver accidents during wreck diving may lead to a recommendation to sink vessels at greater depths (150 to 350 feet).

- Consider using only those steel-hulled vessels which are designed for operating in heavy sea conditions, such as ocean-going tugs, oil rig re-supply vessels, trawlers, and small freighters, which are all structurally sound. The focus should be on structural and habitat complexity of vessels, rather than strictly vertical height or sheer overall length.

- Consult clean-up guidelines and standards for ocean disposal of vessels developed by Environment Canada (1998a, 1998b).

- All petroleum products, both liquid and semi-solid must be removed from tanks on ships with follow-up inspection, and sign off by a USCG marine safety officer. It is not sufficient to draw the tanks down somewhat and then weld the hatch closed. The Liberty ship *Joseph L. Meek* has demonstrated that corrosion of the metal of the ship will eventually release residual fuel into the environment, and that relatively small quantities can trigger regulatory and public relations consequences (Jon Dodrill, personal communication).

- Recommend a buffer zone of 1/4 nm (about 450 m) between any natural hard-bottom community and vessels deployed as artificial reef material in depths less than 50 m. This safety buffer is based upon documented movement of vessels, or parts thereof, in hurricane events.

At depths below 50 m, but less than 100 m, a distance buffer of at least 100 m is recommended. For purposes of these guidelines, hard-bottom includes living natural reefs such as tropical coral reefs, Oculina coral reefs, oyster reefs, worm reefs, and areas of naturally occurring hard bottom or rocky outcrops to which are attached well-developed varying biological assemblages such as perennial algal species, and/or such invertebrates as sea fans, bryozoans, sea whips, hydroids, ascidians, sponges, or corals.

- Recommend assurances of vessel stability in a 20-year return interval storm event at the depth placed as demonstrated in a stability analysis conducted by a marine engineering company. This is a minimum acceptable level of stability. For vessels deployed within ½ nm (about 900 m) of natural coral reefs, well developed hard-bottom communities, or oil and gas infrastructures recommend that the vessel stability requirement at the depth placed increase to resistance to movement in a 50-year storm event.

- Avoid the use of explosives to the extent possible in sinking vessels under 150 feet in length where alternate sinking methods (opening sea cocks, flooding with pumps, opening up temporarily sealed pre-cut holes, etc. is feasible). If explosives must be used for sinking larger vessels with many watertight compartments, there should be careful placement by experts of the minimal amount of structural cutting explosives necessary to sink the vessel safely and efficiently. The minimization of vessel damage, and the avoidance of harm to marine life, are important vessel sinking objectives. A written demolition plan drafted by experts undertaking the demolition is recommended, along with USCG coordination. Potential impacts to marine mammals, turtles, and fishes should be considered.

- Develop and implement cleaning standards for pollutants known to occur on ships. Require testing for PCBs on boats and ships constructed prior to 1975 (when PCB manufacture ended). Require an asbestos inspection. Asbestos that is secured or encased may be left undisturbed and in place prior to sinking (EPA does not consider asbestos a hazard in the marine environment but it can be a health hazard when airborne. Since sinking of a vessel is considered structural modification of a facility, ships to be sunk as artificial reefs fall under requirements for asbestos inspection).

- Develop and coordinate inspection standards with EPA, USCG, and affected state regulatory agencies.

- Liability issues must be recognized and addressed by permittees who are required to provide long-term responsibility for materials on their permitted artificial reef sites, including ships. Demonstration of this responsibility could include liability insurance, posting a bond or other indemnifying instrument to ensure resolution of liability issues associated with the towing, cleaning and sinking of ships on state submerged lands. This liability includes damages caused by movement of the materials during storm events.

- Use the consistency process under the Coastal Zone Management Act to ensure vessels constructed as reefs in permitted sites in the Exclusive Economic Zone (EEZ) are held to the same standards as vessels placed in adjacent state waters.

- Reassess all constraints that may be placed on sinking a ship (i.e., minimum depth, distance from shore, complexity of vessel that may require additional technical assistance, stability requirements, vessel orientation, cost, time involved in project, etc.), and decide early on whether one or more of these constraints will result in a final outcome that will not be successful in achieving the project's objectives.

<u>Federal Vessel Reefing Program Development Recommendations</u>

- Gulf and Atlantic Marine Fisheries Commissions and Councils should investigate possible federal programmatic alternatives to the multi-year, drawn-out process of securing individual MARAD vessels under current circumstances that result in very high expenditures per vessel.

- Recommend if a federally sponsored large-scale military ship-sinking program becomes a reality, then efforts to coordinate such a program should occur at the national level through the ASMFC and GSMFC. This would avoid interstate competition for vessels and preferences given to those states that have more substantial reef funding resources than others.

- Recommend through the ASMFC and GSMFC, identification of the large military vessel needs for all states and regions therein. Establish an orderly vessel distribution ranking system based upon each state's need, interest, and ability to accommodate such vessels in an environmentally safe manner that meets planned objectives and regulatory requirements. Identify what vessel classes may be the most appropriate, as well as least appropriate, for use to meet state artificial reef objectives. For example, aircraft carriers due to sheer size may be inappropriate for a shallow-water coastal marine environment. However, the advantages and disadvantages in relation to project objectives should be discussed in advance of hastily committing to a project. The appropriate fisheries councils and NMFS should also be consulted and involved in the coordination process. The councils, NMFS, and FWCC should approve any recommendations proposed by the GSMFC and ASMFC regarding federal ship disposal. The continuation of independent efforts by individual states, local government or private entities to secure large MARAD and Navy vessels would be expected to impact the role interstate fisheries management commissions and councils would have in this vessel distribution process.

- Recommend that the federal government identify those inactive fleet vessels that may be in such unsound physical conditions or with environmental cleanup problems so extensive as to pose an unacceptable risk and expense for reefing. Conversely, recommend that vessels available for reefing with the fewest environmental problems and in the soundest structural condition also be identified.

- Recommend that the federal government create a centralized office, or identify a single point of contact to administer all federal vessel disposal for purposes of reefing (as opposed to dealing separately with USCG, MARAD, U.S. Navy, etc.)

- Recommend that as part of a national coordinated reefing plan, and prior to the release of any ships under such a program, that the federal government be encouraged to the maximum extent possible to take all necessary steps to fund the cleaning, preparation, towing and sinking of these vessels in their entirety as a turnkey project, at a location selected by the state reef program designated to obtain the vessel. If some cost sharing were necessary, the bulk of this extra cost would be born at the local coastal government level, by private individuals, or by the state artificial reef agency, or a combination, whichever was appropriate for the circumstances.

- Recommend that as part of the planning process for sinking vessels, particularly those complex naval auxiliary and combatants where orientation of the vessel once sunk is important, that the original stability information and associated blueprints be available along with marine engineer, architect, and naval demolitions expertise, if necessary.

- Recommend that the federal government develop and present to the individual coastal states, the ASMFC and GSMFC, and the federal Gulf, South Atlantic and Mid Atlantic Fishery Management Councils a formal reefing plan that includes an estimate of the number of vessels that can reasonably be cleaned and deployed on a yearly basis by state, based upon availability of Navy/MARAD/EPA approved shipyards that can serve as cleaning and salvage facilities. If the federal government cannot fund this reefing program in its entirety, the plan should provide a clear estimate of any anticipated funding shortfalls that would have to be absorbed by states and/or their stakeholders. The federal government should also prepare an Environmental Impact Statement (EIS) developed in accordance with the National Environmental Policy Act (NEPA). The alternative that the federal government provide grant funding to states to deal with MARAD and Navy combatants when such vessels are released “as is/where is” without any accompanying technical expertise and assistance is not a preferred alternative.

- Recommend that as part of a coordinated national ship sinking plan, that the EPA, in conjunction with the USCG and other agencies, develop a consistent and detailed artificial reef vessel cleaning, preparation and inspection protocol. The commissions should continue to press for a comprehensive set of vessel cleaning and preparation standards that would apply uniformly to both federally donated military vessels and civilian vessels procured from the private sector.

- Recommend that the EPA provide a unified agency policy that addresses the issue of a vessel sunk as an artificial reef as a “disposal” project versus a “continued use” project.

- Recommend that the EPA clarify issues related to environmental liability and damage, under the Resource Conservation Recovery Act (RCRA) and Comprehensive Environmental Response, Conservation, and Liability Act (CERCLA). For instance, is the MARAD or the Navy, as originators of a material (ship) and any associated hazardous waste, responsible for that material or is environmental liability and responsibility transferred by title to the artificial reef permit holder?

- If a federal large ship artificial reef program is developed, recommend that serious consideration be given to placing some of these vessels as enhanced habitat in established Marine Protected Areas (MPAs) in both the Gulf of Mexico and Atlantic Ocean, with particular emphasis on supporting potential reef fish spawning aggregations, and providing deep-water outer shelf habitat enhancement at depth of 200-500 feet to such species as snowy grouper, Warsaw grouper, speckled hind, gag, red snapper, amberjack, and other fully or over exploited reef fish species. The artificial reef subcommittees of the interstate fisheries commissions could coordinate with the NMFS and the Gulf and South Atlantic Fisheries Management Councils to identify either existing MPAs, or create new artificial reef zones for these ships with Special Management Zone (SMZ) designations that would accommodate complete or partial restriction of fishing gear. The authority to create new SMZs or other MPAs rests with the Regional Fishery Management Councils and NMFS. Any new SMZs or MPAs for such a project should be in an area that has very limited or absent hard-bottom habitat resources and is otherwise not utilized. This will prevent any possible user conflict, and should be supported by all.

- Recommend that if a national large military ship reefing program were established that involved coordination through the interstate fisheries commissions, then any new independent ship-by-ship individual applications to MARAD by state agencies terminate.

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## 2.3 FERRO-CEMENT VESSELS AND DRY DOCKS

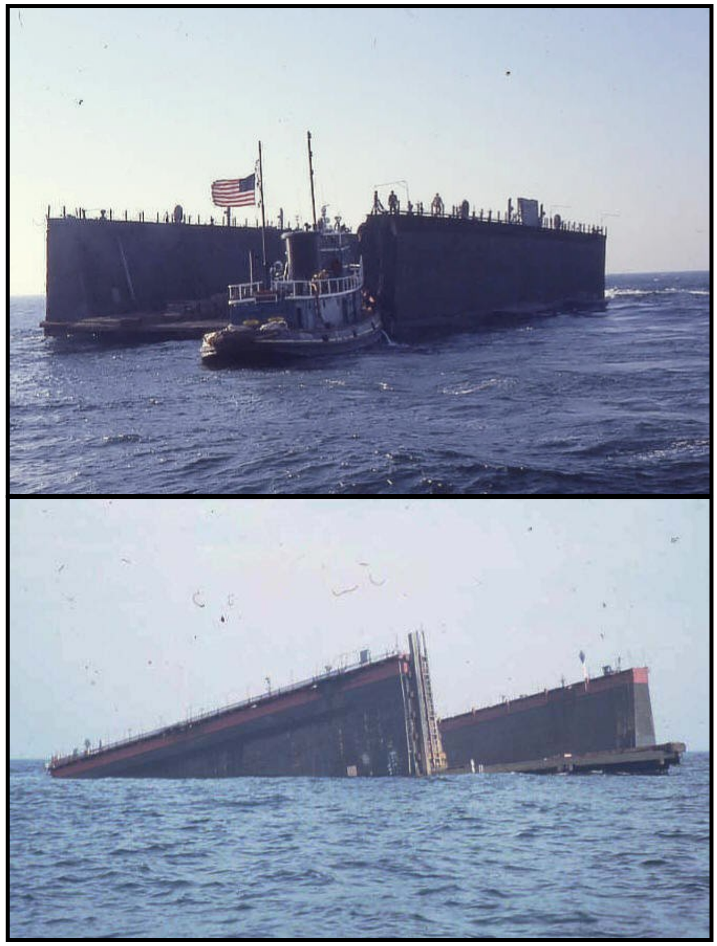
### Ferro-cement Vessels

Information on the use of ferro-cement vessels as artificial reefs is sporadic, though available. These vessels have become rare due to their composition and the availability of other hull materials. As recreational hulls, they are relatively free of pollutants and can be cleaned with minimal involvement and towed to sites with small vessels. Lee County, Florida reported sinking a 60-foot ferro-cement boat which remained intact only about four months. The sides collapsed and the vessel was eventually covered over (Bob Wasno, personal communication). A 50-foot ferro-cement sailboat, sunk on hard bottom in a 70 foot deep dredge depression in 1993 off Broward County, Florida, was still intact after two years, and had hundreds of mangrove snapper milling around the hull and interior (Jon Dodrill, personal communication). Two ferro-cement vessels were placed off New Jersey. One vessel, unballasted, disappeared. The ballasted vessel remains functional (Bill Figley, personal communication). North Carolina has sunk two ferro-cement vessels in approximately 65 feet of water since 2012 (Gregg Bodnar, personal communication). The vessels are approximately 50 feet long, and were derelict vessels acquired by a local artificial reef association. To date, the vessels have remained in their intended locations.

### Dry Docks

Dry docks have been utilized as artificial reefs off Alabama, New York, Virginia, and northeast and southeast Florida. Dry docks were readily accepted as reef material in New York's artificial reef program. The structures used were 30 to 50 years old, made from treated yellow pine, had significant steel components, and were considered stable with a 20 year estimated lifespan. Sonar surveys of three dry docks within ten years of deployment showed some deterioration, including collapsed wing walls. Complaints were received from trawlermen about catching large timbers in their nets. Though it could not be verified that the timbers were from the dry docks, New York no longer accepts them in their program. The existing dry dock reefs, however, continue to function effectively as fishing and diving reefs (Chris LaPorta, personal communication). In the early 1980s, wooden dry docks were sunk off Virginia Beach, Virginia and there are no reports of major structural damage. It is strongly recommended that wing walls be removed prior to sinking, or they may become detached and can resurface or appear onshore (Mike Meier, personal communication).

Alabama has deployed dry docks, which are made of large heart pine timber. These large structures were used to float ships for repair in Mobile Bay. The first one was deployed in 1972. This dry dock is still a viable reef structure and popular fishing site, though recent surveys have not been conducted to determine any level of dissociation. Alabama has been pleased with the performance of this material, and deployed another dry dock in 1999. Alabama would not hesitate to reef another dry dock if the opportunity was available. (Craig Newton, personal communication).



The tremendous resistance offered by the surface area of the wing walls of a large dry dock, and the impacts of strong current and surge activity of a major storm event on these structures is illustrated by the response of a large dry dock off Jacksonville, Florida, to a hurricane event. The U.S. Navy donated the steel dry dock, which was 615 feet long, 127 feet wide, and 57 feet tall. At that time, it was one of the longest structures ever sunk on the Atlantic Coast as an artificial reef. The dry dock sank in 20 minutes in 125 feet of water without the use of explosives on Sept. 13, 1989. Following the passage of Hurricane Hugo shortly after its deployment, the dry dock was noted to have shifted its long axis orientation from 330 degrees to 20 degrees, and both of the massive 13 foot thick wing walls had separated at the base and fallen over. Several years later, even with wing walls collapsed, the structure was still considered by locals to be a successful artificial reef, attracting a variety of marine life (Berg and Berg 1991, Rinehart 1991, Virginia Vail, personal communication).

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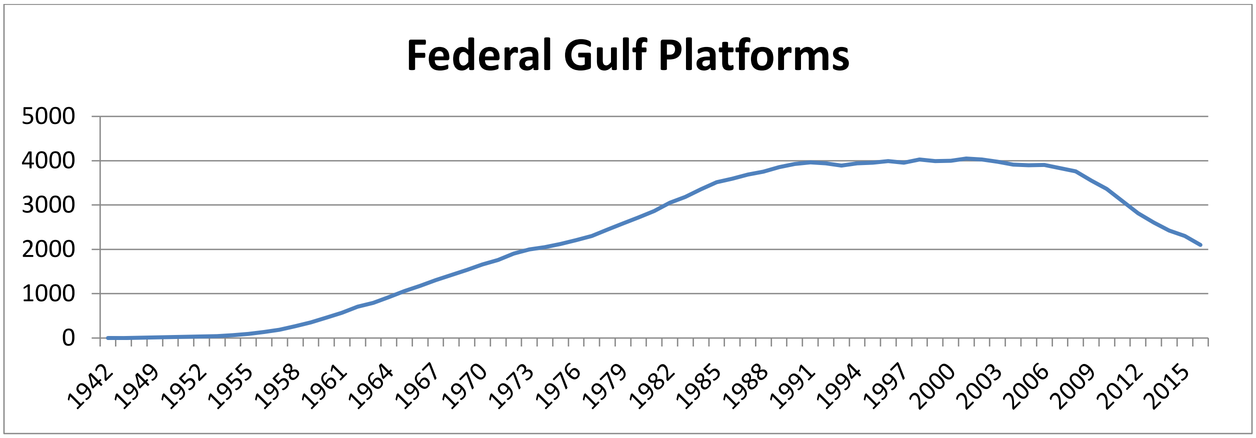
## 2.4 OIL / GAS PLATFORMS AND SIMILAR STRUCTURES

<u>History of Rigs-to-Reefs</u>

Offshore oil and gas exploration began in the Gulf of Mexico shortly after the end of World War II. Louisiana geologist Dean McGee recognized that since oil and gas reserves were often associated with salt domes on land, the same situation would occur in Louisiana's shallow waters off Ship Shoal. Early in 1946, Kerr-McGee acquired the first offshore leases 43 miles south of Morgan City, Louisiana. The leases covered about 40,000 acres in fairly shallow waters. In 1947, petroleum platforms first began functioning as artificial reefs when Kerr-McGee completed the world's first commercially successful oil well 10.5 miles offshore out of sight of land by developing new technology to drill in 18 feet of water. They began drilling operations on September 12, 1947 and made history when they struck oil 22 days later, on the morning of October 4. Since that time, technology has improved, and offshore oil and gas development has expanded into waters well over 7,000 feet (U.S. Department of Interior 2000).

While the actual number of extant petroleum platforms currently on the Federal U.S. Outer Continental Shelf (OCS) in the Northern Gulf of Mexico is hard to quantify, as of 2016 they totaled approximately 2,100. Petroleum platforms facilitate the extraction and processing of oil and natural gas after the drilling rigs have discovered hydrocarbons, and developed wells to bring them to the surface. Due to the location of oil reserves in the Gulf, fixed platforms are primarily located offshore of Louisiana and Texas. They come in a variety of sizes and configurations, ranging from simple single pile (leg) caissons to complex towers in 1,754 feet of water. For deep waters greater than 1,500 feet, advances in technology have allowed for the installation of floating production platforms such as semi-submersibles, tension leg platforms, and spars.




Gulf of Mexico Federal OCS Platforms Source: Bureau of Safety and Environmental Enforcement (2017)

Over the years, it was recognized by fishermen, citizens and the scientific community that petroleum platforms were extremely valuable as marine habitat. The legs were covered in marine growth and each platform inadvertently created a marine reef microcosm. So it was no surprise that their removal and scrapping caused concern by scientists and citizens, which stimulated a need to protect this existing marine habitat.

In 1980, the U.S. Minerals Management Service (MMS), along with other agencies, academia and the petroleum industry, initiated an effort to develop a Rigs-to-Reefs Program for the Gulf of Mexico through an interagency agreement with the National Marine Fisheries Service (NMFS). The agreement laid the framework to:

- Develop a national policy that recognized the artificial reef benefits of oil and gas platforms;
- Prepare a Rigs-to-Reefs Program plan for the Gulf of Mexico;
- Establish standard procedures to ensure and facilitate timely conversion of obsolete platforms as reefs;
- Identify research and studies necessary to optimize the use of platforms as reefs; and
- Identify legal restrictions that could prevent using obsolete platforms as reefs.

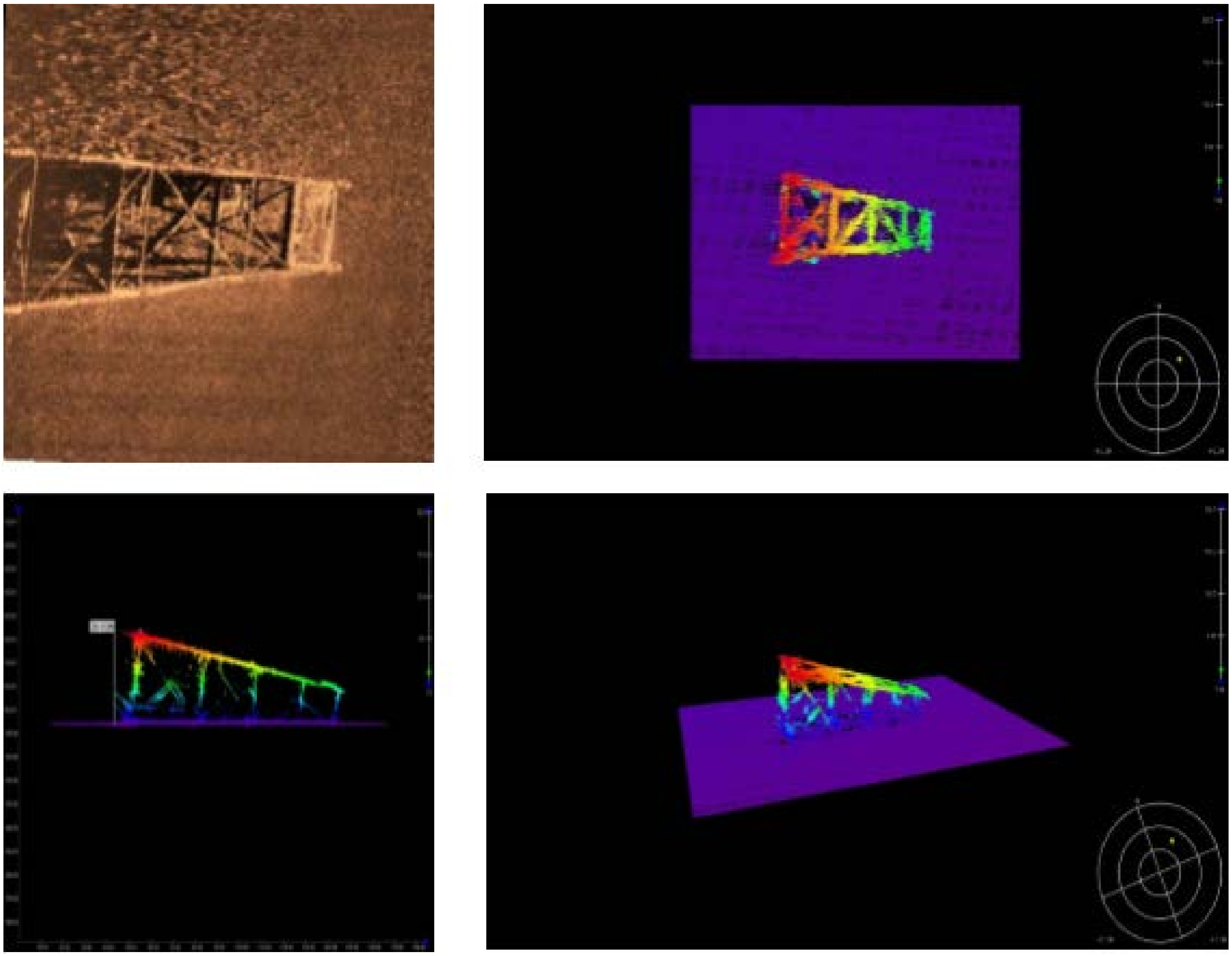
This goal was realized when The National Fishing Enhancement Act was signed into public law (Public Law 98-623, Title II) in 1984. The U.S. Congress signed the Act because of increased interest and participation in fishing at offshore oil and gas platforms, and widespread support for effective artificial reef development by coastal states. The Act recognizes the social and economic values in developing artificial reefs, establishes national standards for artificial reef development, provides for creation of a National Artificial Reef Plan, and provides for establishment of a reef-permitting system.

In 1985, NMFS laid the foundation for Federal endorsement of offshore artificial reef projects when it developed and published the National Artificial Reef Plan under Title II of the National Fishing Enhancement Act of 1984 (33 USC 2101). Since then, MMS (and through its reorganization) has supported and encouraged the reuse of obsolete oil and gas platform jackets as artificial reef material, and can grant a departure from removal requirements under 30 CFR §250.1725(a) and applicable lease obligations provided that:

- The structure became part of a state reef program that complied with the National Artificial Reef Plan;
- The state agency acquired a permit from the U.S. Army Corps of Engineers, and accepted title and liability for the reefed structure once removal/reefing operations were concluded;
- The operator satisfied any U.S. Coast Guard navigational requirements for the structure; and
- The reefing proposal complied with MMS engineering and environmental reviewing standards.

Dauterive (2000) discusses the development of the Rigs-to-Reefs policy, progress, and perspectives through the 1990s. During this same time-frame, several Gulf states established Artificial Reef Programs to incorporate this material into their habitat programs.

From the 1980s to date, the Rigs-to-Reefs Program has undergone several modifications, with the most significant event occurring after Hurricanes Katrina and Rita hit the Gulf coast in 2005. During the hurricanes, more than 100 petroleum platforms were damaged or destroyed, and many laid scattered on the ocean floor. Platform operators applied to MMS to convert many of these downed platforms to artificial reefs by leaving them in place after well abandonment was completed and hazardous materials were removed. As the number of reefing requests increased, MMS became concerned of the impact of artificial reefs being scattered across the Gulf without a management plan. In 2009, MMS drafted the *Rigs-to-Reefs Policy Addendum: Enhanced Reviewing and Approval Guidelines in Response to the Post Hurricane Katrina Regulatory Environment* (MMS, 2009) to establish specific guidance for reefing petroleum platforms.



Oil rig (MP 279) deployed off the coast of Mississippi as an artificial reef in 311 feet of water with almost 130 feet of relief off the bottom (David Evans and Associates, Inc. 2016).

Soon after the Deepwater Horizon rig explosion on April 20, 2010 and subsequent oil spill, the MMS was restructured into the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE), which in turn, underwent a major reorganization in October 2011. BOEMRE was replaced by the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE). BSEE currently oversees the decommissioning of obsolete platforms and their use as artificial reefs in federal waters (state agencies regulate platform decommissioning in their respective state waters).

On September 15, 2010, prior to this restructuring, BOEMRE issued a Notice to Lessees (NTL) entitled *Decommissioning Guidance for Wells and Platforms* (also known as the “Idle Iron Policy”) (BOEMRE, 2010). The notice clarified that the BOEMRE policy for removing platforms from the ocean bottom should be as soon as possible, but no later than five (5) years after decommissioning the platform (i.e., platform no longer useful for operations).

The Idle Iron Policy created a sense of urgency for many petroleum companies in the Gulf, and many bypassed state Rigs-to-Reefs Programs altogether to facilitate removal, thereby creating a significant loss of marine habitat. This urgency still exists today. In the last five (5) years, platform removals in the Gulf have averaged 207 per year. At that rate, it is feasible that all 2,100 standing platforms in the northern Gulf of Mexico could disappear by 2029, creating a significant loss of marine habitat.

- However, it is not always economical to convert a platform into an artificial reef. Many factors are considered when creating a Rigs-to-Reef, including: the size of the structure, water depth, distance from shore, proximity to final reef site, and potential resale value (Michael McDonough and J. Dale Shively, personal communication). Other factors affecting conversion of an obsolete platform to an artificial reef include structural complexity and stability, navigational safety, future maintenance and liability, and other OCS users.

<u>State Rigs-to-Reefs Programs</u>

With the lack of natural hard substrate in the Gulf of Mexico, and the decline of many marine species Gulf-wide in recent years, the need for sustainable marine habitat is critical. In addition, the steadily increasing popularity of sport diving and fishing in the Gulf makes the use of obsolete petroleum structures a highly attractive option in creating artificial reefs. Benefits of using platforms as reefs include: 1.) social and economic benefits to the local community through the recreational/charter fishing and diving industry; 2.) petroleum jackets are durable and stable with long life spans as reefs that could exceed 100 - 300 years or more based on simple corrosion rates (Quigel and Thorton, 1989; Roberge, 2008); 3.) the high vertical profiles of platforms attract both pelagic and demersal fishes; 4.) the hard substrate provided by platforms allow the settlement and growth of invertebrates; and 5.) depending on location, platform reefs can hold a large biomass of commercially and recreationally important fish species.

Since petroleum platforms are so commonplace in the Gulf, many citizens and management groups today have a misconception that they are permanent, and will always be available for fishing. However, this is not the case. Before the Rigs-to-Reefs program was established, many coastal states who recognized the potential of these structures as artificial reefs, began seeking ways to secure the platforms from their coastal waters as fish habitat.

The first decommissioning of a federal platform occurred in 1973 with South Timbalier 23, offshore Louisiana. This platform was removed, but not reefed. At that time, more than 2,000 platforms had been installed in the Gulf of Mexico, primarily offshore Louisiana and Texas. By the end of 1980 almost 200 platforms had been decommissioned and removed from the Gulf of Mexico.

In 1978, Exxon offered a 2,200-ton experimental Subsea Production System (SPS) to the State of Florida for use as an artificial reef. After two years of negotiations, the SPS was severed from the sea floor in Louisiana's West Delta area, and towed 300 miles to a preselected site in Florida.

By 1982, a Tenneco structure was removed from the coast of Louisiana, towed 275 miles, and placed approximately 22 miles off the Florida coast. A year later in 1983, Marathon Oil Company towed a 1,650-ton oil platform 220 miles from Louisiana to an artificial reef site 50 miles south-southeast of Mobile Bay, Alabama.

Today, once a platform is identified for decommissioning, Gulf states having a Rigs-to-Reefs Program begin negotiations to obtain the structure for its reef program. While a detailed synopsis of each Gulf state's reefing program utilizing petroleum platforms is beyond the scope of this report, a brief overview by state is given below. Total number of platforms reefed by state range from zero to 391 (Table 2.4.1).

Table 2.4.1 Number of petroleum platforms deployed as artificial reefs within state/federal waters of each state at the end of 2016.

| State | Platforms Reefed | R2R Habitat Footprint (acres) (1) | Number of Platforms Remaining in Federal Waters | Rigs-to-Reefs Program? (4) |
|---|---|---|---|---|
| Florida | 4 | Unknown | 0 (2) | No |
| Alabama | 7 | 0.95 | 39(3) | No |
| Mississippi | 16 | 1.81 | | Yes |
| Louisiana | 391 | 244.90 | 1,888 | Yes |
| Texas | 158 | 66.10 | 175 | Yes |
| California | 0 | 0.00 | 23 | Yes |
| **Total** | 576 | 313.76 | 2,125 | 2 No : 4 Yes |

Notes: 1.) Based on final survey data; estimated for FL, AL, MS where some surveys are missing.
2.) No platforms were installed in FL federal waters.
3.) For both AL and MS combined.
4.) "Yes" signifies that a State has a legislatively mandated Rigs-to-Reefs Program.

- Florida

Florida does not have specific legislation authorizing a Rigs-to-Reefs Program, but four platforms have been reefed offshore of several Gulf counties. The first reefing took place in 1980 (some records indicate 1979) with the placement of an Exxon experimental subsea template which was transported from offshore Louisiana and placed in 106 feet of water 27 miles SSW of Sikes Cut, Franklin County, FL. The other three platforms were deployed off Escambia and Dade/Broward counties from between 1980 and 1993. All decommissioned energy structures were donated by Tenneco, Exxon, and Chevron oil and gas companies, with responsibility and liability assumed by the recipient Florida counties holding the artificial reef permits. No funding was expended by either local coastal governments or the state of Florida on preparation, transport, or deployment of the structures.

From a statewide perspective, decommissioned energy structures are not a significant component of Florida's overall artificial reef program. As of October 2017, there were over 3,300 reported public reef sites off both of Florida's coasts combined with Rigs-to-Reefs, which accounted for four sites. Depth requirements for these platform structures are in excess of 100 feet to allow for suitable navigational clearance of at least 50 feet. This makes the sites less readily accessible to fishers and divers, though boaters who have the means to access these reefs place high value on them (Robert Turpin, personal communication).

On a local basis, the decommissioned petroleum structures are an important component of county artificial reef programs. Off Escambia County (Northwest Florida) in particular, where the Chevron and the Tenneco structures are placed, the decommissioned rigs are valued for their durability and stability, being resistance to both movement and major structural damage in hurricane events.

There is currently no active offshore energy production in Florida state waters or in the Exclusive Economic Zone immediately adjacent to the state, which limits the state's ability to obtain additional platforms or develop a significant Rigs-to-Reefs program.

- Alabama

Though Alabama does not have specific legislation creating a Rigs-to-Reefs program, the state does accept petroleum platforms into its Marine Resources Division Artificial Reef Program, similar to Louisiana, Texas, and Mississippi. Alabama saw its first Rigs-to-Reefs structure with the reefing of a Marathon Oil Corporation platform in 1983. Since that time, Alabama has incorporated six other platforms into its reef program. Alabama does not have specific reef areas designated for petroleum structures; they are reefed within its large 1,030 square mile permitted reefing area.

- Mississippi

In 1999, Mississippi's legislature, realizing the importance of an artificial reef program, approved state statutes which gave the Commission on Marine Resources the authority to develop the Rigs-to-Reefs program. Legislation similar to that of Louisiana and Texas was developed to allow for the inclusion of obsolete platforms into its reef program and associated donations. Ownership and liability of reefed platforms are transferred to the state. Early in 2000, Mississippi received its first two donations. These platforms were located and reefed 25 miles southeast of the Chandeleur Islands in 185 feet of water. To date, 16 platforms have been added to the program's 2,491 reef acres.

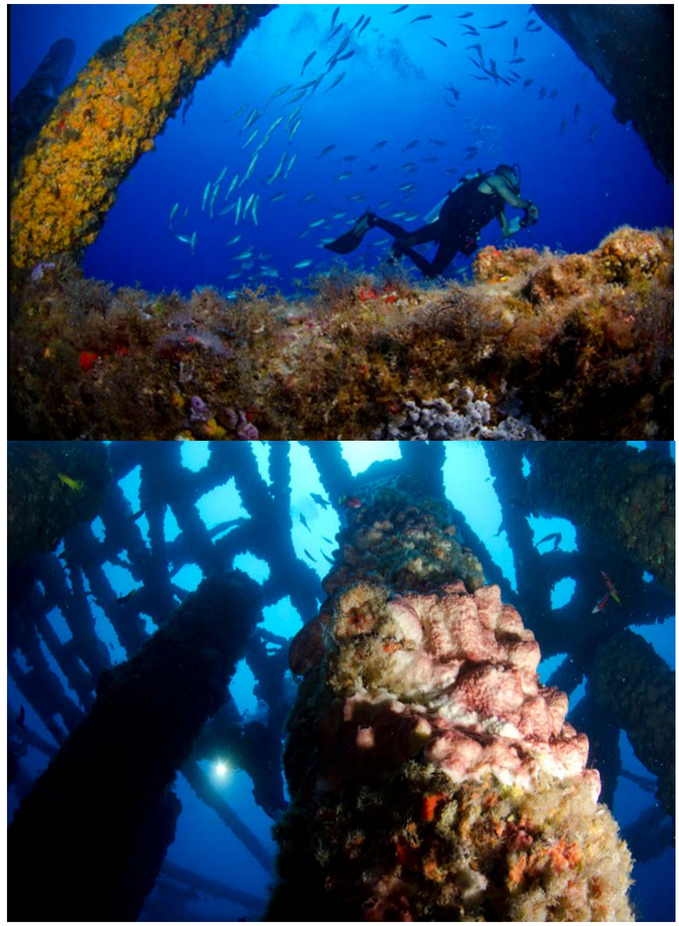
- Louisiana

On June 25, 1986, the Louisiana legislature signed into law *The Louisiana Fishing Enhancement Act* (Act) to take advantage of the availability of obsolete oil and gas platforms that provided valuable reef fish habitat. The Act set up a mechanism under the management of Louisiana Department of Wildlife and Fisheries that allows the transfer of ownership and liability of a platform from an oil and gas company to the state.

Louisiana's artificial reef plan originally created specific offshore artificial reef planning areas through an exclusion mapping process for reef site development, and later added provisions to create Special Artificial Reef Sites (SARS) and Deepwater reef sites outside the planning areas. In 2016, nearshore reef planning areas were approved to allow the development of artificial reefs offshore Louisiana in waters less than 100 feet.

Under Louisiana's artificial reef program, oil and gas companies can pursue the option of reefing their obsolete structures within a state-designated reef site. Occidental Petroleum Corporation (OXY) donated the first platform, SM-146A, an 8-pile structure, to the Louisiana artificial reef program in 1987. To date, Louisiana leads all Gulf states in number of platforms reefed, with 391.

- Texas



Texas Rigs-To-Reefs. Photo Credit Texas Parks and Wildlife Department.

In 1989 Texas passed legislation that directed Texas Parks and Wildlife Department (TPWD) to promote, develop, maintain, monitor, and enhance the artificial reef potential in state and federal waters adjacent to Texas. This legislation also directed TPWD to "actively pursue acquiring offshore platforms for use as artificial reefs in the Gulf of Mexico, in deference to other structures" (Stephan et al. 1990). The *Texas Artificial Reef Management Plan* was approved in 1990, formally establishing the Texas Artificial Reef Program. Later that same year, Texas reefed its first petroleum platform, the Transco Exploration Company 8-pile structure, at High Island A-492. To date, it has 158 platforms and numerous other components of structures (e.g., net guards, decks, caissons, etc.) reefed in 60 permitted reef sites. Overall, Texas has 91 reef sites ranging in size from 20 acres to 1,650 acres. Most platforms are reefed in 40-acre sites.

The Texas Rigs-to-Reefs program is similar to that of Louisiana, with the exception that Texas reefs are not restricted to planning areas. Each individual Rigs-to-Reefs proposal is submitted to BSEE and U.S. Army Corps of Engineers (USACOE). Many platforms are towed to existing permitted reef sites, while others are permitted in place. The approved location of a reef site is determined by its proximity to shipping lanes, anchorages, and other conditions of concern to the USACOE and U.S. Coast Guard.

- Other States

Other than the Gulf states, California is the only other coastal state with platforms in its offshore Federal OCS waters, having 23. After several failed attempts to pass Rigs-to-Reefs legislation, California passed the *California Marine Resources Legacy Act* (AB 2503) in 2010 to establish a program to allow partial removal of offshore oil structures. No platforms have been reefed to date due to a lack of public support (many Californians compare Rigs-to-Reefs with ocean dumping), misinformation dispersed by some groups, and a general lack of understanding of how valuable platforms are as marine habitat (Blue Latitudes LLC 2017). For years, researchers at the Marine Science Institute, University of California - Santa Barbara have documented the importance of these platforms in forming refuges for rock fish (*Sebastes* spp.) and providing valuable habitat to other marine life (Schroeder and Love 2004; Love et al. 2003; Caselle et al. 2002).

Reefing of Petroleum Platforms

- General Process

Many petroleum platforms have a productive life span of 30-40 years before oil reserves are too low to make them economically viable to operate. When an Outer Continental Shelf (OCS) lease expires and/or development and production of platform operations cease, companies are obligated to decommission and remove their facilities (30 CFR §250.1725(a)) and clear the seabed of all obstructions (30 CFR §250.1740). At this point, platforms are decommissioned (all production stopped), wells plugged, the structure is removed down to -15 feet below the mudline and taken into shore for scrapping or reuse per federal regulation.

In lieu of complete removal, a petroleum company can request a departure from BSEE per 30 CFR §250.1730 and enter into an agreement with a state that has an authorized Rigs-to-Reefs program to reef the structure. The state will direct the conditions of reefing through a Material Donation Agreement (or similar). The agreement will detail where the reefing will occur, how the structure is to be reefed, when the state will accept liability for the structure, and the negotiated donation amount to the state reef program for assuming future liability and maintenance. In a typical platform donation, the petroleum company will save money by entering into an agreement with a state to reef the platform. The company then reefs the platform at their expense, while donating a percentage (normally 50%) of the realized savings to the state management agency.

Donation amounts are generally unique to the individual structure, and vary due to the size and type of platform, its location, and water depth. For example, Texas donations have ranged from less than $100,000 to $2.5 million. Texas has waived the donation in several cases where reefing would have been a net loss to the company to ensure they acquired the habitat for the reef program. These funds are deposited into state treasury departments where they are used to manage the reef programs.

Decks are not typically incorporated into reefing programs, since they essentially need to be stripped down to structural steel to meet environmental requirements. The decks hold the petroleum production equipment, crew quarters, cranes, and other equipment. Most companies do not find it cost effective to clean the decks offshore and prefer to let the salvage yards onshore, equipped to deal with the various equipment and contaminants, repurpose or dispose of the decks. Under special circumstances, decks may be considered, provided they are free from all potentially hazardous and non-structural items. Certification that the decks are clean is generally performed by a third party, and a certification report provided (Maher 1993). Historically, Louisiana accepted some decks toppled by Hurricanes prior to 2005, and Texas accepted one that was dislodged off a barge during a storm while in transit to shore in 1991. Only two decks have been purposely prepped for reef deployment with the platform jacket.

Not all platforms are good candidates for reefing. Reefing a platform in place or towing it to an existing reef site is dependent on the size of the structure, structural integrity, US Coast Guard clearance requirements, proximity to navigational safety fairways, water depth, tow distance, and other OCS uses. Each states reef program varies in how reef sites are selected and developed. For example, Texas currently can request to reef a platform within any area of Texas waters by applying for and receiving an approved Individual Permit (Section 12, Rivers and Harbors Act of 1899) through the U.S. Army Corps of Engineers.

While the process of reefing a platform can be fairly straight forward, changes in regulations, policy, or permit processing can alter the process. For instance, the U.S. Army Corps of Engineers-Galveston District (USACOE) recently changed Texas' permitting requirements that had been in effect since 1990. In the past, Texas was able to add additional platform jackets within an established reef, provided the active reef permit requirements were met. When a permitted reef site approached expiration (typically every 5 years), TPWD would request an extension so that the site remained active for additional reef enhancement as platforms became available. Currently, the reef permit expires after each reefing event. To enhance the reef with additional platforms, TPWD must resubmit a reefing request for each new platform. The permit process can take 3-6 months per request, and in some cases, has resulted in the state program losing platforms because the operator decided not to wait for the permit before removing the platform.

Changes in offshore jurisdictional boundaries can also alter the process of reefing a platform, as is the case of High Island 389A, a platform which was installed years before the Flower Gardens Banks area of the Gulf of Mexico was designated a National Marine Sanctuary. The platform now lies within the established sanctuary boundary which is managed and regulated by the U.S. National Oceanographic and Atmospheric Administration (NOAA). To date, the additional permitting process has delayed the reefing for over 5 years.

- Platform Deployment Options

Once oil or gas wells are properly plugged and abandoned and the structure meets engineering and environmental standards, there are three reef deployment options available to the petroleum company: topple-in-place, tow-and-place, and partial removal (Dauterive 2000). The topple-in-place and tow-and-place reefing options require the well conductors and jacket legs to be severed at least -15 feet below the mudline. The severance of the well conductors and jacket legs is either performed via explosives or mechanical methods (mechanical removal is the preferred method with the least environmental impact).

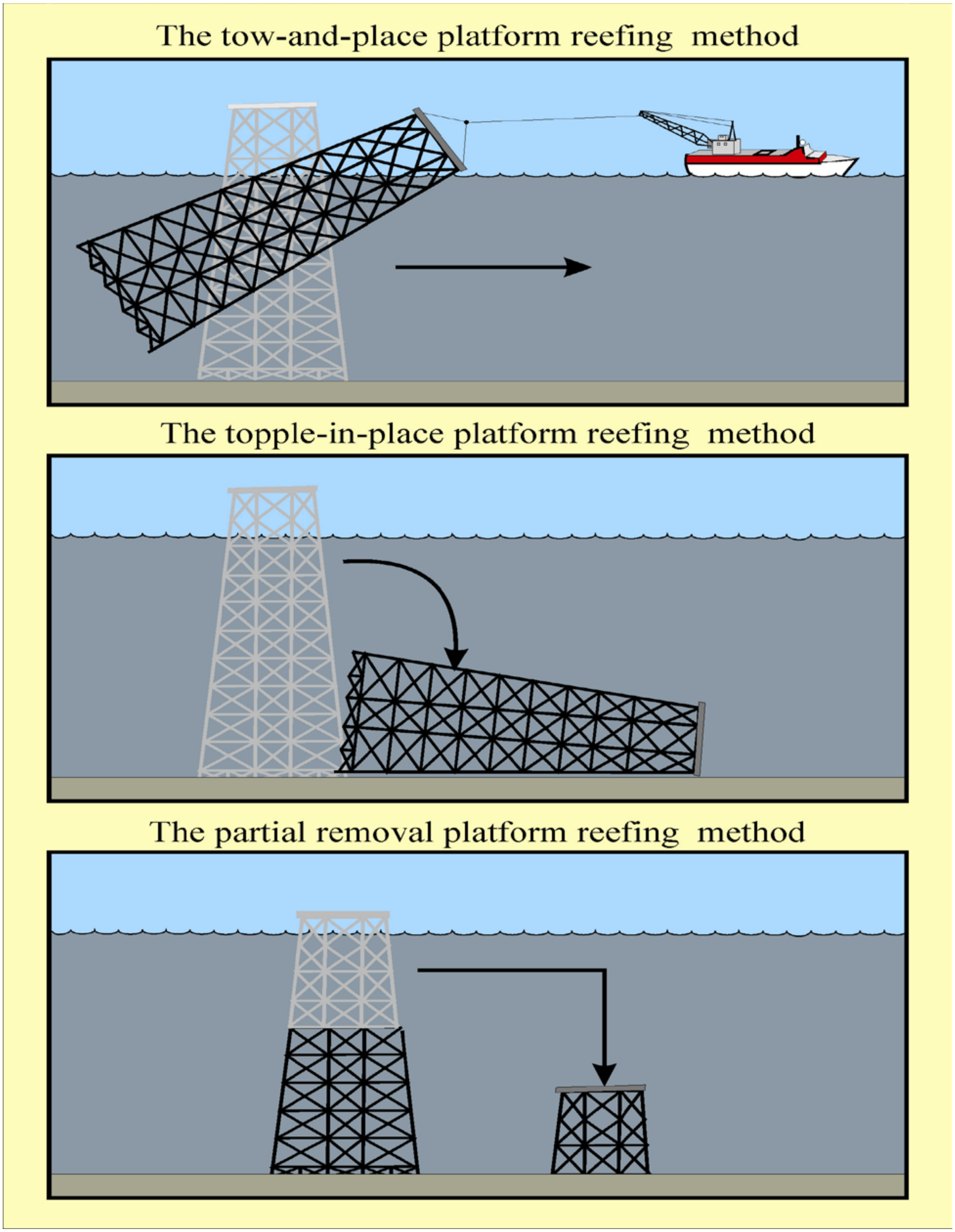
In 2005, the U.S. Minerals Management Service drafted a Programmatic Environmental Assessment to address structure-removal operations (MMS 2005). If explosive severance is the chosen decommissioning method by the operator, mitigations are applied based on charge amount, charge configuration and species-delineation zone (shelf <200m or slope >200m). The mitigation and monitoring requirements were developed in coordination with protected species scientists (from NOAA fisheries and MMS), and explosive-severance experts. NOAA Fisheries Observers from the Platform Removal Observer Program (PROP) are required to perform Marine Protected Species (MPS) detection surveys for all blasting scenarios, except for very small blasting scenarios. Trained company observers are allowed to perform MPS detection surveys for very small blasting scenarios. However, mortality of turtles and marine mammals is not acceptable; therefore, companies use NOAA Fisheries observers for all blasting scenarios to reduce the company's overall liability.

Explosive severance potentially reduces time spent severing the structure, and reduces commercial diver exposure, therefore reducing decommissioning costs. The disadvantage to the use of explosives is the potential mortality of sea turtles, marine mammals, and fish that might be associated with structures. Gitschlag et al. (2001) studied the effects of explosives on fish populations during the explosive severance process, and found that though large numbers of fish are killed, the overall impact to the population was relatively small.

Mechanical severance has developed into a viable and preferred severance option for some operators in the platform decommissioning process. In the early years of decommissioning, mechanical severance often involved utilizing commercial divers to cut the jacket legs and well conductors below the mudline. A range of mechanical and abrasive cutters have been developed over the years to provide an alternative approach to explosive severance. The early devices were time-consuming, labor intensive, less dependable, and expensive. Advances in technology, decreased costs, and reduced commercial diver exposure have put mechanical severance on par with explosive severance. The required cleanup of an unprecedented number of toppled platforms from the 2005 hurricane season provided additional stimulus to the development of mechanical decommissioning methods. The main advantage of mechanical severance is the decreased impacts and mortality to living marine life associated with the platform.

Once the legs are severed, the entire platform jacket can either be toppled-in-place or towed to a designated deployment location as permitted. Toppling the jacket generally involves a derrick barge pulling it over so that the jacket lays on the seafloor in a horizontal position. Towing the structure requires lifting the jacket from the seafloor to a safe towing height, about 40-100 feet above the seafloor, using a derrick barge or other heavy lifting vessel. A jacket can weigh from several hundred tons to more than 6,000 tons, depending on the number of piles and its vertical height. Depending on the depth at the permitted deployment location and the jacket configuration, the towed jacket is either lowered and left in a vertical position (standing upright) or toppled horizontally like a topple-in-place.

The third, and most favored removal option by state agencies, involves the partial removal of the upper portion of the jacket and placing it on the seafloor next to the existing bottom portion of the jacket, or occasionally towed to a shallower reef for deployment. The bottom section of the jacket remains undisturbed from the seafloor up to the designated height where the upper portion is cut. The primary premise for a partial removal Rigs-to-Reefs project is to preserve the artificial habitat in its current state with minimal disturbance; therefore, mechanical methods are used to sever the jacket piles at a predetermined depth that allows for safe navigational clearance.




The three reefing methods available to petroleum companies in the Rigs-to-Reefs Program: tow-and-place, topple-in-place, and partial removal (Dauterive 2000).

The partial removal method is particularly beneficial with deep water structures that are converted into reefs. The relatively undisturbed base of the jacket remains in place, and continues to provide beneficial habitat for a large number of pelagic and reef fish associated with the platform. Also, the deployed upper jacket section provides an equal or slightly lower profile to compliment the standing jacket base, and increases the overall surface area of the structure for habitat enhancement. For deep water structures (>400 feet), the upper jacket is often taken to a shallower reef site closer to shore or recycled onshore.

From 1987-2016, 4,959 platforms were removed from the Gulf of Mexico Federal OCS waters. Of those, 516 platforms (11.19%) have become permanent artificial reefs. Caissons and structures in waters less than 100 feet are not readily assimilated into state Rigs-to-Reefs programs. Only 1.07% of the structures removed from waters 100 feet or less have been deployed or converted to artificial reefs. Petroleum companies typically find it more cost-effective to scrap these shallow water structures. In addition to the financial bottom line, competing uses of the seafloor or water column, navigational clearance, and permitting requirements to develop an artificial reef factor into the decision to scrap or reef a decommissioned structure. As the structures get more complex, and the water depth increases, the rate of capture by state Artificial Reef Programs significantly increases (Table 2.4.2). The rate of Rigs-to-Reefs conversions for decommissioned structures in greater than 200 feet of water increases to 62.11 %.

Table 2.4.2 Percentage of decommissioned platform jackets deployed as artificial reefs.

| **All Gulf States 1987-2016** | |
|---|---|
| **Depth Range** | **% Reefed** |
| 0-100 ft. | 1.06% |
| 101-150 ft. | 18.37% |
| 151-200 ft. | 41.62% |
| >200 ft. | 62.11% |
| **Overall** | **11.19%** |

Habitat Value of Petroleum Platforms

Fisheries of the U.S. have undergone extensive analysis in recent years in response to overfishing and other threats. In 1996, Congress passed the Sustainable Fisheries Act as an amendment to the 1976 Fishery Conservation and Management Act, emphasizing the protection of essential fish habitat (EFH). Eight national fishery management councils were established to incorporate EFH into their fishery management plans. Creating new, and enhancing existing habitat, is one of the recommendations in the 1998 Gulf of Mexico Fishery Management Council document: *Generic Amendment for Addressing Essential Fish Habitat Requirements in (existing) Fishery Management Plans of the Gulf of Mexico.* Habitat added by artificial reefs, especially decommissioned petroleum platforms in the Gulf of Mexico are essential in increasing hard surface area for sessile organisms and other marine life.

Fixed platforms on the Gulf of Mexico continental shelf and slope provide an important source of hard substrate or reef habitat (Reggio and Kasprzak 1991). Bottom habitat in the Gulf is typically dominated by clay, silt and/or sand, with little to no relief. In the 1980s, the Gulf of Mexico Fishery Management Council estimated the total natural reef habitat in the Gulf to be approximately 15,000 square miles, only one-third of which is off Louisiana and Texas where 99% of the platforms in the Gulf exist (GMFMC 1989). Gallaway et al. (1981) estimated that petroleum platforms provided just under 2,000 square miles of reef habitat, increasing the amount of reef fish habitat by an estimated 27%. Rigs-to-Reefs is an important reef habitat in the northern Gulf.

A vast amount of research has been done on the value of obsolete petroleum structures as marine habitat. It is well documented that oil and gas platforms function as important artificial reefs by providing habitat for a variety of marine species only associated with coral reefs, since many of these reef species are habitat limited (Moran 1986, Parrish 1987, Sale 1991, and numerous papers in Stanley and Scarborough-Bull 2003). In addition, platforms are excellent artificial reef material, and meet the *National Artificial Reef Plan* requirements for function, compatibility, stability, and durability needed for prime marine habitat (NOAA 2007).

Petroleum structures simulate the biological benefit of natural hard substrate in Gulf waters such as in the southern waters off Texas. To date, the Texas Artificial Reef Program has observed 151 marine fish species on Texas petroleum structure reefs through its biological monitoring program, which is more than double the 66 species that Dennis and Bright (1988) observed on natural reefs like the south Texas banks (J. Dale Shively, personal communication). These artificial reefs provide substrate for habitat-limited sessile invertebrates such as barnacles, oysters, mussels, bryozoans, hydroids, sponges, and corals. Motile invertebrates and fish species are able to use the encrusting organisms as a source of food and shelter.

Gallaway and Lewbel (1982) classified platforms in the Gulf of Mexico into three separate biotic zones based on distinct platform-associated biofouling communities and fish indicator species. The classifications were: Coastal (Beach to 98 feet), Offshore (98 to 197 feet), and Blue Water (197+ feet). The location and composition of these assemblages were influenced by several factors including: 1.) distribution of turbid layers; 2.) seasonal extremes in temperature; 3.) primary productivity of the surrounding water column, and 4.) degree and extent to which platforms are exposed to Caribbean water masses. Furthermore, Continental Shelf Associates (1982) and Ajemian et al. (2015) showed how factors such as depth and current affected the location of specific fish in relation to vertical and horizontal support legs.

Using a similar classification approach, Dokken et al. (2000) studied three types of biofouling communities on seven Texas platforms characterized by three biotic zones. The nearshore zone included platforms less than 30 miles from shore. The transitional zone included platforms from 30 miles to blue water, with the distance from shore determined by the location of the platform from the Texas coast. Platforms in the blue water zone were located in deeper, clearer water over 60 miles offshore, which had only moderate temperature changes annually. The study showed that the nearshore communities were dominated by mollusks and sponges, with hydrozoans and algae as secondary species. The nearshore community biodiversity was high, but taxonomic richness was low. They reported that transitional communities were dominated by algae and sponges, with some bryozoans, small hard and soft corals, mollusks, and barnacles. Overall diversity and taxonomic richness was high for transitional communities. Bluewater platforms had the highest diversity of all platform communities. Sponges and algae dominated these platforms, with soft corals, bryozoans, and sessile hydrozoans being secondary. Dokken et al. (2000) also reported that vertical zonation on platforms was the most important factor in determining what biofouling communities dominated the structure. Rugosity was observed as a measure of thickness of the biofouling community on platforms and appeared to be affected by a platform's distance from shore. It was also reported that one to four separate biofouling communities developed with depth on these structures.

Platforms also provide the basis for the development of an interactive food web. The high vertical profiles of these reefs attract both pelagic and demersal fishes. They provide habitat for species that feed nocturnally over soft bottoms away from the artificial reef, but which return during the day for cover. Additionally, petroleum structures attract transient species, which may be present at a reef for periods of a few hours to a few days.

In northern Gulf offshore waters, platforms provide resident fish species with food and shelter, and divers/remote operated vehicles (ROVs) frequently see blennies (Blenniidae), small grazers such as butterfly fishes (Chaetodontidae) and large grazers such as Sheepshead (*Archosargus probatocephalus*). Resident fish species relying on reef sites for cover include the Atlantic Spadefish (*Chaetodipterus faber*) and Red Snapper (*Lutjanus campechanus*). Other fish such as Lookdowns (*Selena vomer*), Atlantic Moonfish (*Vomer setapinnis*) and Atlantic Creolefish (*Paranthias furcifer*) are frequently seen feeding on macro-zooplankton and suspended particulate matter (Ajemian et al. 2015).

In addition, Red Snapper, Tomtate (*Haemulon aurolineatum*), and various grouper species (Serranidae) are typically found feeding at areas away from the reef at night, and returning during the day for cover. Large pelagic predators, such as mackerels (Scombridae) and jacks (*Caranx spp*.), are also present near the reef site in the pursuit of schools of prey species. Often, divers and ROVs will observe Great Barracuda (*Sphyraena barracuda*), Almaco Jack (*Seriola rivoliana*), Hammerhead Shark (*Sphyrna spp*.), and Cobia (*Rachycentron canadum*). On occasion sea turtles and marine mammals are observed near petroleum reefs (Ajemian et al. 2015; Texas Artificial Reef Program, unpublished data).

Researchers have found that fish abundance near a platform can range from a few hundred to several thousand individuals, depending on platform, size, location, time of survey, and orientation of the platform on the bottom (Continental Shelf Association 1982, Putt 1982). Putt (1982) found that from June through September, fish populations at platforms were variable, with fish abundance varying by a factor of two, while species composition remained constant. Stanley and Wilson (1990, 1991) examined catch records from recreational and charter boat anglers in the northern Gulf, and found that catch rates and species composition of the catch varied with season, platform size, and water depth. In a study conducted between September 1990 and June 1992, Stanley (1994) estimated an approximate monthly average of 12,000 fish associated with a platform, ranging in size from one-half inch to 3.5 feet. Fish densities not only varied seasonally, but spatially as well, with the highest densities occurring on the north and east sides of the platform, and the lowest on the south and west sides. In general, slightly larger fish are associated with a standing platform, particularly near the middle of the water column, compared to a partially removed or toppled platforms (Stanley 1994).

Ajemian et al. (2015) determined that the effects of converting standing platforms into completely submerged reefs with lower relief are generally limited to pelagic planktivores and piscivores that use the upper water column, and do not affect important demersal species like red snapper. The differences in fish communities at standing platforms was mainly driven by Bermuda Chub, a pelagic herbivore with low economic value. This species is likely more dominant at standing platforms due to greater availability of photosynthetic forage in the shallower portions of the water column.

While the physical structure of a platform provides habitat, its "sphere of influence" extends beyond the structure. Gerlotto et al. (1989) found that fish densities were five to 50 times higher immediately adjacent to a platform than at distances 164 feet away. Stanley (1994) estimated the sphere of influence around a platform in 72 feet of water to be a radius of about 52 feet beyond the jacket. Platforms appear to have a finite reef effect that does not extend beyond visual range of the associated species (Stanley 1994).

In recent years, debates have highlighted questions related to the productivity and habitat function of artificial structures. Numerous studies have documented increases in fish (adult, larval and juvenile) abundance and recruitment to platforms and other artificial structures (Dupont 2008; Gallaway et al. 2009; Lindquist et al. 2005; Simmons and Szedlmayer 2011; Szedlmayer and Shipp 1994) but the source (redistribution, aggregation or actual stock enhancement) of the increase is still debated in the literature (Baine and Side 2003; Pitcher and Seaman 2000; Gallaway et al. 2009; Goodsell and Chapman 2009; Grossman et al. 1997; Shipp and Bartone 2009). For oil and gas platforms off the California coast, scientists have suggested that both the upper depths and the deeper structure may be important to certain species at various life-stages, with platforms acting as both recruitment habitat for juvenile fish and possible refuge areas for adults (Love et al. 2003; Love et al. 2005; Love et al. 2006; Love and York 2006). In addition, a recent analysis by Claisse et al. (2014) estimated secondary fish production at these California platforms to be substantially greater than any other marine ecosystem. This work indicates that non-natural habitats can indeed substantially contribute to local secondary production.

Several studies of Gulf platforms have documented the difference in biomass associated with depth and the area of influence of platforms (Stanley 1994; Stanley and Wilson 1991, 1997, 2000a, 2000b). Other studies have shown the differences between artificial structure provided by platforms as compared to natural hard-bottom areas (Wilson et al. 2003, 2006; Rooker et al. 1997), and how the fish community composition is different between these two types of habitats. Diversity is greater at natural sites, while biomass per unit area is greater at standing platforms (Wilson et al. 2003, 2006). For red snapper (*Lutjanus campechanus*), arguably the most economically important species in the Gulf, Wilson et al. (2006) noted that the species was proportionally most abundant at a low-relief natural hard-bottom area. However, Ship and Bartone (2009) suggested that the addition of artificial habitat in the Gulf has resulted in an increase in the harvest potential of red snapper, and any decrease in artificial structure (such as large-scale platform removals) may have negative results on catch. Evidence also suggests that some artificial structures in the Gulf may serve as long-term residence sites for reef-associated species such as red snapper (Schroepfer and Szedlmayer 2006; Szedlmayer and Schroepfer 2005). While it appears that larger (age 3+) red snapper may migrate to deeper, less vertically structured habitat, oil and gas platforms may harbor greater numbers of younger age-2 red snapper (Gallaway et al. 2009). In areas off the south Texas coast, where natural reefs and platforms are limited in number, removal of existing platforms may affect reef fish populations, and could limit settlement of reef fishes (Lindquist et al. 2005).

Importance of Petroleum Platforms to Recreational and Commercial Fishing

With the development of petroleum production in the Gulf of Mexico, numerous fishermen from Texas to Florida quickly recognized the bountiful fishery resources beneath these platforms. Since their installation, the platforms have become an important fishing destination for both recreational and commercial fishermen, and have long been recognized as *de facto* artificial reefs. It has been estimated that nearly 20 to 50% more fish occur at platforms than over the nearby soft bottoms of the Gulf of Mexico (Dressen 1989). Researchers have documented species composition and abundances of fishes at several platforms, and concluded that each standing platform seasonally serves as critical habitat for thousands of fish, many of which are commercially and recreationally important (Stanley and Wilson 1996, 1997, 1998, 2000b). Furthermore, it has been determined that anglers who fish around platforms catch larger, and more desirable fish than marine recreational fishermen who fish other areas of the Gulf (Witzig 1986). Researchers using data from the US National Marine Fisheries Marine Recreational Fisheries Survey have estimated that 30% of the recreational fisheries catch were caught near platforms off Louisiana and Texas (Avanti, Inc. 1991).

Petroleum platforms converted to artificial reefs enhance the fishing and diving opportunities for the public and commercial fishermen. For example, in Texas there are over 1.2 million saltwater recreational anglers (16 years and older). Ditton et al. (1990) found that 47% (564,000) of these anglers fished from a boat in the Gulf of Mexico, and approximately 300,000 to 400,000 anglers had fished at offshore platforms or artificial reefs. In a 1995 survey, party boats on the Texas coast took an estimated 372 trips to Texas reefs, or about 1,310 trips to any artificial structure (including standing platforms that were not reefed) in the previous twelve months. Trips to artificial structures accounted for 40% of the total number of trips taken offshore by the survey group (Ditton et al. 1995). A study of fishing at artificial reefs by Schuett et al. (2016) found the highest percentage of boat owners in Texas took one to five trips to the Gulf in the last 12 months and fishing at standing rigs and oil production structures was highly important.

In addition, petroleum platform reefs, especially those with a 50-ft clearance, can offer various diving opportunities for divers, dependent on their level of skill and training. The preferred diving depth for most dive charters is 70-100 feet (Ditton et al. 1999). Many of the reefed platforms will be in water depths deeper than this, but recreational divers today frequently venture down to 120-130 feet, and deeper platform reefs are used by the increasingly popular technical diving community who can exceed depths of 200 feet. While the number of recreational divers varies by state, some estimates of economic impact to local communities range well over $2m annually (Malki et al. 2010). With ever increasing demands for diving resources, petroleum reefs provide unique and exciting diving opportunities.

Similar Structures

The United States Atlantic coast has been designated off limits for oil and gas drilling since the early 1980s. A unique area was created offshore of Georgia in the 1980s where the U.S. Department of the Navy (DON) operated aircrew training facilities similar to those popularized in the movie “Top Gun.” These Beaufort Tactical Aircrew Combat Training System (TACTS) Towers were constructed in 1987, reported to have a 20-year life span, to provide aircrew training, and performance evaluation in air-to-air combat, but are now functionally obsolete. TACTS Tower ranges were operated by the Warfare Assessment Station of the Naval Surface Warfare Center, maintained by the Beaufort, South Carolina Naval Air Station, and were utilized by the U.S. Navy, Marine Corps, and Air Force communities between 1990 and 2009.

Towers consisted of a grid of eight platforms that were similar to small oil rigs located 30 to 60 nautical miles (nm) off of St. Catherine's Island, Georgia, in approximately 70 to 150 feet of water. The eight platform grids covered an array of 115 km × 50 km area of the middle to outer continental shelf, roughly 6,000 km$^2$. All Towers are described as free standing, steel tubular structures that are attached to the seafloor via piles driven down inside of and welded to the tubular legs to secure the towers in place. There are two styles of platforms - four-legged master platforms, and three-legged remotes. These unmanned facilities provided rapid (real-time) tracking of military combat aircraft (typically F-18s) on the flight range, and permitted instructors onshore to observe and interact with pilots on the range during exercises.

Multiple vessels fishing at GADNR TACTS Tower “R5”. Photo Credit: GADNR, January Murray

During 1999 to 2001, the South Atlantic Bight Synoptic Offshore Observation Network (SABSOON), through support from the National Oceanographic Partnership Program, functioned as a real-time observational network on the continental shelf utilizing the TACTS Tower Range off of Georgia. Oceanographic and meteorological instruments were deployed at two central platforms where TACTS Towers provided power and access to wide bandwidth microwave communications. Data were continuously logged and transmitted to shore hourly. SABSOON was intended to provide real-time meteorological observations and time series records of coastal ocean conditions, as well as serve as a test bed for deployment of new oceanic sensor systems

(Nelson, 2003).

TACTS Towers are highly visible structures reaching 180 feet in height. They provide exceptional recreational fishing and diving opportunities as *de facto* artificial reefs. The available metal surface area of tower legs quickly were colonized by barnacles, soft corals, and sponges providing the basis of a food web. Towers created high relief hard-bottom habitat in otherwise primarily soft bottom areas, making them popular destinations for anglers targeting saltwater gamefish such as grouper, sheepshead, black sea bass, red snapper, king mackerel, amberjack, barracuda, tunas, dolphin, and wahoo. In 2005, the DON - Naval Submarine Base (NSB) Kings Bay contacted GADNR regarding artificial reefing of the eight decommissioned TACTS Towers, since they were no longer required for missions, out of compliance with current safety standards, system was replaced with GPS-based TACTS, and demolition would provide naval forces a valuable training opportunity. The removal and disposal of the towers would eliminate navigational hazards, maintenance costs, personal safety, potential illicit human-use liabilities, and enhance fish habitat within areas permitted by GADNR.

In 2012, the process of decommissioning the towers as surplus property began with a notice of availability of naval real property sent to several federal stakeholders including, but not limited to, the U.S. Fish and Wildlife Service (USFWS); National Marine Fisheries Service (NMFS); Georgia Department of Natural Resources; U.S. Coast Guard, Office of National Marine Sanctuaries; U.S. Army Corps of Engineers; U.S. Environmental Protection Agency; Bureau of Ocean Energy Management, Regulations and Enforcement; Naval Facilities Engineering Command; and NSB Kings Bay. GADNR responded with interest in receiving the Towers as artificial reef material. In 2014, the DON prepared an Essential Fish Habitat (EFH) Assessment for the removal and transfer of the TACTS Towers to support an EFH consultation with NMFS, and to satisfy the compliance requirements of the Magnuson-Stevens Fishery Conservation and Management Act. Additionally, the DON prepared a Biological Assessment for the removal and transfer of the TACTS Towers to support a Section 7 informal consultation for federally listed species with NMFS and USFWS, as well as a Section 7 informal conference for federal candidate species with NMFS, and to satisfy the compliance requirements of the Endangered Species Act. The public was given an opportunity to comment on the draft *"Overseas Environmental Assessment (OEA) for the Removal, Disposal, and Transfer of the Tactical Aircrew Combat Training System (TACTS) Towers, Naval Submarine Base Kings Bay, Georgia."* Upon completion of the environmental review process, funding will need to be obtained from the U.S. Congress before the deployment of the eight TACTS Towers are scheduled.

The DON intends to deploy the TACTS Towers as reef material onto the Federal OCS seafloor within one square nautical mile of their current location. In accordance with the State of Georgia, offshore artificial reef Programmatic General Permit No. 36 (PGP 36), mechanical methods will be used to severe Tower legs at predetermined heights below the water surface to preserve existing artificial reef habitat, and tower surface structures will be toppled in place to predetermined depth clearances. The DON, not GADNR, will implement the eight TACTS Tower deployments. The water depth at which the legs are severed and surface structures deployed will be legally compliant to allow for safe navigation, and will range from approximately -35 to -60 feet MLW, depending on the Tower location. GADNR does not accept ownership of the TACTS Towers until they are properly deployed on the seafloor, per the terms and conditions of the DON deployment plan and

PGP 36 (January Murray, personal communication). This ensures the state of Georgia is not liable for adverse impacts to shipping, commercial fishing, recreational fishing, national security interests, and/or natural resources in the event deployments were unsuccessful.

Benefits

- Oil and gas platforms, as well as similar structures, have proven to be excellent artificial reef material. The *National Artificial Reef Plan* cites five major characteristics or standards for artificial reef materials. These standards, together with siting and management, generally determine the success or failure of an artificial reef project. These include function, compatibility, durability, stability, and availability. Oil and gas platforms possess all these characteristics.

- Function refers to the selection of materials which are known to be effective in stimulating desired growth of micro- and macro-organisms, and providing habitat for target species. It is well documented that oil and gas platforms function as artificial reefs by providing habitat for a variety of species otherwise only associated with coral reefs, since many of these species are habitat limited (Moran 1986, Parish 1987, Sale 1991). This fact is further emphasized by the fact that over 70% of all recreational angler trips in the Exclusive Economic Zone off Louisiana are destined for one or more of these structures (Reggio 1987), while Ditton et al. (1995) found that 40% of all Texas offshore trips were to artificial structures. The steel members of the platform provide the necessary hard-bottom substrate for many of the encrusting organisms critically important in developing reef habitat.

- Oil and gas platforms have proven to be compatible with the marine environment. BSEE's "Rigs-to-Reefs" Policy (IPD 2013-07) and decommissioning regulations (30 CFR §250.1700 Subpart Q) ensure that operators requesting a departure from complete removal and participation in a state artificial reef program adhere to engineering and environmental standards.

- Oil and gas platforms are very durable and stable, rarely moving from where they were placed. From 2009-2012, LDWF contracted with a professional surveyor to use multi-beam techniques at all of Louisiana's offshore artificial reefs - 71 at the time. Water depths ranged from 50-600 feet. A majority of the deployed platform jackets at these artificial reefs had been in the path or influenced by one or more major hurricanes, i.e., Andrew 1992, Lili 2002, Katrina & Rita 2005, and Gustav and Ike 2008. Of the 320 platform jackets surveyed within these artificial reefs, only five structures had detectable movement. However, the movement detected could not be directly attributed to hurricanes. Structure movements may have been attributed to survey error or possible interaction with drill rigs and derrick barge anchoring systems operating within the artificial reefs. Louisiana now has precise structural location information for all its platform deployments, and continues to perform these surveys on a regular basis. Louisiana will now be able to more definitively determine the cause of any future platform movement detected (Michael McDonough, personal communication).

- Platform jackets are durable structures designed to withstand the ocean environment for years. Based on an estimated 15-year life remaining on existing cathodic protection, and utilizing the average corrosion rate of steel immersed in saltwater, Quigel and Thorton (1989) estimated a life span of a platform of approximately 300 years. Roberge (2008) shows corrosion rates of steel in marine waters can average 0.3mm/yr. Using a petroleum jacket thickness of 3 inches as an example, basic corrosion of the entire leg with no protection could be calculated at 254 years. Nineteen percent of the platform jackets deployed as artificial reefs were originally installed as production platforms in the Gulf of Mexico in the late 1950s through the 1960s. These jackets continue to provide durable habitat over 60 years later.

- Platforms are also readily available, with approximately 2,100 in the Gulf of Mexico. However, it is not always economical to convert a platform into an artificial reef. As petroleum companies negotiate a reefing project with a state, many factors are discussed. Of prime importance are: the size of the structure, complexity, water depth, distance from shore, proximity to the final reef site, and resale value of scrap metal. These factors will play a role in whether or not an obsolete platform will become a reef.

- Partial mechanical removal methods using divers or abrasive cutting tools have provided a method for transforming platforms into reefs, leaving the highest structure profile in the water column. This technique has the least impact on the natural resource, and decreases the dangers to sea turtles, marine mammals, and other marine species attached to or associated with the platform.

Drawbacks

- The large size of oil and gas platforms do not always lend themselves to reefing in nearshore waters. The U.S. Coast Guard (USCG) is responsible for developing marking guidelines for obstructions to navigation under 33 CFR 64.30. In the Gulf of Mexico, the 8th Coast Guard District (New Orleans, LA) has jurisdiction from western Florida to the Texas/Mexican border, and determines when private aids to navigation (PATON; aka marker buoy) are required (USCG 1990). The general "rule of thumb" is that if there is 85 feet of clearance above the platform, the USCG may waive the need for a PATON. If the clearance is shallower than 85 feet, a buoy with light may be required. There is USCG guidance on marking reefs, but each PATON request is reviewed by the USCG on a case-by-case basis, and their determination is based on vessel traffic, fishing methods, and the potential for the platform to create a navigational hazard in the area. To avoid the expense of installing and maintaining PATONs to mark Rigs-to-Reefs, most states target platforms in water depths greater than 100 feet, with 200 feet and deeper being prime reefing depths. Along Louisiana and the upper Texas coast, the 100-foot contour exists between 30 to 75 miles offshore, making some reefs inaccessible to many fishermen. The 100-foot contour is significantly closer offshore the lower Texas coast at 15 miles.

- Modifications or changes in the standard decommissioning process and extended tow times to a reef deployment location can discourage oil companies from participating in Rigs-to-Reefs programs. Derrick barge rates currently range from $100,000 to $350,000 per day, depending on the lifting capabilities of the barge. The size of the structure (physical size and tonnage) to be removed determines the type of barge required. This, however, may be turned into a benefit if the time to reef the structure versus taking it to shore can be reduced and/or a smaller decommissioning vessel can be utilized.

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## 2.5 AIRCRAFT

Military Fighter and Training Aircraft Crashing at Sea During Military Exercises

One of the earliest U.S. records of aircraft commencing service as unintended artificial reef material as a result of equipment failure or pilot error occurred on February 12, 1935 when the 785 foot long Navy dirigible, U.S.S. Macon, effected a controlled crash landing and settled by the stern and sank off the California coast in what is now Monterey Bay National Marine Sanctuary. The dirigible carried four “hook-on” F9C2 Sparrow hawk fighter planes. The wreck of the dirigible and the four planes were located by remote operating vehicle on June 24, 1990, at a depth of 1,450 feet. Vaeth (1994) reported that the Sparrow hawk cockpits were heavily silted, but all four planes “had survived surprisingly well, some of their fabric still bearing original insignia and markings. To the camera, they may look in good enough condition to try to raise. However in practice they would probably disintegrate if disturbed.”

Military aircraft operating out of southeastern coastal Navy, Army Air Corps, or Air Force bases before, during, and after WWII became some of the earliest aircraft artificial fishing reefs when these planes crashed or ditched into the ocean during training operations. Video documentation and anecdotal reports indicate that some aircraft ditching and sinking largely intact off northwest Florida in the 1940s to 1950s are still used as artificial reefs (Stephen Bortone and Mike Hendrix, personal communications).

Video footage, in the possession of the Florida Fish and Wildlife Conservation Commission, taken around 1992 and donated by Mike Hendrix (personal communication), showed three 40 to 50-year old aircraft wrecks at depths exceeding 90 feet off northwest Florida. The film illustrates that, under certain conditions, aircraft wrecks can have considerable longevity as both fish habitat and fish attractant (Jon Dodrill, personal communication). Three examples from the video report follow. A Corsair fighter, ditched while trying to make a carrier landing in 1943, came to rest upright on its landing gear in 140 feet of water. Visible in the video were vermilion snapper, gray triggerfish, spadefish, amberjack, blue angelfish, and butterflyfish. A torpedo bomber crashed and sank onto a soft mud bottom in the late 1940s. Warsaw grouper, red snapper, gray triggerfish, and angelfish were visible in the video taken of this popular fishing and diving site. A two-seated biplane crashed and broke into two pieces in the 1940s and came to rest in 97 feet of water. Several large stingrays, small grouper, snapper, many triggerfish, and some black sea bass were visible around the wreck.

A P-47 single-seat Thunderbolt fighter that ditched in 65 feet of water 25 miles off Franklin County, Florida, allegedly while returning from the ill-fated Cuban Bay of Pigs Invasion in April 1961, was salvaged in 1995 with the framework largely intact, except for wingtips and broken canopy glass. The dorsal surface of the aluminum skin of the fuselage and wings had hundreds of small perforations due to corrosion which had allowed fine sand and silt to enter the fuselage and wing interiors, adding thousands of pounds to the weight of the aircraft (21,000 pounds combat loaded) and probably contributing to its stability on the bottom. The aluminum on the lower surface of the aircraft in contact with the sediment was not as badly corroded. The heaviest aluminum framework, and all stainless steel parts were in good condition. The rubber tires were still intact and contained air. Lighter alloy metals with magnesium and zinc components were gone.

Publication of the wreck site a short time prior to salvage hastened the decline of the grouper population on the wreck, and also resulted in artifact removal (Rick Lee, personal communication).

Unpublished aircraft crash sites in the Gulf of Mexico off the Florida Coast between Crystal River and Naples, Florida are utilized by both commercial vertical hook and line fishermen and commercial divers using mixed gas SCUBA and rebreathers. The latter groups operating in depths between 120 and 400 feet have visually identified several wreck sites as aircraft. These deeper aircraft wrecks that are a mix of aircraft types, some submerged as long as thirty years, have been utilized repeatedly to commercially harvest reef fishes, without indication of substantial movement of the material. Any wrecked aircraft in 80-120 feet generally have not survived extensive shrimp trawling activities in this area (William Ward, personal communication).

Aircraft Intentionally Disposed of in the Ocean that Later Served as Artificial Reefs

The earliest aircraft intentionally placed in the ocean that later served as successful artificial reef dive sites occurred in the Pacific Theater at the end of WWII. At war's end, aircraft at the Roi-Namur Island airfield in the Kwajalein Atoll (Marshall Islands, Pacific Ocean) were stripped of useable parts and dumped into the ocean. Some of these planes were placed at a depth of 120 feet in a lagoon at a site locally known as the Airplane Graveyard. The site is protected by a coral reef and the island itself. Bird (2002) provided photos of a F4-U Corsair fighter, a B-25 bomber, and a Dauntless SBD dive bomber, all with fuselage and wing frames intact, and with only some loss of the aluminum skin over portions of the wing frames and tail sections. Other aircraft noted were a C-46 transport and an Avenger. Bird (2002) noted when examining the B-25: "Although there is a bit of coral growing on it, the aluminum skin of the plane is still fairly shiny." These aircraft, which have been in the water over 55 years, serve as a popular local dive site.

Douglas SBD Dauntless dive bombers at the Airplane Graveyard in Kwajalein Atoll, Roi-Namur. Photo Credit Brandi Mueller

Today there are hundreds of obsolete and damaged military aircraft, not suitable for overseas sale or public display that have accumulated over time and are stored at various facilities throughout the United States. While funding was originally readily available to secure and maintain these aircraft while operational, funded programs and initiatives to address the post operational fate of these aircraft are not always in place. In at least some situations, there is no mechanism or incentive that enables aircraft programs to profitably dismantle and recycle aluminum components of these aircraft (Scott Mauro, personal communication). In the continental U.S., beginning in the mid 1970s, some aircraft whose designs had reached a point of obsolescence after 25 to 40 years occasionally became available to organizations interested in the intentional placement of such aircraft as artificial reefs.

## Aircraft Purposefully Deployed as Artificial Reefs

No coastal states other than Alabama, Florida, South Carolina, and North Carolina are known to have intentionally pursued the use of aircraft as artificial reef material. Florida and North Carolina represent the two major states where surplus aircraft have been intentionally deployed as artificial reefs during the last 30 years. As of 2002, the Florida Fish and Wildlife Conservation Commission's database on artificial reefs lists the following known occurrences of aircraft, purposefully placed for use as artificial reefs: one DC-4 off Broward County (1985, 71 foot depth), two Navy F-4 Phantom fuselages off Miami-Dade County (1988, 81 foot depth), three twin engine Martin 404 and one DC-3 fuselages off Collier County (1986-88, 28 foot depth), one DC-3 fuselage off Wakulla County (1988, 23 foot depth), one F-101, one F-102, one Sikorsky helicopter, and one T-33 trainer, all off Bay County (mid-late 1970s, early 1980s, 60 to 70 foot depth, (Danny Grizzard, personal communication), a Boeing 727 jet placed off Dade County (1993, 82 foot depth), placements of approximately 30 Navy A-6 Intruder aircraft fuselage sections in 100 feet of water off St. Johns County in northeast Florida (1995), three Air Force F-106 drone jets with wings still attached and nose cones removed placed off Bay County, northwest Florida (1995, 110 foot depth), 26 A-6 Intruder aircraft off Volusia County, northeast Florida (1996, 135 foot depth), eight A-7 Corsair jets and a T-2 trainer off Jacksonville, northeast Florida (1997, 70 foot depth), and a Lockheed Neptune P2V-3 bomber sunk off Pinellas County, central west coast Florida (2000, 43 foot depth). North Carolina has placed six aircraft for use as artificial reefs at two locations at depths ranging from 53 to 65 feet. These include two C-130 cargo fuselages, two intact F-4 Phantoms (minus the engines), and two A-4 fuselages (Steve Murphey, personal communication). Other aircraft placements include the 1992 placement of an aircraft tail assembly section in 90 feet of water at Alabama's Morisette Reef (Walter Tatum, personal communication), and a South Carolina Deployment in 1995 of one A-7 fighter aircraft in 50 feet of water (Robert Martore, personal communication).

## Military Fighter, Training Aircraft, and Helicopters

There are some records of aircraft placed in less than 100 feet of water that have survived at least a decade. F-101 and F-102 jets, a navy T-33 trainer, and a Sikorsky helicopter, all placed off Bay County, Florida in 60 to 70 feet of water, survived as fishing and diving sites at least 10 years (Danny Grizzard, personal communication). The last known status (2002) of the T-33 trainer and the F-102 is uncertain. The F101 fighter, mentioned above and deployed in 1982, was reportedly still intact as of 1997 (Frank Mancinelli, personal communication). By 2001, the Sikorsky helicopter remnants had degraded to the point where they are no longer recognizable as a helicopter (Mille and Horn 2001). Another privately placed helicopter performed effectively as a fishing and diving reef off Escambia for several years in the early 1990s, until it was destroyed by Hurricane Opal (1995) (Edwin Roberts, personal communication).

Two F-4 Phantom aircraft, sunk in April 1992, offshore of North Carolina at depths of 53 feet and 65 feet respectively, are still attracting fish. One F-4, still supported on its landing gear, sheltered several gag grouper under its wings when observed in 1995. An additional two A-4 fighters were deployed during the same time-frame in 53 feet of water. One North Carolina A-4 aircraft was substantially damaged when a load of concrete material was deployed on top of it (Kurtis Gregg, personal communication). As of 2001, both remaining undamaged aircraft types have maintained their position and remain in good condition, despite exposure to several hurricanes during the decade of the 1990s (James Francesconi, personal communication).

One A-7 fighter aircraft was deployed in June 1995 approximately 10 miles offshore of South Carolina at a depth of 50 feet. The small fighter plane was filled with concrete and deployed with the wings attached. Subsequent observations found that the aircraft has remained in place. Minimal benthic fouling has occurred on the aircraft surface (Robert Martore, personal communication).

Several F-106 drone jet fighters deployed September 25, 1995, in 106-112 feet of water off Bay County, Florida, were visually evaluated in 1997 and again in 2001. The aircraft deployment was sponsored by the Tyndall Air Force Base Dive Club in cooperation with Bay County. Maher and Horn (1997) examined a single intact F-106 oriented upright on the bottom and originally deployed without the nose cone or engines. The plane was 65 feet in length, with a wingspan of 38 feet and a maximum vertical relief of 20 feet at the top of the vertical tail fin and a weight of approximately five tons. They reported 10 species of fish, but relatively low abundances. Recreationally important fishes observed around the aircraft included greater amberjack, red snapper, gray snapper, gray triggerfish, and scamp. Maher reported, "The thin aluminum skin of the aircraft was easily punctured by my finger and/or dive knife, indicating that some oxidation had occurred." Maher and Horn (1997) stated that the plane had "a well-developed bio-fouling community consisting of predominantly encrusting soft sponges." In November 2001, a second assessment was made of two F-106 drones from the original 1995 deployment (Mille and Horn 2001). Both aircraft observed were intact and at the location of the original reported deployment, despite having been exposed to Hurricane Opal in October 1995 and Hurricane Georges in September 1998. The observers noted little degradation of the aircraft. Ten fish species were noted. In excess of 100 greater amberjack were recorded. Other recreationally important fish recorded in lesser numbers were gray snapper, gag, scamp, and red snapper. Bio-fouling levels on the aircraft appeared to vary with the surface area location and orientation of the aircraft.

Thirty Navy A-6 Intruder fighter aircraft fuselage sections were deployed off St. Johns County in 104 feet of water in June 1995. A review of video footage taken one month post-deployment indicated that the majority of the aircraft components were sunk within a 250 foot diameter circle. The video confirmed that plexiglass canopies were left in place, and on at least one aircraft, fish were getting inside the cockpit canopy and unable to escape. Fish species documented in the video included barracuda, amberjack, and round scad. Grouper and snapper species were not seen at that time. As of 2000, the aircraft were still utilized by charter fishermen, and had not shifted location (Gene Burns and Jim Netherton, personal communication).

On July 18, 1996, 26 unballasted ex-Navy A-6 Intruder fighter aircraft were pushed overboard from a barge into 125-135 feet of water as part of a local government project off Volusia County (Florida East Coast). During deployment, there was some evidence of aircraft gliding through the water column in route to the bottom. A depth recorder indicated probable aircraft at seven separate locations, and it is expected that the combination of elevated seas, and gliding through the water column during deployment caused a scattered distribution of aircraft on the bottom. Since the aircraft are at depths of 130 feet, in situ observations to verify individual aircraft locations are few, and limited to qualified technical divers. By 2002, many of the 26 aircraft had never been individually located nor observed. One month post-deployment, Neal (1996) reported viewing a single aircraft at a depth of 125 feet. No other aircraft was visible from that location, despite horizontal visibility of 75 feet. After one month, barnacles covered the external surface of the plane. Occasional small grunts and a lone black sea bass were the only fish seen. On October 11, 1998, over two years post-deployment, divers located and dove on a single aircraft near the site of the initial dive. Morrissette (1998a) reported that the aircraft was heavily encrusted, but fish were small and sparse. Small seabass, tomtates, gray triggerfish, and red snapper were most commonly observed, with occasional gag grouper, sheepshead, barracuda, and a single Atlantic sharpnose shark noted. Morrissett (1998b) reported another dive attempt on December 6, 1998, once again locating only a single aircraft in 134 feet, but apparently a different one, with an unrelated piece of wing section noted northeast of the plane. Fouling was noted as "uniform" over the aircraft's surface. Pitcher (2000, 2001) conducted dives at 126 feet on a single aircraft associated with this project and reported the presence of a single grouper, a single red snapper, a single lobster, a single gag grouper, and many gray snapper.

Eight Navy A-7 Corsair jets and a T-2 trainer were deployed off Jacksonville, Florida in 60-65 feet of water on July 12, 1997 (Kaulakauskis 1997). Unlike the A-6 aircraft deployed off St. Augustine, the A-7 aircraft off Jacksonville were deployed with the landing gear down. Observations showed that with the landing gear down, currents eventually scoured the gear into the substrate, allowing the aircraft to be more stable on the bottom. By 2002, the aircraft were observed to still be in place. Due to shallower depths and closer proximity to shore, the aircraft are more frequented by divers and fishermen than the deeper water aircraft off Jacksonville (Edward Kaulakauskis, personal communication).

<u>Commercial and Military Cargo Aircraft and Bombers</u>

Four Florida aircraft artificial reef deployments and an aircraft ditching in shallow water off southeast Florida are worth discussing in the context of scenarios for artificial reef programs to avoid in the future. Between February 1986 and March 1988, one DC-3 and three twin engine Martin 404 aircraft were deployed about five miles offshore from Gordon Pass in Collier County in 28 feet of water. Only the fuselages were used, and they were secured to the bottom with steel cables attached to concrete culverts through holes cut in the sides of the aircraft. The cables apparently served as saws and cut through the aluminum, resulting in the separation of the top of the fuselage from the bottom. Hurricane Andrew in 1992, followed by a storm in March 1993, effectively eliminated or buried all remnants of these aircraft artificial reefs (Kevin Dugan, personal communication). Additional efforts to locate remains of the DC3 using a grid search in the vicinity of the prior known coordinates with bottom depth recorders in November 2002 revealed no trace of the aircraft (Tom Maher, personal communication). Another such incident occurred when the wingless and tailless fuselage of a DC-3 cargo plane was anchored in 23 feet of water, seven miles southwest of the St. Marks Lighthouse in Wakulla County, Florida, in July 1988. Within a year, the anchoring cable had cut through the fuselage, resulting in the breakup of the aircraft. As of 1995, no parts of the aircraft could be located (William Horn, personal communication).

While still intact, the DC-3 aircraft off Collier County discussed above entrapped a sea turtle which had entered through an open door of one of the aircraft. The trapped turtle became disoriented, was too large to escape through the windows, and drowned inside the fuselage. Subsequent efforts to cut larger holes in the fuselage to prevent future incidents weakened the structural integrity of the aircraft, and probably accelerated its eventual break up (Kevin Dugan, personal communication).

The largest intact commercial aircraft intentionally deployed as an artificial reef was a 135-foot long Boeing 727 passenger jet named "The Spirit of Miami." It was deployed and anchored in 80 feet of water off Key Biscayne in Dade County, Florida in 1993 at a cost of about $45,000 to the county, and up to $60,000 in volunteer contractor and owner time and labor. The jet was transported to the staging area with wings and tail section disassembled. The aircraft was reassembled before transport by barge and subsequent deployment with a crane at the reef site.

Within two months after initial deployment there were signs of vandalism. Bottle pins attaching the wings to the fuselage were removed on three different occasions resulting in a situation where the wings could no longer be tightly attached to the fuselage when the pins were replaced. There were indications that divers were also tampering with the anchoring system that consisted of seven special anchors secured to the wings and fuselage and costing about $750 each. Within 18 months, tropical storm Gordon (November 1994) broke the fuselage in half at the wing mounts. The tail section, which had a 30-foot profile, rolled over on its side, and the wings completely separated from the fuselage. The anchoring system initially held the separate parts in place. (Ben Mostkoff, personal communication). However, within two months the tail section had moved into 98 feet of water, far enough from the wreck that it could not initially be located during a subsequent evaluation. The independent pieces continue to provide some degree of fish attraction. Miami-Dade County Department of Environmental Resources Management (DERM) staff reported that in 2000, the nose section and majority of the fuselage were still on site, with the detached wings also in the general vicinity. The whereabouts of the tail section, however, is unknown to county staff (Tim McIntosh, personal communication).

The largest bomber fuselage deployed as an artificial reef was a Lockheed Navy P-2V3 Neptune Bomber deployed as a veteran's memorial in 43 feet of water in the Gulf of Mexico, 12 miles west of Dunedin, Florida (Northern Pinellas County) on July 2, 2000 (St. Petersburg Times 2000). The Neptune Bomber served as a memorial less than two months. With the passage of the first summer tropical storm, the wingless bomber fuselage was ripped off the barge and completely destroyed (Dr. Heyward Mathews, personal communication). Two C-130 cargo plane fuselages were deployed in the water off North Carolina for less than a year, unanchored in 60 feet of water, when a June 1995 evaluation indicated one fuselage had broken into three pieces, and the other had collapsed in on itself (Kurtis Gregg, personal communication).

Large military cargo and bomber fuselages and conventional passenger aircraft, even securely anchored, do not hold up in shallow water in the face of seasonal storm events or shifting tidal currents. Improper anchoring using cables, which themselves may corrode or break, or which may saw through lighter gauge aluminum as the aircraft moves, hastens aircraft deterioration.

## Aluminum Corrosion and Aircraft

A major problem in maintenance of aircraft is corrosion (Edward Kaulakauskis, personal communication). Unlike carbon steels, which rust whatever their composition, an alloy of aluminum can be specifically selected for resistance to seawater corrosion, though the most corrosion resistant, pure aluminum is a weak metal and is rarely used. To strengthen the metal, small amounts of other metals are incorporated with aluminum. Aluminum alloys which are corrosion resistant are the aluminum-magnesium, aluminum-manganese and the aluminum-silicon-magnesium varieties. However, unlike corrosion resistant marine vessel aluminum alloys, aircraft aluminum alloys are not designed to be exposed to seawater and must be treated with protective coatings. Further, aircraft aluminum is of a much thinner gauge than marine vessel hull aluminum. Aircraft aluminum alloys often contain copper. The aluminum-copper alloys are strong but the tradeoff is that they have very low corrosion resistance. If left untreated, aircraft aluminum alloys can rapidly corrode in seawater (Warren 1980). To protect against corrosion, the military has developed an extensive corrosion treatment program for all active aircraft (Edward Kalakauskis, personal communication). The Navy has one of the best corrosion prevention programs and goes to the extent of “shrink wrapping” aircraft in plastic to minimize corrosion during transport, when aircraft are expected to be exposed to salt spray. The efforts and processes of the Navy's corrosion prevention program result in aircraft lasting a number of years; however, eventually they are subject to corrosion.

## Benefits

- Aircraft deployment as an artificial reef is uncommon enough to catch the attention of the news media. Deployment of a Boeing 727 passenger aircraft off Miami for use as an artificial reef made national news, drew national and international attention to that county's artificial reef program, resulted in estimated advertising benefits that exceeded two million dollars, and created over four million personal "impressions" in the media during an 18 month period (Ben Mostkoff, personal communication). In situations where a military base is involved, the military-civilian cooperative effort is perceived as good public relations for that armed service or particular base.

- Like sunken ships, aircraft, especially if intact, have a recreational diver novelty appeal greater than some other artificial structures.

- Little known aircraft wreck sites in northwest Florida have been prized fishing locations for recreational anglers for decades.

- Aluminum alloys, of the correct grade, may exhibit greater corrosion resistance than carbon steel of similar thickness. The corrosion rate will depend on the type of alloy, contact with dissimilar metals, paint coatings, water depth, temperature, exposure to water movement, and fouling organisms.

- Aircraft use may be cost effective if the military handles all costs of cleaning, preparation, transportation, and deployment.

Drawbacks

- Aircraft fuselages or parts thereof can be unstable and short lived in shallow water (less than 50 feet) or high current situations at greater depths.

- Aluminum alloys, of the wrong grade, may exhibit inferior corrosion resistance than carbon steel of similar thickness (aircraft alloys are usually specifically thin and not of the correct alloy). The corrosion rate will depend on the type of alloy, contact with dissimilar metals, paint coatings, water depth, temperature, exposure to water movement, and fouling organisms.

- The aircraft's heaviest single structural component is the engine. With the engine removed, the remaining air frame is lighter than heavy gauge steel or concrete structures with similar surface area. Aircraft may require additional ballasting (concrete poured into the fuselage). Use of an external anchoring system would involve additional expense and necessitate periodic checking and maintenance, although this has been shown to be ineffective because of diver tampering.

- Aircraft are designed to fly. Leaving the wings on in their entirety could cause the aircraft to glide as they descend through the water column. Unless placed in a controlled manner by being lowered to the bottom by crane, aircraft deployed in deep water may have a tendency to be widely scattered on the bottom. This scenario may or may not meet the intended objective of the reef.

- Wings are often removed from aircraft for ease of transportation and for parts refitting and reuse if the general aircraft type is still in service (the military refer to an aircraft with engine, wings, and landing craft removed as a canoe or carcass) (Scott Mauro, personal communication). However, the complete and permanent removal of wings in their entirety from the aircraft may reduce habitat complexity, compromise structural integrity, reduce stability once the aircraft has been deployed, as well as render the material of lesser interest to divers. The dilemma is that wings, nose sections, and portions of the tail in some more modern military aircraft types have a high carbon fiber content and might need to be considered for removal regardless. Only the central fuselage tube remains to function as an artificial reef.

- The aircraft itself, or an anchoring system, may be subject to vandalism by divers at shallower depths, or sustain damage when anchors of large recreational vessels drag and hang in the aircraft.

- From a recycling perspective, re-utilization of high-grade aluminum for artificial reef deployment may not be cost effective. In addition to titanium fuselage panels that are currently recycled on some aircraft, aircraft fuselage aluminum has potential salvage or recycling value that may provide revenue levels that would compete against aircraft deepwater disposal or use as artificial reefs.

- The cost to transport aircraft over land from a distant site, combined with proper cleaning, preparation, offshore deployment, and anchoring/ballasting costs may render aircraft less cost effective than other available, more stable materials which could provide the same degree of structure and habitat benefit.

- Synthetic lightweight components such as carbon fiber materials in portions of more modern military aircraft fuselages, wings, and tail sections may outlast the aluminum or metal alloy structures and disassociate into the marine environment decades later. This lightweight but high strength material is bonded to become an integral part of the airframe or wings in some aircraft types, so it cannot be removed without partially dismantling the aircraft. This effort may not be cost effective.

- Aircraft topcoat or undercoat paints containing chromium compounds present an environmental concern whose level of risk should be evaluated by the Environmental Protection Agency.

- Jagged metal edges and instability of aircraft following damage or breakup in storm events may present a diver hazard.

Considerations

- A decision to use aircraft as artificial reef material should be based on ready availability from a military facility and low or no costs. The donor of the aircraft should be required to clean them to environmental specifications, and their use must be allowed by the active permit specifications. Historically, the most successful aircraft projects have involved fighter aircraft donations from military facilities that provided assistance and expertise in demilitarizing, cleaning, preparing, and transporting the aircraft in return for positive publicity.

- Planes with wings attached without additional ballast may glide in the water column and may not sink vertically to the bottom. If they are not being individually lowered all the way to the bottom, they should be individually temporarily buoyed in advance of deployment to confirm final resting location. Pieces of aircraft (tail sections or individual wings) should not be independently deployed. Multiple aircraft deployments designed for a dive site in deeper water should be individually lowered by crane and temporarily buoyed to assure the close proximity of two or more aircraft. If only fuselages are available, consideration should be given to securing two or more fuselages together prior to deployment to reduce potential for rolling and to increase habitat complexity.

- Small, heavily built, combat fighter aircraft are likely to be more stable and durable in an exposed marine environment at depths greater than 150 feet than larger military cargo, bomber, or commercial passenger aircraft. Military aircraft, such as those formerly operating off aircraft carriers, when placed in deep water can be expected to have a longer life expectancy as artificial reef habitat, based upon reports of the existence of 35 to 55 year old deeper water military plane wrecks still functioning as reefs. These aircraft may resist surge/current better than large military cargo or commercial aircraft fuselages with more extensive surface area and higher relief. This latter aircraft category along with small civilian aircraft are not recommended for use as artificial reef material based upon documented experiences to date.

- Aircraft were not specifically engineered to remain stationary in a high energy ocean storm situation. The deeper the depth the plane is placed, and the more protected the environment from major storm events, the better the aircraft seems to fare over a period of decades. Additional concrete ballasting of the fuselage if no anchoring system is planned, is recommended to improve the surface area/mass ratio.

- Aircraft should be deployed in areas that typically have low current conditions and in water depths exceeding 90 feet. This will minimize the effects of storm surge.

- Aircraft are constructed of varying grades of aluminum alloys, depending on their designed function. When considering aircraft as artificial reefs, managers should consider the type of aluminum alloy and its anticipated longevity in seawater.

- When preparing aircraft, the plane should be completely demilitarized (i.e., armaments removed or disabled). The fuel and hydraulic lines, wiring, low density plastic, or carbon fiber or other synthetic materials should be removed. Where wings remain on aircraft, multiple through holes should be drilled in the wings to allow air to escape and water to enter. Degreaser should be used to flush out residual fuel and hydraulic fluid. Luminous dials should be removed, as they contain toxic materials. Fuel manifolds should be cleaned, and the aircraft should be completely steam-cleaned prior to deployment.

- Areas where fish or other marine organisms can be trapped should be opened to water flow by cutting escape holes, removing or completely opening plexiglass, canopies, etc.

- Consideration should be given to cutting several openings in the aluminum fuselage skin in areas where the fuselage is an enclosed tube, to facilitate fish entry access points and water circulation.

- Anchor systems are limited by the life of the cables, shackles or attachment points which may well be shorter than the lifespan of the plane. Any anchoring systems that would cause cable abrasion against or cut into the aircraft structure itself should be avoided, along with expensive maintenance-intensive systems or those that would promote vandalism or theft.

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## 2.6 RAILROAD, SUBWAY, AND STREET CARS

### Overview

During the 1980s, North Carolina, Florida, Alabama, Mississippi, and New Jersey experimented with the use of obsolete railroad box cars as artificial reef habitat. The most intensive single project was conducted by North Carolina in 1985 and 1986. The state's artificial reef program deployed 210 railroad box cars (10 each at 21 different sites) at depths between 35 and 85 feet (Steve Murphey and Kurtis Gregg, personal communications). In July of 1986, Mississippi sank four box cars with a jumbo hopper barge in 65-feet of water (Lukens Consulting 1995). In 1987 and 1988, Lee and Sarasota Counties, Florida sank 48 and 40 box cars, respectively, on six different sites. During June 1988 in northern Gulf waters off the western Florida panhandle, Okaloosa County deployed 16 box cars at eight locations ranging from 60 to 108 feet deep (Jack Spey, personal communication). The same year, off Bay and Gulf Counties, Florida, another 17 box cars were placed at 12 sites across depths ranging from 60 to 130 feet in depth (Jon Dodrill, personal communication). In 1989, Alabama deployed 16 steel box cars at two 100-foot locations (Guy Hunt and CSX Reefs) off its coast (Walter Tatum, personal communication and Lukens 1993). Following a five-year hiatus in box car deployment, Lee County, Florida in January 1994 placed 60 steel CSX railroad hopper cars on sites ranging from 70 to 90 feet of water. Twenty-four of these were stacked, while 16 were not (Steve Boutelle, personal communication).

### Steel Railroad Hopper Cars

The Lee County, Florida metal hopper cars were inspected after approximately 2.5 years following the 1994 deployment. The group of 16 cars that were stacked in 90 feet of water did not show any signs of structural damage or weakening of the welds due to hydrodynamic or other forces. The reef was very productive, providing habitat for large goliath grouper, gag, and large schools (100+) of gray snapper. A total of 19 species were identified on the reef. Observations indicated that the stability and complexity of this type of reef material was moderate to good, while durability is thought to be moderate. The metal walls were showing signs of corrosion, particularly around the holes which were punched to increase water flow through the units. However, after 2.5 years, corrosion was present only on the surface of the metal, not yet affecting its strength.

Also assessed in 1996 were the two single hopper cars in 90 feet of water, which were located about 60 feet from each other at the same location as the stacked cars. Fish species diversity was similar to the larger stacked car reef, but fish abundance was lower on these individual units. This would be expected due to the smaller profile and footprint of these individual units. It was observed that some of the welds at the corners of the cars were cracking; however, it is not known to what degree this will affect the structural integrity of the units. Based on these observations, it was hypothesized that individual hopper cars were subjected to greater hydrodynamic forces per car, compared to the stacked units in which the currents/surges were deflected by the various angles of metal, and thus reduced in force. That evidence has led to the conclusion that any future deployments should stack rail cars, rather than deploying them as individual units (Tom Maher, personal communication).

The hopper cars were again visually inspected by Lee County artificial reef staff in 2001. Most of the hopper cars were still intact, with the main pile of cars showing good integrity; however, there were some individual cars that showed loose, flapping sides and others with sides missing completely. Fish population levels were still classified as good, with schools of very large crevalle jack and barracudas. Goliath grouper were also present. Further inspection in 2003, nine years post-deployment, revealed gaping corrosion holes in the metal sides of the cars, resulting in the physical loss of about 50% of the side plating surface area, either through corrosion or physical loss of metal plates. Bare frames were exposed. Fouling on the remnant metal on the sides was light because of the layers of metal sloughing off. The stacking of the cars still provided some complexity. (Chris Koepfer, personal communication). Twenty-one fish species were noted under conditions of 50-60 feet of visibility in 72-degree bottom temperatures. Scamp, greater amberjack, gray snapper, and lane snapper reported as common (20-99 specimens each) and yellowtail snapper were observed as frequent (11-20 specimens). A Lee County Fish Census Field Report in 2003, monitoring a railroad hopper car site, also noted several Goliath grouper.

The use of steel hopper cars, which possess additional cross bracing compared to box cars (due to compartment dividers), may provide longer lasting vertical structure. The North Carolina hopper cars continued to provide some fish habitat after a decade. Some of these cars were subject to scouring, which produced depressions along the base of the cars of up to five vertical feet. Although the number of grouper utilizing these hopper cars was lower than along natural ledges, the average size appeared to be larger than in the natural population (Kurtis Gregg, personal communication).

Railroad Box Cars

Steel box cars, approximately 14-feet high, 50-feet long, 10-feet wide, and weighing 49,000 pounds each, initially provided good vertical profile. They had an open interior and good circulation when doors were removed, welded open, or when additional holes were made. The structures had considerable surface area, and provided good habitat to large numbers of baitfish. Lobster, grouper, vermilion snapper, and amberjack were noted on the north Florida box cars (Danny Grizzard, personal communication). In the initial six months after deployment of box cars in 100 feet of water off Alabama, remote video from the NMFS showed box cars intact (Walter Tatum, personal communication); however, subsequent anecdotal observations indicate that these box cars have likely collapsed (Steve Heath, personal communication).

The structural integrity of most box car reefs began to be compromised within two years of deployment. The structural failure and flattening of the majority of the box cars in North Carolina occurred within two years post deployment, resulting in only about half of the sites being located by side-scan sonar surveys which confirmed the condition of the railroad cars (Steve Murphey and James Francesconi, personal communications). About 90% of the deployed box cars were wood and steel and, at present, provide little or no profile, aside from a few relatively intact end panels that are still standing. The remaining 10%, which were steel hopper cars, had remained intact as of the last survey in 1997. Finding groups of ten box cars after collapse has, however, proven to be worthwhile for North Carolina fishermen, since demersal target species are usually larger and more abundant on box cars than on other more easily located materials on the same site (Kurtis Gregg, personal communication). Most recent reports (James Francesconi, personal communication) indicate the box car sites are not identifiable by color fish scopes, except for fish they may be holding. They are providing small amounts of low profile ledge habitat for groupers and black sea bass.

The collapse of 48 wood and steel CSX box cars off Lee County, Florida began within months after their 1987 deployment. These box cars were placed in 72 feet of water in eight sets of six cars each. Six months after the box car deployment, Chuck Listowski, the Lee County Artificial Reef Coordinator at that time, wrote: "Until an investigation or study can be done to determine that box cars are, in fact, a viable artificial reef material, we will not advocate their use at this particular site" (Chuck Listowski, personal communication to Virginia Vail). A 2003 status report on the Lee County CSX box cars found that all box cars were totally collapsed, though some very low profile metal remnants remained visible on the seafloor (Chris Koepfer, personal communication). Deterioration of the wood apparently played a role in the rapid demise of box cars in both the Lee County and North Carolina projects.

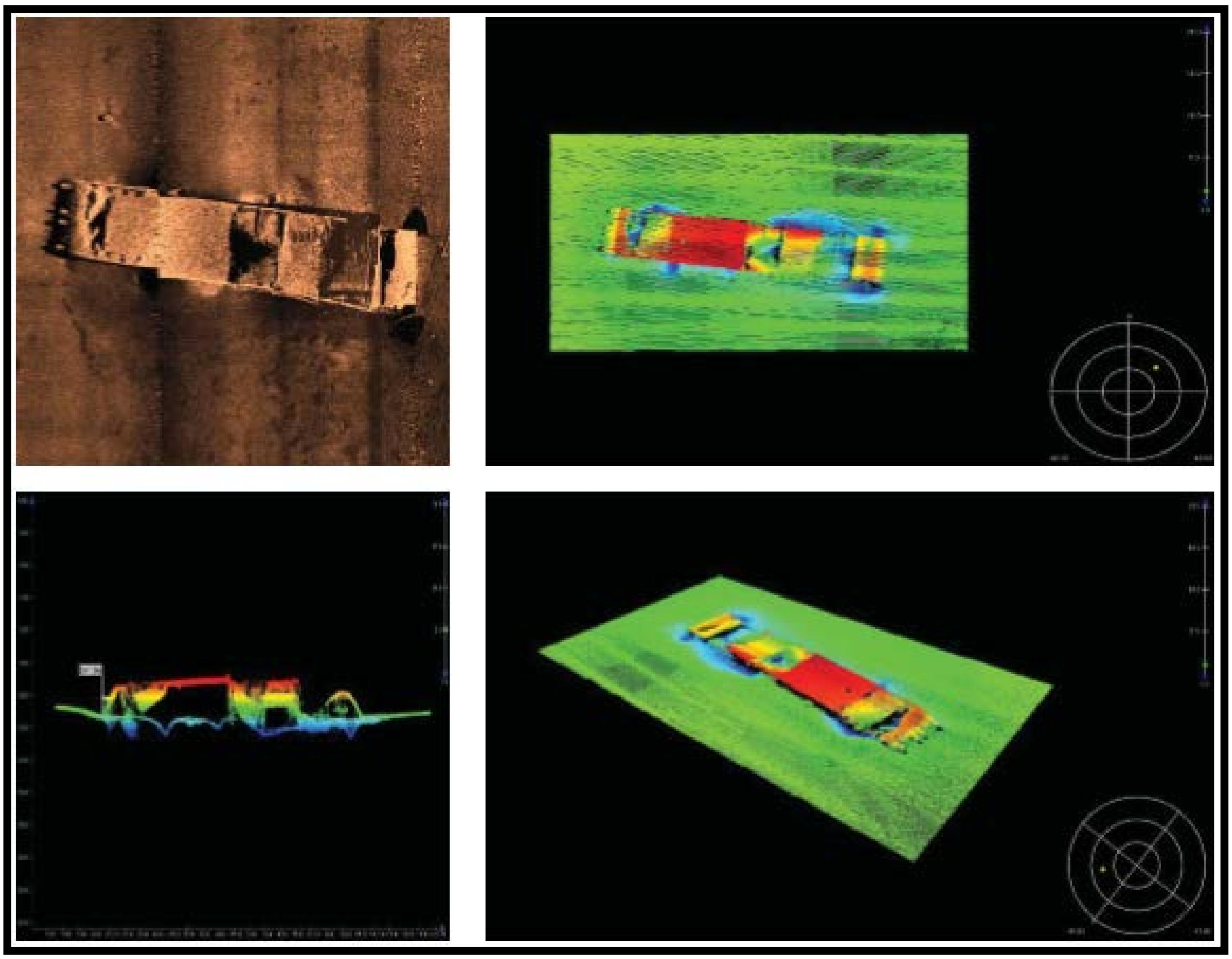
After six years, some steel box cars off Sarasota County, Florida experienced collapsing roofs and long walls, while the end panels remained standing (Jon Dodrill, personal communication). One set of 10 box cars in 50 feet of water were fully collapsed providing no relief. Only parts of the chassis were visible (Mike Solum, personal communication). Another pair of Sarasota County box cars were noted to have only an end panel of each still standing after six years. Depending on how the sides collapsed, they occasionally provided a lean-to shelter for large fish like goliath grouper. Nevertheless, even the nearly flat walls were still being used as a ledge-like shelter (Jon Dodrill, personal communication.)

Sarasota County staff reported that local fishermen and divers were initially very happy with the box car project but became disappointed when the cars had collapsed within a few years. Sarasota County does not believe the box cars were a cost-effective project, would not use them again, and would not recommend their use (Mike Solum, personal communication).

Partially collapsed box cars in Northwest Florida continue to provide reduced habitat, the effectiveness of which may depend upon how the walls of the box cars randomly collapse on one another. Fallen walls create a ledge or overhang effect which, when combined with scouring, provide habitat for grouper, sea bass, and snapper species. In 69 feet of water offshore of Okaloosa County, Florida, one end wall remained standing on each of two box cars after six years. Sixteen species of fish were still observed on those box car remnants, including large schools of amberjack and spadefish (Bill Horn, personal communication). Invertebrate growth was dense on the still-vertical, outer corrugated end panels of the box cars. These end panels are structurally stronger than side panels, because they are designed to withstand the jarring impacts of coupling with other cars.

An inspection of a 14-year old box car in 73 feet of water off Bay County revealed the box car to be substantially degraded with all sidewalls collapsed and lying horizontally on the bottom. Less than two feet of vertical relief remained. The low-relief collapsed wall structure was observed to be providing some habitat for benthic colonization, 13 species of fish, primarily juveniles, and overhang structure for one large goliath grouper (Mille and Horn 2001).

Box cars in water deeper than 100 feet were believed to remain intact for longer periods than those placed in shallower water. It is thought that at greater depths the effects of storm surge, which would stress and weaken the welds, would be less. Video footage, shot in October 1991 of a CSX steel box car deployed in 108 feet of water in June 1988 off Okaloosa County, Florida, showed it lying on its side. The metal roof had collapsed and was in several pieces on the seafloor, but all four sides were still attached (Jack Spey, personal communication). However, observations of two box cars by Christy (2002), one in 98 feet of water and one in 112 feet of water off Okaloosa County, revealed that all side walls and end walls of both cars had collapsed; however, their orientation on the bottom still provided enough cover so that 60-80 red snapper were present, along with grouper, triggerfish, amberjack, and some tropical fish species. The second box car site was inhabited by a mix of both red snapper and gray snapper, along with gag and amberjack. Both sites were characterized as holding surprisingly high numbers of fish, despite the low relief of the collapsed box car walls.



The Box car Barge deployed in 1986 off the coast of Mississippi in 69 feet of water (David Evans and Associates, Inc. 2016).

Although conventional box cars in Florida were partially collapsed within 2-6 years of deployment, and completely collapsed by 14 years post deployment, the low profile remnants of the collapsed metal frame and steel sidewalls at depths of 70-112 feet of water apparently did not move from their original deployment sites when exposed to Hurricanes Erin (1995), Opal (1995) and Georges (1998) (Jon Dodrill, personal communication).

Lukens Consulting (1995) reported on the vertical heights of the corners of four steel box cars deployed inside a barge offshore Mississippi in 1986. As the barge was sinking, it overturned, spilling the four box cars out onto the seabed. The first measurements of the height of the box cars were taken in 1989, and the second measurements were taken 2.5 years later. Those data indicate that the box cars used offshore Mississippi had not collapsed over a six-year period since their deployment. In 2001, a side-scan survey of the site by the Mississippi Department of Marine Resources showed three of the box cars still on site, with some minor movement of the box cars to the east. The side-scan sonar data indicated that box cars sides had not collapsed. However, the box cars were not evident in a 2016 survey of the site.

Subway Cars

The earliest recorded use of subway cars as artificial reef material occurred in 1990 when five subway cars were placed on a New Jersey reef at a depth of 65 feet. Only the car bodies were deployed with wheel trucks removed. In 2000, diver surveys indicated that these cars were still providing three-dimensional structure. The center section of some cars had collapsed, while others were intact. It is not clear whether this damage occurred on deployment, or was due to deterioration (Bill Figley and Bill Muir, personal communications).

In 2001, the New York City Transit Authority (NYCTA) offered 1,300 obsolete subway car shells to state programs as reef material. These cars, dating from the late 1950s and 1960s, weighed 9 tons and were 9 feet wide, 9.4 feet high, and 51.5 feet long. They were composed of sheet steel 0.07 inches thick. A small amount of non-friable asbestos was on the walls between two layers of steel.

Both the New York and Philadelphia regions of the EPA provided guidance on the asbestos issue. The asbestos was found in a small quantity and was bound in a solid matrix (non-friable). There was no mechanism for detrimental effects to the marine environment. The Philadelphia office of the U.S. Army Corps of Engineers and the NMFS supported the use of these cars as reef material. Bill Muir of the EPA, after examination of the submerged New Jersey subway cars and NYCTA transit cars, projected a 25 to 30 year life for the material underwater.

With the asbestos and durability issues addressed, Delaware signed an agreement to accept 400 subway cars from the NYCTA. The agreement was later amended and Delaware now has over 700 of these subway cars deployed in 85 feet of water. The cars continue to support a vast invertebrate assemblage and dense populations of sea bass and tautog.

South Carolina deployed 200 NYCTA subway cars between 2002 and 2003 on reef sites ranging from 90 to 120-feet deep, and has continued to monitor their development and productivity over the years since. After 10 years of submergence, over 90% of the cars remain intact and upright. They support extensive invertebrate colonies, including hard and soft corals, and large and diverse fish assemblages. These sites are also extremely popular with divers and fishermen.

New Jersey (250), Virginia (150), and Georgia (50) also received subway cars from New York City, and all report that these reefs remain in good condition and continue to be productive. The


NYCTA “brightliner” subway cars deployed in 2008 at HLHA Reef off Georgia. Photo Credit: GADNR.

Ocean City, Maryland Reef Foundation rejected the offer of subway cars based on their concerns about the public perception of the associated asbestos. Initial water testing for asbestos concentrations in Delaware, however, showed levels similar to background levels in seawater and within the drinking water standard established by the EPA. The state of Florida also declined the subway cars, because the sheet metal did not meet existing state standards for thickness of metal in reef materials.

In 2006, the New York City Transit Authority again approached states with the offer of acquiring additional subway cars which were soon to be retired. Unlike the previous cars that were made of carbon steel, the new vehicles were constructed of stainless-steel, and were larger in size, 60-feet long, 10-feet wide, and 12-feet high. It was thought that the stainless-steel construction would make the cars even more durable than those with carbon steel bodies. Due to the success of the previous subway car reefs, several states enthusiastically agreed to accept the cars. Delaware, New Jersey, Maryland, Virginia, South Carolina, and Georgia all received “brightliner” subway cars for their reef programs between 2006 and 2008. Within approximately 6-9 months after deployment, however, most of these states began seeing problems with the cars. Sheet metal siding and roof panels were detaching from the bodies, side walls and roofs were collapsing, and in some cases, large ripped and jagged pieces of metal were moving considerable distances offsite. Within a year of deployment almost all states reported the near complete collapse of all stainless subway cars.


The end of a “brightliner” subway car, deployed in 2010 at CCA-JL reef, remains standing upright in Georgia waters. Photo Credit: January Murray, GADNR.

A collapsed “brightliner” subway car deployed in 2010 at CCA-JL reef continues to provide low relief quality habitat in Georgia waters. GADNR divers observed red snapper to have an affinity for collapsed versus intact subway cars along the Georgia coast. Photo Credit: January Murray, GADNR.

In some cases, damage to the stainless-steel cars began during deployment. Roof panels were occasionally gouged or torn by the heavy equipment used for moving and deploying the cars at sea. Once these panels became damaged, the constant stress of underwater currents continued the rapid deterioration of these thin, sheet-metal panels. Divers often reported roof panels “flapping” in the currents soon after deployment.

It has also been speculated that differences in construction materials may have played a large part in their deterioration. Although wall and roof panels were made of stainless-steel, which should have been very corrosion resistant, rivets holding the panels in place were not. These differences in metals may have led to ionization which hastened corrosion of the rivets, allowing wall panels to break free. Collapse of most of the stainless-steel subway cars was due to loss of supporting wall panels, not corrosion of the walls themselves.

NYCTA “Redbird” subway cars deployed off Georgia in 2002 at CCA-JL Reef (25 cars) and L Reef (25 cars). Photo Credit: GADNR.

Because of the near universal collapse of stainless-steel subway cars in all states and in all water depths, the New York City Transit Authority discontinued its reefing program. In most instances, the collapsed stainless-steel cars still provide low relief habitat. Their value as reef material, however, is not as great as the intact, high relief carbon steel “Redbird” cars and this may make reefing them not a cost-effective alternative. Any future use of subway cars as artificial reef material should begin with a thorough analysis of the construction materials of the vehicles.

Street Cars

During September 1958, six wooden street cars were placed in 60 feet of water, approximately one mile offshore from Redondo Beach, Santa Monica Bay, Los Angeles County, California by biologists from the California Department of Fish and Game. Over 2,800 fishes were concentrated in and around the street cars within the first 25 months. In 1960, two additional street cars were placed on reefs at Malibu and Santa Monica, both in Santa Monica Bay. Subsequent surveys conducted 4.5 years after the Redondo placement showed that only low relief structure remained (Carlisle et al. 1964). The authors subsequently concluded that material less susceptible to the boring action of marine organisms is recommended for reefs expected to last longer than three to five years.

Benefits

- Box cars can easily be cleaned and prepared compared to other materials. Cutting of holes may be required for air vent purposes and to provide better water circulation in the box car's interior.

- Box cars, to date, have been donated, so only cleanup, preparation, and sea transportation costs were incurred.

- Box cars are a manageable size for deployment from a barge, but are large enough to provide considerable surface area and vertical relief.

- Box car vertical profile is attractive to both pelagic and demersal fish species. Loss of vertical relief through side wall collapse may continue to provide low relief, hard bottom/ledge habitat. While flattened box car structures may be perceived as too hard to locate by some, other fishermen may view this as a benefit that reduces fishing pressure (and competition) at the site.

- Subway cars, though made of relatively thin gauge steel, are engineered for strength and are much more structurally complex than railroad box cars.

- Some subway cars have a projected lifespan of 25 to 30 years.

- Some subway cars have proven to be fully functional as artificial habitat, offering trophic support to reef fish by supporting invertebrate communities.

- Subway cars have considerable vertical relief and surface area and may be available in large numbers.

- Subway cars may be provided at little or no cost to artificial reef programs because the NYCTA cleans and delivers them on site at no cost to the programs.

Drawbacks

- Vertical relief of box cars is not sustained over an extended period. Most of the vertical relief on steel walled box cars appears to be lost within four years, with complete wall collapse and loss of nearly all vertical relief at depths of 90 feet or less occurring by 14 years.

- Fully or partially collapsed box cars are difficult to locate on a depth recorder.

- Box cars as secondary-use materials become available only when they are no longer serviceable. Usually this means that deterioration of the roof and other portions of the car has already begun. The heaviest gauge steel (wheels, axles, wheel frames) is normally removed from the box car for further use by the railroad.

- The vertical profile of conventional box cars is, in most cases, reduced by 90% within 6-14 years of deployment after the roof and all sides have collapsed.

- Stainless-steel subway cars have been shown to collapse and deteriorate in as little as 6 months. Large pieces of sheet metal may move considerable distances offsite.

- Availability of box cars and subway cars is unpredictable. Access to surplus cars is dependent on the proximity of the rail line and a railhead to a marine staging area.

Considerations

- Combination wood and steel surplus box cars deteriorate rapidly in the marine environment. The wood structural components render them less than ideal for use as artificial reefs. Deployment of large numbers of such box cars (more than 30 per site with close spacing) may still provide years of fishing opportunity, even following box car collapse. However, the transportation costs involved in such a large project would need to be evaluated and weighed against utilizing other materials that may have the same or superior ability to meet the reef objectives over a more extended period of time.

- Welding braces between the long side walls has been proposed as a means of prolonging the vertical profile of a box car. The use of steel hopper cars, with two lateral walls separating each car into three bins, may reduce outer wall flexing and wall collapse.

- Stacking of railroad cars may provide greater reef longevity.

- Observations offshore Florida indicate that hopper rail cars are more durable than standard box cars.

- Removing doors and windows of subway cars provide good interior circulation and openings for fish and other organisms.

- Determination of the construction materials of subway cars is critical in assessing their value as reef material.

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## 2.7 DESIGNED STRUCTURES

Overview

Secondary use materials may predominate artificial reef development efforts depending upon project-specific goals; however, the use of structures designed for artificial reef construction purposes continues to increase throughout the United States and worldwide. According to Grove et al. (1991), the trend towards the construction and use of designed artificial reef structures largely began when reef programs directed their efforts to take advantage of new knowledge of fish behavior and oceanic processes.

Early versions of designed reef structures largely relied on secondary use materials, such as tires, in their designs and were necessarily configured to accommodate these materials. Some of the earliest designed reef structures constructed for fisheries enhancement include 4’ x 4’ log huts built and deployed by South Carolinians in the late 1830s to improve fishing for sheepshead (McGurrin, 1988). Similarly, bamboo frames filled with sandbags and other materials were deployed off the coast of Japan to facilitate the harvest of grunts (Vik, 1982).

Beginning in the late 1980s, the utilization of designed artificial reef units in formal designed research projects was occurring in Gulf and Atlantic waters off Florida (Hixson and Beets 1989; Kruer and Causey 1992; Bortone et al. 1994; Eklund 1996; Lindberg and Loften 1998; Sherman et al. 2002). In the early 1990s, Florida’s and Alabama’s artificial reef programs began to incorporate the construction and deployment of modular designed artificial reef units as an alternative to “materials of opportunity” that became prohibited to use as artificial reef structures (e.g. washing machines, fiberglass boat hulls and auto bodies). Some of the early prototype structures in Florida were constructed with lighter weight plastic or PVC components that did not hold up in ocean conditions. Failures included delamination and movement of plastic corrugated sheeting from AquaBio units (Turpin, 2001), and disassociation of recycled plastic frame modules (Horn 1995; Turpin and Bortone 2002).

Concrete and tire tetrahedron modules that were deployed offshore Alabama from the mid-1990s-2010s. Photo Credit: ADCNR

Experimentation with the use of secondary use materials fabricated into modular units continued to the early 2010s. In Lee and Citrus Counties in Florida, an artificial reef using concrete telephone poles stacked together, termed the “Lincoln Log Reef,” was constructed by alternately stacking concrete poles on top of each other to form a square area held together by metal straps and rebar. Unfortunately, within a few years the metal straps failed and the modules collapsed into a pile. Additionally, tetrahedron modules created with concrete and tires were deployed offshore of Alabama from the mid-1990s to the early-2010s. Concrete tetrahedron-shaped modules incorporated steel cutouts from manufacturing operations were also deployed offshore of Florida and Alabama during this time period. However, artificial reef modules deployed after the early-2010s were constructed with primary-use materials and modules no longer incorporate secondary-use materials.

Concrete tetrahedron modules that incorporated steel cutouts from manufacturing operations were deployed offshore of Alabama and Florida from the mid-1990s-2010s. Photo Credit: ADCNR

The advent of “modernistic reef modules” came to the forefront in Japan as a result of a government subsidy program that was initiated in 1952 utilizing primary-use materials and structures designed to meet project-specific goals (Sheehy 1982; Grove et al. 1991). In contrast to earlier structures, these engineered configurations no longer incorporated secondary use materials for construction, but rather used prestressed or reinforced concrete, steel, fiber-reinforced plastic (FRP), plastics, ceramic, and other composite materials that allow the exact fabrication and manufacture of the engineered designs. Materials utilized to construct designed structures were also selected for resistance to corrosion/abrasion and other durability considerations, as well as strength, structural/design demands, and biological compatibility (e.g., pH, rugosity, etc.). The ability to modify mixtures and the flexibility to cast concrete into a great variety of forms makes the material ideal for developing prefabricated units, although steel is used in larger structures due to weight considerations associated with concrete.

Working with fisheries biologists and ecologists, engineers in Japan and other Asian nations have developed hundreds of designed artificial reef structures to carry out numerous large-scale fisheries enhancement projects since the 1960s (Grove et al. 1991). Standards required for Japanese units are summarized by Grove and Sonu (1985), including durability/stability (minimum of 30 years of usable life, ability to withstand handling/placement rigors, resistant to burial/movement); safety (non-toxic, handling safety); functionality/biological effectiveness (proven and tested record of fish aggregation, attraction/production of targeted species, creation of desired habitat, biotic diversity); and economy (not too expensive, availability). Other engineering considerations are surface area, complexity, void spaces, surface texture, light/current penetration, relief, shape/profile, hydrodynamics, and more, depending on the purpose of the reef and the targeted fisheries.

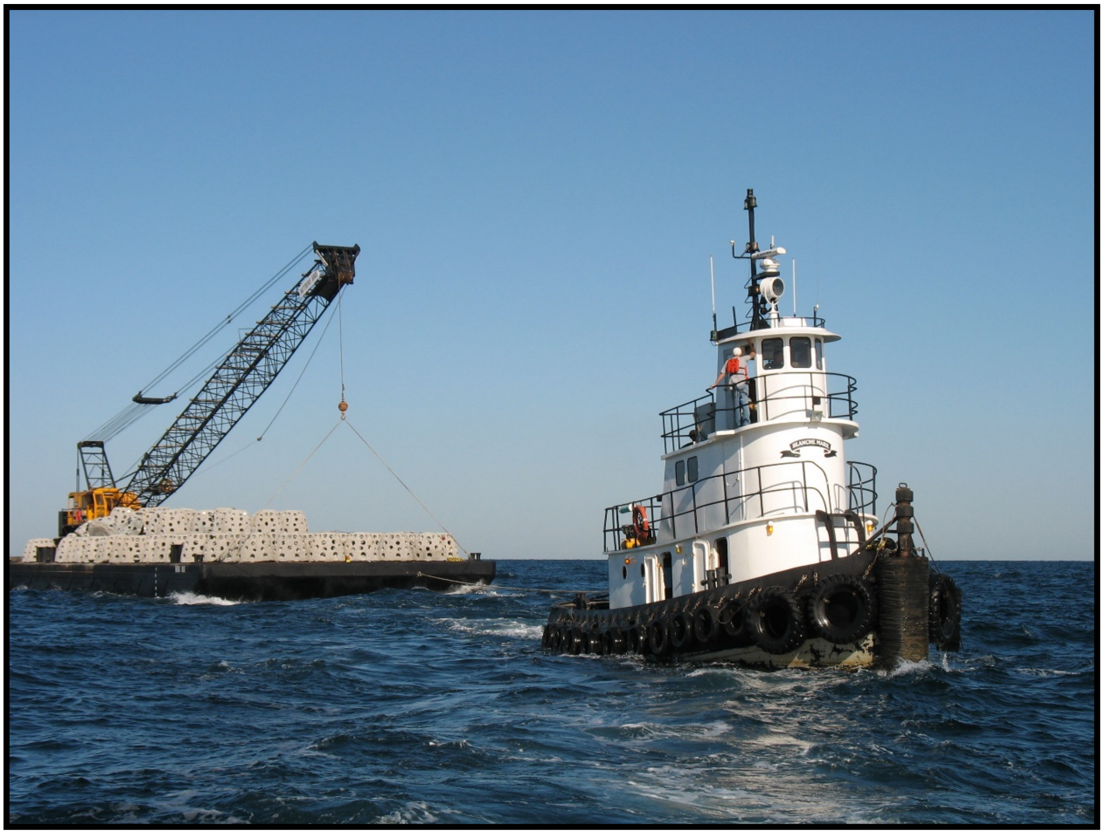
The first generation of designed artificial reef structures developed in Japan primarily consisted of relatively small, hollow concrete cubes or cylinders with "windows" in the sides (Sheehy 1985). Along with another basic dome structure ("turtle blocks"), these manufactured units provided the simple building blocks for several significantly larger designed artificial reef "chamber" structures reaching 10 m in height and weighing up to 34 tons (Mottett 1985). By 1985, more than 100 types of designed artificial reef modules had been certified for use by the Japanese government (Sonu and Grove 1985). Examples of designed artificial reef structures developed in Japan and Taiwan may be found in publications by Sheehy (1981, 1982), Grove and Sonu (1985), Sheehy (1985), Sonu and Grove (1985), and Vik (1982).

Experimentation and small-scale deployments of specifically designed artificial reef structures began in the United States in the late 1970s, and remained sporadic into the 1980s. Except for notable exceptions such as the deployment of FRP cylinder units off Jacksonville and Panama City in 1981 (Sheehy 1983). This is largely due to the relatively high construction costs, low availability of units, limited distribution of artificial reef unit venders domestically, and continued abundance of secondary use materials. Despite limited sales historically, interest was generated within the United States regarding Japanese and Asian artificial reef technology and designed structures. Subsequently, American artificial reef programs and commercial enterprises began to experiment with, evaluate, and construct more affordable designed structures (McGurrin 1988; Bell et al. 1989; Bell and Hall 1994; Gregg 1995).

Several Atlantic coastal states began to experiment with and utilize different types of designed artificial reef structures in varying scales for reef development in the early 1980s (Mike Meier, personal communication). While materials of opportunity are still relied upon for many artificial reef construction projects, in recent years coastal states began utilizing designed reef structures at increasing levels to carry out artificial reef development objectives. This expanded utilization of purposely designed reef structures is due, in part, to the development of more cost effective and dependable designs, increases in funding levels of some artificial reef programs and the limited availability of previously utilized secondary use materials.

In 2001, Maher surveyed several Atlantic, Gulf of Mexico, and Caribbean artificial reef development programs on their use of designed modules which were not simply fabricated from secondary use materials. According to Maher, "Of the eleven states that responded to the survey, only two states (Alabama and Louisiana) had never used designed artificial reef modules within their public artificial reef programs. However, a number of various module types have been deployed through the private reef-building program in Alabama."

The rapid increase in the utilization of designed artificial reef structures is likely due to a number of factors. The most important of these has been the commercial manufacture of several designed artificial reef structures that are affordable and readily available, which are important considerations in planning and budgeting artificial reef construction projects. Substantial improvements have also been realized in concrete formulations and designed structures that provide immediate ecological advantages and offer potentially longer service than many materials of opportunity. Other factors contributing to the increasingly widespread use of designed artificial reef structures include increased levels of funding for many artificial reef programs, greater interest in designed structure technology, and the reduction of previously dependable sources of reef materials (e.g., concrete recycling). Maher (2001) also notes efforts by the states to dispel their images as solid waste disposal operations by utilizing designed structures and the preference for standardized units in research.



A barge of designed reef modules being transported offshore of Mississippi for deployment. Photo Credit: GSMFC

Maher (2001) located 44 different modules that had been designed or patented in the United States; although, only 31 designs had actually been deployed. Of this total, several designs were used only on a limited basis for specific research studies and mitigation, while others are no longer produced. Several structures are commercially available, while some represent program designs, either for research, construction, or both. Maher's survey in June, 2001, indicated that over 31,000 designed structures had been deployed along the eastern seaboard, in the Gulf of Mexico, and off Puerto Rico. To date, most designed artificial reef structures deployed in the United States have been relatively small (19 to 70 cubic feet in volume) and are made from readily available, durable materials such as concrete or steel fashioned into domes, tetrahedrons, pyramids, cylinders, squares, and other shapes. Examples of these designs are found in McGurrin (1988), McGurrin and Wilson (1991), and Maher (2001). One study evaluated the use of plastic cone-shaped artificial reef modules in a northwest Florida bay environment (Bortone et al. 1994). However, larger designed structures have been utilized since 2013 to create higher profile and more complex reefs to provide habitat for a more diverse community assemblage. Some of these larger designs provide as much as 25'+ of vertical relief and over 1,200 cubic feet in volume.

A significant benefit of utilizing designed artificial reef structures is the flexibility in which the structures can be designed for the budget available for each project. Models can be designed without interior void spaces or engineered with interior void spaces that feature additional shelves or compartments inside the module to increase the overall complexity of the structure. Therefore, the structural complexity of the designed structures can vary depending upon the budget and goals of each project. For example, a lower quantity of modules that are more complex in design can be utilized for a similar budget as a higher quantity of modules that are less complex in design in order to meet project-specific goals.

Modular reefs have been embraced by the scientific community to answer a variety of ecological questions relating to artificial reef ecology, design and placement. The ability to standardize reef size, shape, and location has been helpful in a variety of studies to gauge the needs of target species and life histories. Such work includes the use of concrete cube modules to evaluate artificial reef characteristics and fishing mortality on gag grouper productivity and reef fish community structure in the Northeast Gulf of Mexico (Lindberg and Loftin 1998) or investigate spacing patterns of artificial reef modules (Frazier and Lindberg 1994).

Two different size designed reef modules utilized for reef development in Mississippi nearshore and offshore waters. Photo Credit: GSMFC

A few artificial reef programs have occasionally utilized large, more complex, designed structures in reef construction projects representing one-time opportunities (Ben Mostkoff and Jeff Tinsman, personal communications). Two well-known examples include mitigation efforts in Delaware Bay (Steimle et. al., 1991) and offshore of Dade and Broward counties in Florida (Mostkoff 1993; Banks and Fletcher 2001). To date, these large units have only limited applications for U.S. programs due to their relatively high production and deployment costs, as well as the continued availability of other materials of similar scale (e.g., vessels). Florida and Alabama artificial reef programs began utilizing large designed structures as artificial reef habitat in 2013. Some of these structures provide up to 25’ of vertical relief and provide over 1,150 cubic feet of refuge, foraging opportunities and substrate for marine organisms to inhabit.

Designed artificial reef modules have also been used for reef restoration of ship grounding sites. The first major structural restoration of a damaged reef occurred in 1995 during a restoration project for two separate incidents, the 40 m M/V Alec Owen Maitland, and the 142m M/V Elpis, which separately ran aground in the Key Largo National Marine Sanctuary in 1989 (Bodge 1996). To repair the fractured coral reef, coral rubble, and large craters created at the grounding sites, numerous innovative materials and marine construction techniques were implemented at a final construction cost of $1,047,000. The project’s intent was to re-create a stable foundation to resemble the natural reef structure. At the Elpis site, work involved mechanical transfer of coral rubble back into the craters, placement of 4.25 foot diameter limestone boulders, and backfilling with carbonate sand to re-establish the existing grade. At the Maitland site, work included excavation of coral rubble and precision placement of 40 pre-cast "Reef Replicating Armor Units" with the gaps between the units and the crater perimeter being filled in situ with a specially-designed, non-separable underwater concrete, into which coral rubble and soft corals were impressed (Bodge 1996).

The modular unit known as reef balls with transplanted coral attached has been utilized in a pilot project in an effort to restore severely damaged Oculina or ivory tree coral (*Oculina varicosa*) habitat in the Oculina Experimental Closed Area off the central Florida east coast, where 90% of this coral habitat has been reduced to rubble by trawling and other fishing activities. Submersible studies in 2001 indicated fish abundance around the reef balls was much greater than over dead rubble habitat and that these units may be functioning as focal points for renewed grouper spawning activity (South Atlantic Fishery Management Council 2003).

Artificial reef program managers need to be mindful of the design of modular-type artificial reef structures. Utilizing a structure to mitigate an environmental issue may lead to anthropogenic and biological issues if the structure is not carefully designed to prevent negative impacts. State reef program managers should consider the design of artificial reef modules to lessen the potential for entrapment of marine life or entanglement with fishing gear and anchor ropes. Artificial reef modules should be designed such that marine organisms can easily escape interior void spaces within the structure if needed. For example, modules should be designed such that large marine organisms (e.g. sea turtles) can escape from the interior of the structure. The escape holes should be located within the highest portion of the structure a sea turtle may reach and it should be accessible for the sea turtle to navigate unimpeded to the opening. Additionally, the structure should be designed to consider entanglement of fishing line. Overhanging, horizontal protrusions with sharp, angular edges should be limited if entanglement of fishing line is anticipated.

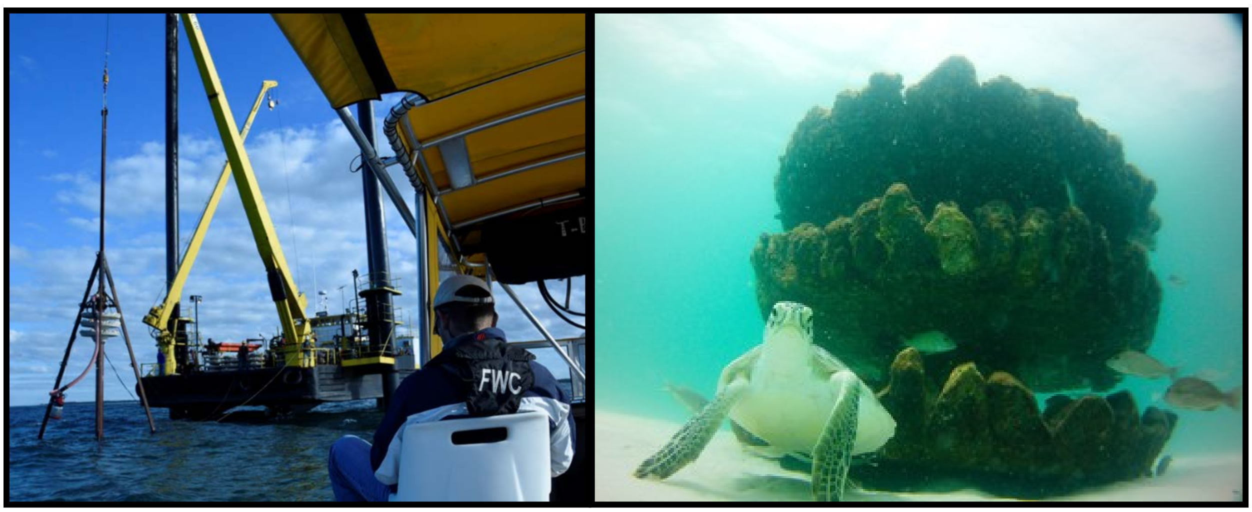
The performance of individual designed reef structures may vary considerably, depending on their specific characteristics as well as location of deployment and intended results (Bell et al. 1989 and Bell and Hall 1994). Including breakups, movement, and burial, failures have been reported for both past and presently available designed structures (Bell and Hall 1994; Gregg 1995; Florida DEP 1996; Turpin 2001; Henry Ansley, personal communication). Not all available designed structures have been uniformly subjected to adverse environmental stresses or their performance tested in the many varying habitats that exist along the Atlantic seaboard and throughout the Gulf of Mexico. Unit costs are also highly variable between designs and from one geographic area to another (Maher 2001). Utilization of designed reef materials will vary among artificial reef programs, based on the specific needs, financial and local resources, site and logistical demands, and development objectives of individual programs. Regardless, designed structures should be engineered to withstand the hydraulic and chemical stresses of the marine environment and should not feature components that are not structurally sound or portions that could disassociate from the structure.

### 2.7.1 Shallow, Nearshore Reefs

Artificial reefs constructed using designed modules within the shallow waters of the near beaches should be specially engineered to mitigate numerous potential negative outcomes. Designed structures should be engineered to ensure locational stability during high wave energy events. A possible method to ensure long-term, locational stability would be to anchor the module into the seabed. The type of anchor and depth at which it is installed below the seabed should be appropriate given the substrate on which the designed reef structure is placed and the shape/size of the designed artificial reef structure.

Shallow, nearshore reefs within 1,000' of the shore were first installed along the Florida panhandle in the mid-2010s followed by Alabama in 2018. Each of these reef sites consists of numerous anchored reef modules consisting of concrete/limestone discs affixed to a piling jetted between 12' and 15' into the seabed. To date, this anchoring system has proven to be extremely effective of ensuring locational stability. For example, category 4 Hurricane Michael passed directly over numerous anchored reef modules installed in water depths less than 25'and all of the modules remained stable.

Starting in 2016, Florida started to construct some snorkeling reefs using specially designed reef modules. These modules were designed to be very stable in the high energy environment and allowed for very high deployment precision (Keith Mille, personal communications).




Snorkeling reefs deployed off the northwest Florida coast. Photo Credit: FLFWC

Shallow, nearshore reefs may increase SCUBA, snorkeling, skin diving and/or kayaking activities around the artificial reef site(s). Outreach efforts to educate local vessel operators should be performed to mitigate negative interactions between in-water users and vessels. Additionally, signage along shore access sites should include an advisory regarding the use of dive flags, information regarding distance from shore, and shore-based users to use precaution when considering swimming to the reefs (particularly if they are not strong swimmers).

### 2.7.2 Memorial Reefs

In recent years, there has been an increased interest in memorial reefs in which cremated remains are incorporated into an environmentally-safe cement mixture which is formed into a designed reef structure (e.g. Reef balls). These reef structures are then deployed on a permitted reef site to create new marine habitats.

Artificial reef memorialization can be a significant enhancement to artificial reef programs. Memorialization is the only form of artificial reef development that comes with its own, independent funding. Recreational fishing and diving habitat can be increased without either federal or state funding, or the need to actively solicit donated funds (George Frankel, personal communications).

An Eternal Reef. Photo Credit: Eternalreefs.com

Given the sensitivity of memorialization, there is the need for specific standards regarding participation for those companies and individuals who are looking to make reef memorialization an ongoing for-profit or not-for-profit business. These standards should address both the materials being used, and the experience of the individuals doing the placements.

The Green Burial Council is the only not-for-profit, independent certifying organization that has established standards for the funeral industry regarding 'green' or conservation memorialization. In 2010, the GBC recognized that reef memorialization was an important part of conservation memorialization and looked to establish standards and criteria for those looking to become involved with providing a marine based conservation memorial choice.

In 2011, The Green Burial Council adopted one, two, and three leaf, or a good, better, best criteria for undersea memorial reef memorialization. These criteria addressed materials; design; reef siting; and inclusion of cremated remains. Since they initially adopted these standards for cremation memorialization they have stopped certifying cremation memorials because of the growth of cremation options and of a lack of resources to keep up with the changes.

<u>Benefits</u>

- The availability of designed structures facilitates long-term artificial reef development program planning, and improves budgeting.

- Since designed structures can be procured on an as-needed basis, artificial reef development activities are not dependent on or dictated by the availability or lack of availability of suitable secondary use materials.

- The availability of desirable secondary use materials may be decreasing.

- Designed structures can be selected or engineered to address the specific goals and objectives of an artificial reef program or specific artificial reef, including targeting specific fisheries, life stages, biological communities, user groups, and gears.

- Although initial investments may be higher, greater returns from these one-time fixed costs may yield comparatively greater cost-benefits and returns than possible with secondary use materials, if the designed structures are more effective or have a longer service life.

- Recent developments in the U.S. private manufacturing sector have made some designed structures readily available at more affordable prices to artificial reef programs.

- Designed structures can be specifically engineered to meet requirements of a particular reef site/substrate.

- Designed structures can be selected/engineered to maximize specific unit characteristics, such as complexity, void/hole number and size, relief, texture, and more.

- Construction from durable components such as concrete or steel should result in long-term service.

- Problems and expenses associated with material toxicity or cleaning can be completely avoided.

- In some instances, transportation and deployment of designed structures may be easier.

- Designed structures facilitate and promote the utilization and incorporation of extensive artificial reef research and engineering conducted in Japan, Taiwan, and elsewhere into United States artificial reef development efforts.

Drawbacks

- Reef programs with minimal financial backing may find it hard to afford the often higher initial costs of construction projects utilizing designed materials as compared to lower-priced efforts involving donated secondary use materials.

- Generally higher costs per unit of designed reef structure, as compared to secondary use materials, may discourage some reef managers and backers of reef programs from using designed structures.

- In some areas, suitable and even preferred secondary use materials remain available.

- Most affordable designed reef structures lack some of the appeal and potential public interest that can be generated in the sinking of certain secondary use materials (such as a large ship), and some reef user groups, such as divers, may be less interested in their use for popular reef applications.

- Research and development for new designs with broad-range application can often be too expensive for individual reef programs or private companies to invest in, since the product would likely have a relatively small, limited market.

- Requiring cranes and deliberate barge operations, deployments of designed structures at sea and under variable conditions can be more demanding than with concrete pipe, rubble, and many other secondary use materials which may be simply pushed over without lifting or breakage concerns.

- Much of the initial investment in a designed structure may be negated if the final correct placement and proper orientation of the unit on the ocean bottom does not occur or cannot be ensured without excessive additional labor commitments and costs.

- As with any materials, past failures of designed structures affect their future use and the willingness of programs to commit additional funding toward these units. Often failures of one type of engineered unit may be assumed or applied to other designed structures.

Considerations

- Artificial reef program managers should be aware of the types of designed reef materials that are available, and attempt to understand how they might utilize these or similar reef structures to carry out specific artificial reef construction and management objectives.

- Further research and development of designed reef materials needs to be conducted along the entire Gulf of Mexico and Atlantic seaboards, with aggressive field testing to broaden the menu of available, suitable designs for artificial reef programs.

- Stability, subsidence, and scouring of existing designed artificial reef structures on fine or soft sediments need to be documented. Designed structures need to be engineered to permit long-term artificial reef development on fine or soft sediments, including estuarine areas.

- Greater efforts should be made by artificial reef programs nationwide to share their experiences (successes and failures) with designed structures.

- There should be greater cooperation between artificial reef programs and private manufacturers to define reef program needs/concerns, engineer appropriate designs, and facilitate follow-up evaluations.

- Designed structure technology must be adaptable to local situations, including small scale projects and interest groups with limited budgets (Brock et. al., 1985).

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## 2.8 MILITARY HARDWARE

### Overview

The occasional procurement, preparation, and utilization of military hardware for Gulf and Atlantic States artificial reef programs has focused on obsolete, multi-ton, mobile, armored equipment of high durability and stability. In the 1990s this equipment was procured primarily through formal partnership efforts between the Department of Defense and state artificial reef program managers. One of the principal means of securing this reef material was through a pilot program known as "Reef Exercise" or REEF-EX. REEF-EX, a joint Department of Defense-civilian cooperative program, was intended to benefit both the military services, as well as U.S. local coastal economies while increasing commercial and recreational fishing opportunities and enhancing national fishery resources. The REEF-EX program has provided obsolete main battle tanks, armored personnel carriers, Sheridan tanks, and other military battle hardware for ten state artificial reef programs from New York to Louisiana.

### REEF-EX '94

In 1993, the U.S. military, in addressing options to dispose of thousands of obsolete or excess main battle tanks (MBTs) owned by the Army Materiel Command (AMC) and stockpiled at various military bases in the U.S., determined that immersion in seawater was an acceptable method of partial demilitarization. The decommissioned tanks were no longer needed by any U.S. military service branch, or other federal agencies and were not scheduled to be purchased by eligible foreign countries (Finegan 1995b).

The Defense Logistics Agency (DLA), the agency in the Department of Defense charged with handling, storage, and disposal of surplus military equipment, considered the alternative of donating the equipment to coastal states for artificial reefs in order to provide a greater economic benefit than the short term gain realized from selling the tanks for scrap. Four inch thick hardened steel tank armor made the MBTs difficult to cut up and required demilitarization and shipment by rail to distant specialty scrapping facilities in the Midwest (Currie 1994). The DLA first contacted the Alabama Department of Conservation and Natural Resources, Marine Resources Division, regarding the possibility of placing the material in the artificial reef general permit areas offshore Alabama. Alabama was very supportive of the concept, and provided the DLA with supporting documents from the Office of the Governor and members of the U.S. Congress. From this initial support REEF-EX '94, a military program, was organized.

### Environmental Planning

The U.S. Environmental Protection Agency (EPA) developed federal requirements for placement of MBTs in the marine environment, including a detailed cleanup checklist in order to minimize environmental hazards. No materials controlled under the TSCA, including PCBs and asbestos (except asbestos between bulkheads or otherwise contained), could be left on the tanks (Muir 1994a). The list had to be certified as completed after each tank was cleaned and inspected (Muller 1995). These MBT cleanup checklist and certification activities included the following: 1) engine/power pack removal; 2) completely draining and sealing both fuel tanks; 3) draining and plugging drive trains; 4) removing all hydraulics including turret, hydraulic reservoir, and pump; 5) draining and plugging the cannon recoil mechanism; 6) discharging fire extinguishers; 7) removing radioactive dials, knobs, and gauges; and conducting associated wipe test to detect any radiation; 8) removing batteries; 9) welding open or removing hatches and rear engine grill doors; and 10) removing synthetic seat covers. The MBTs were also double steam cleaned inside and out. Additionally, merely sinking tanks in seawater did not constitute full demilitarization. Further demilitarization of the MBTs required securing the main gun tube, spot welding the breech mechanism, removing the range finding/sighting mechanisms, and removing any remnant small or large caliber ammunition (Finegan 1995b, Muller 1995, Jon Dodrill, personal communication). Tanks were to be individually inspected by representatives from EPA, the U.S. Coast Guard, U.S. Army Corps of Engineers, and the state agency receiving the tanks. Checklists for each tank were to be certified by each agency as completed. This did not prevent any local, state, or federal agency from requiring more stringent preparation once the equipment was shipped to that state (Muller 1995).

In order to meet the EPA requirements for serving as artificial reefs, the MBTs had to meet the most basic reef material criteria of being hard, clean of contaminants, and provide suitable elevated profile. The MBTs also had to demonstrate a high likelihood that the ecological and economic enhancement value of placing them in the water would exceed the value of scrapping and recycling the metal. The EPA felt these criteria could be met. Following the development of formal cleaning standards, the EPA determined that the MBTs were acceptable artificial reef material. The EPA recommended that Alabama prepare a reef management plan for placement of the tanks and subsequently monitor the reefs, both to assure the public that there is no environmental danger from the tanks, and to show true environmental enhancement. EPA also expected that a national coast-wide deployment of hundreds of combat military vehicles would require an Environmental Impact Statement (EIS) (Muir 1994b). For REEF-EX ’94 an Environmental Assessment for Use of Obsolete Military Tanks for Artificial Reef Construction was prepared by DLA and the Army Materiel Command. This was later followed by a 1995 Environmental Assessment for the expanded Gulf and Atlantic coast-wide national REEF-EX project for Fiscal Year 1995 and beyond (Muller 1995). Based on considerations of economic, social, and environmental effects, the Army Corps of Engineers concluded that the REEF-EX project, as proposed, would not cause any significant or controversial adverse effects to either man’s environment or terrestrial, aquatic, or marine habitat, and that as a result, a formal EIS would not be required. The project had a signed Finding of No Significant Impact (FNSI). The EPA and FNSI summaries and announcement of availability were published in the June 26, 1995 issue of the Federal Register (Robert Ogle, personal communication).

The innovative REEF-EX initiative was funded by the Office of Civil-Military Cooperation, Office of the Assistant Secretary of Defense for Manpower and Reserve Affairs, with some matching funding from participating states encouraged. The Army Materiel Command’s Tank-Automotive and Armaments Command worked with the DLA’s Defense Reutilization and Marketing Service and the General Services Administration (GSA) to release the obsolete/excess MBTs to states for their artificial reef programs (Finegan 1995a). The Army’s objective was to provide individual and collective training, including joint training with other services and military personnel from other countries. REEF-EX ‘94 utilized representatives from more than two dozen Army, Navy, and Air Force Reserve units, as well as military staff from the United Kingdom and U.S. Coast

Guard support. These entities worked in a cooperative civilian-military partnership with marine contractors, stevedores, railroad personnel, and state resource management agencies (Snyder 1994). Reserve units received training in the logistics of planning, handling, loading, and transporting of armored military vehicles by land and sea (Finegan 1995a).

REEF-EX ’94 culminated in three phases of multiple deployments of 106 MBTs off Alabama. The initial phase was a pilot deployment of six tanks placed individually by crane on the seafloor in early June, 1994. The expense of using an 800-ton crane combined with the slow pace of the pilot deployment resulted in a switch in deployment techniques. The remaining tanks were deployed by being pushed off alternating sides of a barge using a forklift. This was accomplished without the barge having to anchor. (Snyder 1994).

REEF-EX ’95

The planning and operational success of REEF-EX ’94 in the Gulf of Mexico off Alabama provided the impetus for a national REEF-EX ’95 effort. This effort was initiated off Florida’s gulf coast with 40 M60 MTBs evenly distributed off Escambia, Okaloosa, and Bay Counties in the Florida Panhandle in December, 1994. This was followed by another 40 tanks distributed among the southwest Florida gulf coast counties of Hernando, Pasco, Pinellas, and Sarasota in April, 1995. All tanks prepared for Florida were jointly inspected at the Anniston Defense Depot prior to movement by EPA Region 4 personnel and the Florida Department of Environmental Protection on behalf of the involved coastal counties, the U.S. Coast Guard, and the USACOE. In August, 1995, Georgia deployed a total of 39 M60 MTBs at six offshore reef sites located 7 nm to 23 nm from shore. REEF-EX activities then moved to other states. In addition to MBTs, two additional armored vehicle types, armored personnel carriers (APCs), and Sheridan tanks, were subsequently deployed.


M60 MTB deployed off a barge at a Georgia offshore artificial reef site. Photo credit: GADNR.


M60 MTB colonized by robust ivory tree coral and 12+ reef fish species at Georgia's SFC reef site 20 years post deployment. Photo credit: GADNR.


M60 MTB colonized by robust ivory tree coral and 12+ reef fish species at Georgia's SFC reef site 20 years post deployment. Photo credit: GADNR.

First used in REEF-EX '95, M113 armored personnel carriers have also proven to be exceptional artificial reef material. Although somewhat smaller and lighter (12.5 tons fully loaded) than M60 MBTs (56 tons fully loaded, 42 tons stripped for reefing), APCs are still heavy enough to remain extremely stable on the ocean bottom, while their more compact size affords greater efficiency during transportation, since more vehicles can be accommodated per barge load. After demilitarization, armored personnel carriers are, essentially, large steel boxes. This open design provides excellent habitat for numerous bottom species including black seabass, red snapper, and groupers. (Robert Martore, personal communication).

M551 Light Tank "Armored Reconnaissance/Airborne Assault Vehicle" (AR/AAV). Photo Credit Mark Holloway

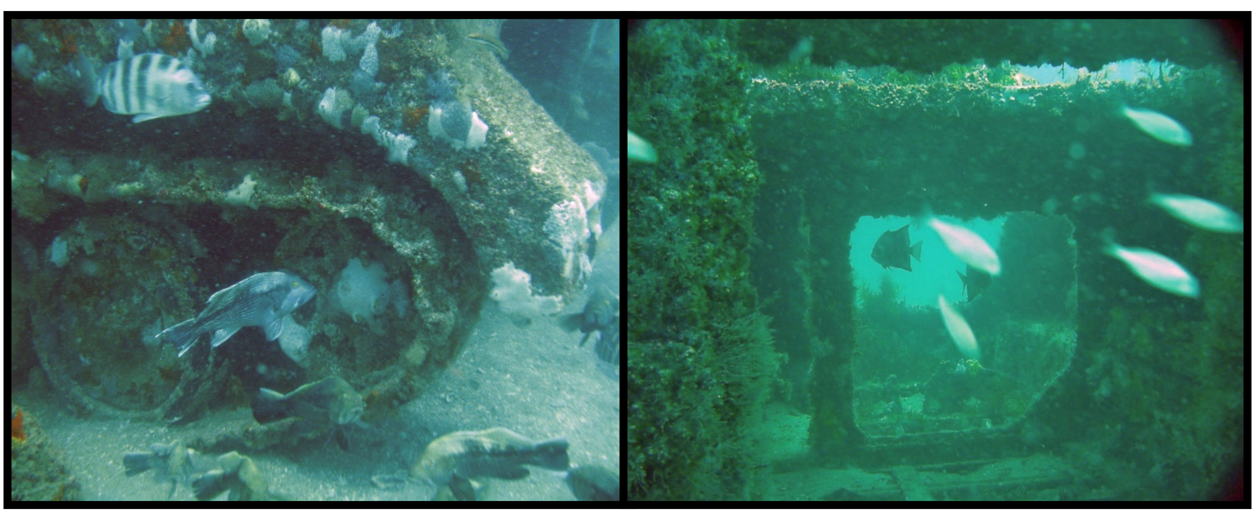
M551 Armored Reconnaissance Assault Vehicles, also known as Sheridan tanks, have also been made available for use as artificial reefs. Two major concerns raised over these units (14 tons fully loaded) were that they are made of aluminum and may not last long in salt water, and they have foam flotation inside aluminum layers which may affect buoyancy and which may be introduced into the marine environment. The foam flotation, along with an inflatable collar, allows the vehicles to be deployed into water and floated to land. Bill Muir of the Region III Office of the EPA (personal communication to Lieutenant Colonel Don Dale) inspected a Sheridan tank and concluded that the two concerns stated are not of any significance. He stated that the gauge of the aluminum in the units is thick enough to expect the units to last over 50 years. Regarding the issues related to the foam, Muir's information indicates that the foam is a polyurethane resin that will break down in salt water within five to ten years, well before the possible corrosion of aluminum side walls. It is generally thought that the overall weight of the Sheridan tanks is enough to overcome the buoyancy of the foam, thus negating any concern over stability on the bottom.

When the federal REEF-EX component of the Civilian-Military Cooperative Program was terminated in September, 1995 due to lack of funding, several states continued to work individually with their local National Guard units to prepare and deploy locally available obsolete armored equipment. A Department of Defense program called Civilian-Military Innovative Readiness Training (CMIRT) funds state National Guard units to undertake various training exercises beyond their normal weekend drills while at the same time providing a benefit to civilian agencies. Numerous Atlantic coastal states from New York to Georgia utilized this program to engage their respective National Guard units in the de-militarization, cleaning, and deployment of military armored vehicles for their state artificial reef programs. The state of Georgia obtained six Landing

Craft Mechanized (LCM) 1 and 6 Type Classes for deployments at four reef sites during 1983-1984, 1987, and 2004. Georgia's LCM have remained stable and provide offshore habitat for goliath grouper, juvenile and adult red snapper, black sea bass, and robust ivory tree coral (January Murray, personal communication). The state of South Carolina has operated its own version of REEF-EX continuously for over 15 years. The South Carolina Army National Guard (SCARNG) has demilitarized, cleaned, and transported over 500 obsolete armored vehicles, including M60 battle tanks, M113 armored personnel carriers, combat engineering vehicles, and armored reconnaissance vehicles for use on South Carolina artificial reefs.

A deployment of demilitarized armored vehicles from the SCARNG. Photo Credit SCDNR.

In northwest Florida in 2001, Okaloosa County artificial reef staff partnered with Eglin Air Force Base, and deployed multi-ton MBT turrets from tanks destroyed in hard target weapons practice. MBT turrets with cannon barrels intact were deployed upright at depths of 75 and 120 feet. From the turrets alone, recreational boaters have reported spearing gag grouper and catching red snapper on hook and line. The County declined to accept piles of loose tank treads for use as artificial reef material (Cindy Halsey, personal communication).



Armored personnel carriers deployed as artificial reefs off South Carolina. Photo Credit SCDNR.

Military Hardware Monitoring

M60 MBTs are 10.75 feet tall, 27 feet long, and 11.9 feet wide. They weigh approximately 42 tons with the engines and other materials removed and have proven to be very stable on the ocean bottom. When Hurricane Opal hit the Florida panhandle, just to the east of Alabama in October 1995, many small artificial reefs located in the Alabama general permit areas were moved by the storm surge. The MBTs deployed in 1994 remained in place and retained their abundant fish populations. This was particularly significant for the charter boat fishery, which was able to use the REEF-EX artificial reef sites to satisfy previously booked fishing trips.

Forty MBTs placed in Gulf of Mexico waters off the Florida panhandle in December 1994 also remained intact and stationary in 65-110 foot depths in or adjacent to the path of category 3 Hurricane Opal (October 1995) that also displaced or destroyed a number of small reefs in northwest Florida's reef system. Florida artificial reef program staff inspected one of the shallowest deployed tanks (67 feet) in November, 1995 at a location off Okaloosa County in the direct path of Hurricane Opal one month previous. The tank sat upright in a depression about 2-3 feet deeper than the surrounding sand but the tank treads were only covered to a depth of six inches. Twenty-four different species of fish were noted on this tank including such recreationally important species as red snapper, gray snapper, gag grouper, sheepshead, and gray triggerfish (Horn, et al, 1995).

Observations of the earliest M60 tank deployments off the Florida Panhandle indicated that all MBTs did not land in an upright orientation. Monitoring dives immediately after deployment and again 5 years later revealed several tanks either completely upside down or on their sides. Regardless of orientation there has been minimal subsidence into the bottom and no movement (Turpin 2001). Video taken topside combined with visual observations of the initial deployments that resulted in tanks landing upside down suggested that the tanks were being pushed too slowly over the edge of the barge. At the point the tank reached the edge of the barge, the forklift stopped aggressively pushing straight ahead and the tanks lost forward momentum. The MBTs were slowly eased over the edge of the barge, tipped straight down and entered the water vertically. They subsequently flipped upside down during their free fall through 80-90 feet of water. Later tanks were pushed more rapidly and steadily off the barges and not lifted up in the rear by the forklift. Tanks deployed in less than 50 feet of water also appeared to land upright with greater frequency (Jon Dodrill, personal communication).

Tanks lowered by crane during REEF-EX '94 included six off Alabama and two off Miami-Dade County (Southeast Florida). The six Alabama crane deployments resulted in all six tanks either being flipped on their sides or upside down when the lifting slings apparently snagged as they were pulled out from under the tanks by the 800-ton crane. Two tanks lowered by crane in Miami-Dade County were placed in an upright position. Divers removed lifting straps so they would not hang up on the tanks, and the tanks remained in their upright position. (Jon Dodrill, personal communication).

In Florida, off Pasco County, while viewing an upright tank that had not subsided two years post deployment, artificial reef program staff noted the collapse into the engine compartment interior of a fire retardant material lining the ceiling of the engine compartment (Horn and Maher 1997).

This breaking loose and collapse of the engine compartment ceiling shroud was noted on several tanks deployed off Florida (Jon Dodrill, personal communication).

In 1998, the Army led a two-year contract to conduct monitoring on military equipment deployed during REEF-EX in less than 100 feet of water. Beginning in the spring of 1999, consultants with the firm Aquabio evaluated selected reef sites to assess performance of military armored vehicles as reefs. They confirmed the stability of the reefs, noted their attraction for divers, and their effectiveness as habitat for a number of targeted species. They also reported that "a rich epibenthic community, more prolific and diverse than on natural bottom or low profile reef materials, developed on the reefs and provided food and additional microhabitat." Feedback received in interviews with military armored vehicle end users was variable. The most common complaints were related to perceived poor configuration of units on the bottom (too spread out), and lack of initial accurate location information. They identified other problems including upside down orientation of some units that appeared to be associated with increased subsidence in some deep sand areas, blocked or closed access panels between turret and engine compartment on some MBTs reducing fish access and water circulation, and no consideration given to taking advantage of the weight of MBTs to use them in shallow, high energy environments (Sheehy and Mathews 2000; Sheehy et al. 2001). In response to the last complaint, Jon Dodrill of the Florida Fish and Wildlife Conservation Commission (personal communication) noted that the army initially had concerns about deployment of tanks in 25 feet of water off Hernando County, Florida. The Army indicated that this was an insufficient depth to accommodate REEF-EX demilitarizing standards and that the tanks might have to be further modified to conform to the standards of a land-based museum exhibit. The Army eventually waived the museum preparation requirements. Additional navigation issues and state general artificial reef regulations restricting materials placed in the water any shallower than twice the object's vertical relief made extremely shallow water use of MBTs problematic in Florida.

Observations of MBTs and APCs on the sandy sea floor off New Jersey indicate that all vehicles are stable and that their tread bases resist subsidence. Vehicles are also colonized by large numbers of fish and lobster (Bill Figley, personal communication). Off Sarasota County, Florida, a roving diver fish census of MBTs revealed twenty species of fishes that included such grouper species as gag, scamp, red, and goliath grouper. Additionally, there were many greater amberjack, and hundreds of round scad, an important forage species (Florida Fish and Wildlife Conservation Commission fish census database). Monitoring of Georgia's upright MBTs indicate road wheels subsided to half their height, tank surfaces dominated by the colonization by robust ivory tree coral, and over fifteen fish species observed such as black sea bass, queen and blue angelfish, sheepshead, red snapper, and nurse sharks via roving diver fish census (January Murray, personal communication).

The South Carolina Marine Artificial Reef Program continually monitors their military armored vehicles for stability and biological effectiveness. Over 95% of all military vehicles deployed since 1997 remain upright on the ocean bottom with minimal to no subsidence or scouring and no lateral movement. Through the years there has been a steady succession of invertebrate colonization, with the oldest vehicles completely covered with sessile and encrusting organisms. Diverse fish assemblages inhabit these reef sites including recreationally important species such as black sea bass, gag, scamp, and warsaw grouper, red and vermilion snapper, triggerfish, and sheepshead.

Benefits

- Selected military surplus armored equipment is typically of high quality and durability, and expected to outlast most artificial reef material now being used.

- Most military hardware is constructed of heavy gauge steel, extremely durable, very heavy, and, therefore, expected to be stable on the ocean bottom, even under severe weather conditions such as a hurricane.

- Diver observations on the military vehicles deployed offshore Alabama and South Carolina indicate that there was a typical succession of habitation of encrusting organisms, with a rich and diverse assemblage after one year. Encrusting organisms observed included bryozoans, barnacles, gorgonian corals, and spiny oysters, among others.

- Video tape analysis revealed that the most prominent species associated with the Alabama tanks was red snapper, while in South Carolina, red snapper, black sea bass, sheepshead, and gag were all abundant.

- The rich species diversity observed in both states indicates that armored military vehicles provide suitable habitat for a variety of marine organisms, including those that are targeted by fishermen.

- Funds may be available from the Civil Military Defense Fund to assist in the deployment of military hardware.

Drawbacks

- Military hardware is generally located hundreds of miles from potential artificial reef deployment sites, and therefore must be transported at considerable cost.

- Cleaning the tanks to meet both state and federal environmental regulations is time-consuming, requires heavy equipment, and is expensive.

- The size and weight of most military hardware requires that oceangoing barges be used for deployment.

- MBTs, and other military battle hardware, require firm substrates to support their considerable weight.

- Funds available from the Civil-Military Defense fund for deploying military armored equipment have historically been unpredictable and short-lived, resulting in cancellation of planned projects and uncertainty as to what to plan for in the future.

- REEF-EX programs resulted in inequities in matching fund requirements. Some state programs had to provide matching funding for cleaning and loading, while others participating in the same program did not.

Considerations

- The military should be asked to supply the materials in an environmentally clean condition on the bottom at no cost to the program. This benefits the program by adding material to reef sites at no cost, and it benefits the military by providing them with a safe and beneficial place to dispose of their obsolete equipment.

- As with other substantial material, the bottom composition on which military hardware are to be deployed should be evaluated to avoid significant subsidence of the material.

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## 2.9 NATURAL MATERIALS

### 2.9.1 Wood

Overview

In the United States, the first documentation of the use of wood as artificial reef material in the marine environment was the deployment of log hut structures in the coastal waters of South Carolina to attract and provide habitat for sheepshead (Holbrook 1860). Wood, bamboo, log cribs, and palm fronds are used in many parts of the world as reef material for fish attraction devices (FADs), particularly in local traditional fisheries (Grove et al 1991). On the Gulf Coast of Mississippi and Louisiana, willow and wax myrtle branches have been tied in bundles and set on lines to attract peeler crabs for harvest (Jaworski 1979).

Other references to wood, other than wooden vessels, for artificial reef development in the United States are rare. In Mississippi, and probably most other coastal states, there is anecdotal information about placing Christmas trees or brush in nearshore waters to serve as FADs.

Benefits

- One of the benefits of using trees, limbs, brush or other forms of wood is availability.

- Shinn and Wichlund (1989) found that the riddling effect of ship worms, a boring mollusk, in wood increases habitat complexity and provides space for other organisms which are consumed by fish.

- It was observed that the large amounts of food and the complex structure provided by the breakdown of wood reefs attracted large concentrations of fish, even though in one case the reef was located in deeper and colder waters than many of these species of fish normally inhabit. It should be noted that Shinn and Wichlund (1989) were examining wooden vessels.

Drawbacks

- Wood generally has a short life span in the marine environments, as it is broken down rapidly by boring and microbial organisms. As the reef structurally deteriorates, pieces of it are subject to breaking off and floating away from the reef site. Floating wood debris may become a hazard to navigation.

- Wood is a very light material, and must initially be heavily ballasted to keep it on site.

- Processed wood, used for many construction purposes, is often treated to minimize rot. Such processed wood can contain toxic compounds.

Considerations

- Wood resources have limited application as reef material in marine situations for many of the same reasons that wooden vessels are no longer used as artificial reefs. Wood degrades rapidly and would have to be continually replaced at some cost.

- To keep a wooden reef on site, it would need to be heavily ballasted, which could incur the cost of ballast material (e.g. concrete) and labor needed to prepare the material for deployment. Even with ballast, as the wood structure breaks down, there would be a tendency for pieces to be displaced off the reef site.

- Chemically treated, processed lumber could potentially introduce toxic compounds into the environment.

### 2.9.2 Shell

Overview

Shells have historically been used by most coastal states to create or replenish oyster reefs. While the intent of this activity has been to create commercial oyster harvesting opportunities, it should be noted that such reefs also contribute to recreational fishing opportunities. Shell, utilized specifically as nearshore fishing reef material, has been used in Texas since the middle 1950s, and in Mississippi since the late 1970s. Most references generally discuss how shell functions as cultch for oyster spat attachment, rather than how it performs as artificial reef material. Two studies that did evaluate shell as reef material in Maryland had widely different results. Elser (1961), in the upper reaches of the Chesapeake Bay, found no difference in the catch from a paid angler on the reef site versus the control. Arve (1960), using fish traps in Chincoteque Bay, observed that significantly more black sea bass were found on the shell plant site than the control. It was also noted, after comparing two areas planted with shell, the site which had been established for two years as opposed to one year had significantly more black sea bass associated with it. It was suggested that a more mature oyster reef community provides an increase in the potential food available to fishes.

One of the differences between the Elser and Arve studies was the salinity at the study sites. Elser's study site had much lower salinities than Arve’s. The salinity is obviously going to affect the species that would colonize and utilize the potential reef site. One of the considerations when using shell for nearshore artificial reefs should be knowledge of the species it would possibly attract or benefit.

Another study in the Chesapeake Bay area found that bluefish were more abundant on oyster reef sites compared to non-reef sites (Harding and Mann 2001). Stomach content analysis revealed that a more diverse variety of prey was seen in fish captured on the oyster reef habitat. It is assumed that oyster reefs create a complex habitat, which attracts invertebrates and small fish. The increase in the prey community attracts predatory species.

Results from a similar study in Mississippi (Warren et al. 2000) indicated that more spotted seatrout and Atlantic croaker were found on a small oyster reef developed with oyster shell and limestone than off the reef. Stomach content analysis of eight predatory fish captured on the reef revealed little correlation between organisms inhabiting the reef and prey items found in the stomachs of these fish.

Forty-one artificial shell reefs were constructed in Texas coastal bays between 1947 and 1982 (Breuer 1963a, 1963b, Heffernan 1961, 1962, Hofstetter 1961, 1977, 1981, Crowe and McEachron, 1986). Three additional shell reefs have been constructed in Texas since 1989 (Lynn Benefield, personal communication). One large shell replenishment project was completed in 1990 on oyster reefs in Galveston Bay that were damaged by storms (Bowling 1992). Three additional reefs encompassing 37 acres were constructed in Matagorda Bay by the COE as part of an enhancement project at the Mouth of the Colorado River (Bob Bass, Galveston District, personal communication). As mentioned earlier, most references discuss how shell functions as cultch for oyster spat attachment, rather than how it performs as an artificial reef material; however, these shell reefs functioned as natural reefs within three to four years once the oyster populations were established (Breuer 1961, Hofstetter 1961, Crowe and McEachron 1986). Many of the shell reefs, with two to four feet of profile created in Galveston Bay, are still commercially important oyster reefs and excellent recreational fishing reefs, according to local anglers. A minimum profile of one and one-half feet is needed to ensure the permanence of the reef. Lower profile reefs may result in the shell material being buried by siltation (Lynn Benefield, personal communication).

Bradley (1963) and Bradley (1965) evaluated oyster shell as artificial reef material in Texas coastal waters. The first study attempted to assess finfish populations using hook and line, traps, and trammel nets on five reef sites. Results from this study were inconclusive because very few fish were caught. The second study sampled the test sites and the control areas with trawls to see if the habitat had been improved for organisms which could be potential prey items. One of the sites had been developed on shifting sand substrate and was buried. Another site, because of the presence of anchovies in the trawl catch, had larger catches in the control. The other three sites produced more organisms on the shell reef than the controls. However, one of the most productive of these three sites showed very little difference between the test area and the control. Bradley (1965), postulated that, because the reef was established near a concrete breakwater and a ship channel, the habitat was already available for a wide variety of organisms.

Since 1944, Alabama has used oyster and clam shell to enhance the natural oyster reefs in Alabama. This has had the beneficial side effect of enhancing fishing

A load of oyster shells being deployed by MSDMR.
Photo credit: GSMFC

for certain species on those reefs. In 1994, Alabama began to develop an extensive system of inshore low profile artificial fishing reefs. Oyster shell is a major component of several of those reefs. Through 2000, a total of 39,500 cubic yards of oyster shell has been used in this program.

In offshore natural habitats, young red snapper are strongly attracted to any type of small structure that provides relief (e.g. shells) (Workman and Foster 1994). In laboratory studies, shell has been shown to be a preferred substrate over sand for juvenile red snapper (Szedlmayer and Howe 1997). These observations were borne out in field collections off Alabama where 80 - 81% of the age-0 red snapper were caught at one station over a relic shell bed (Szedlmayer and Conti 1999). Oyster shell has been utilized to create small offshore experimental reef sites that have been effective in providing habitat for 0 and one-year old red snapper (Steve Szedlmayer, personal communication), and have management implications about recruitment (Workman and Foster 1994).

Availability of oyster shell for restoration and enhancement projects has become increasingly scarce in most coastal states. Competition for dwindling shell supplies can impact restoration projects, as shells must be purchased, and obtainable oyster shells are typically used as decoration, in construction projects, fill for drainage, and to build pervious driveways. With clam shell being difficult to obtain, reef managers would be dependent on oyster shell for reef development. This will incur the cost of purchasing the shell, probably from several local oyster houses, loading the shell, and possibly stockpiling the shell until it could be transported to a reef site.


GADNR's oyster shell bagging machine was used in partnership with the Coastal Conservation Association of Georgia to create over 900 bags with 14 volunteers in three hours. The bagging machine consists of a lower hopper filled with shells that travel up a conveyor belt and out of an upper hopper into pre-tied plastic mesh bags. Bags are then passed off for additional tying and are loaded onto a trailer. Photo Credit: January Murray, GADNR.

Given that suitable shell material is often in short supply, many states (Texas, Louisiana, Florida, Georgia, South Carolina, and North Carolina) have attempted to bridge this gap by establishing community-based oyster shell recycling programs. Collection of recycled oyster shell from local restaurants, oyster roasts, and outdoor events is a critical component in obtaining this type of natural cultch material to restore shellfish habitat. This method has been proven successful but has limitations since it is supported by donations and partnerships. The Georgia Department of Natural Resources (GADNR) partners with local restaurants to pick up shell donations two to three times per week, and has also established multiple shell recycling centers along the Georgia coast where citizens are encouraged to recycle unwanted oyster shells (January Murray, personal communication). Shells are cured for three to six months or longer, and volunteers are engaged to bag loose recycled oyster shells. Shell bagging is a labor intensive activity so many States have invested in oyster bagging machines to reduce labor costs.

Benefits

- Shell reefs present little hazard to navigation if planted at a low profile, and, therefore, can be used in shallow water situations without the cost of a permanent buoy. Signage is typically a requirement of regulatory agencies permitting shell reef projects.

- These types of reefs do not pose a substantial threat to fishing gear, such as trawls, which might be lost or torn by other types of reef material.

- Clean mollusk shells are compatible with the marine environment.

- States such as Texas, Louisiana, Florida, Georgia, South Carolina, and North Carolina have established community-based restoration programs and partnerships to obtain recycled oyster shells from local restaurants, oyster roasts, and outdoor events.

Drawbacks

- Clam shell was one of the principal materials used for cultch or nearshore low profile reef development in the Gulf of Mexico region. Large deposits of these shells exist in Louisiana and Texas. The shells were mined with a hydraulic dredge and barged into areas for reef development. Dredging of these deposits has been halted in many areas because of environmental concerns.

- In some states, oyster or clam shells are generally not donated materials and must be purchased. With clam shell being difficult to obtain, the reef manager would be dependent on oyster shell for reef development. This will incur some cost of purchasing the shell, probably from several local oyster houses, loading the shell, and possibly stockpiling the shell until it could be transported to the reef site.

- The need for shell material for oyster reefs may make stockpiling for fishery reefs more difficult.

- Shell is a small, lightweight material, and consequently, would have a tendency to be silted over in moderate to high energy situations, especially if the substrate is shifting sand or mud.

Considerations

- Shell may be effective in providing offshore habitat for juvenile red snapper; however, experimental shell reefs in offshore Mississippi were silted over relatively quickly (Ian Workman, personal communication). Utilizing shell as offshore reef material may require continued addition of shells to the same area in order to provide the relief needed to avoid siltation.

- Development of inshore sites could have some positive effects on fishing, depending on several environmental conditions at the site. First, the bottom should be stable, not shifting sand, or silty mud to keep shell from subsiding. The depth and current should be taken into consideration to avoid scattering the material so thin that it would provide little continuous hard bottom habitat. An intertidal bank slope of less than 15 degrees is preferable at inshore sites in order to reduce the risk of materials moving post construction.

- Reef profile high enough to avoid siltation of shells is important for reef permanence. GADNR deploys reef units ~15 inches in total height along intertidal mudflats where two wooden pallets (4’L x 4’W) are banded together with metal straps and ~17 bags of shell are placed in one layer on top in order to obtain adequate reef height and combat sedimentation during the first year of recruitment (January Murray, personal communication).

- Knowledge of the salinity regime at a prospective reef site is important for several reasons. If one of the objectives is to establish a viable oyster reef, which would increase the relief and hard substrate surface area of the low profile fishing reef, then salinity is of importance for oyster growth and survival.

- Salinity requirements differ among species and within a species' life history. Knowledge of species that could benefit from shell reef development should be investigated.

- Further research is needed into the effectiveness of low profile shell reefs as fish attractors or foraging areas, and what role they play as fish habitat.

- Research is needed to evaluate the effectiveness of low profile shell reefs at different distances from already established structures (ie. breakwaters, piers, bridges, or other shell reefs).

- If fresh shell is to be used as artificial reef material, care should be taken to avoid using shell with organic material attached.

- If constructing an oyster reef, it is important to time deployment with spat fall.

2.9.3 Rock

Overview

Until recently, rock has not been used extensively as artificial reef material in the United States, except on the west coast. The California Department of Fish and Game has been actively building reefs with rock since 1958. Comparisons between reefs constructed from rock, prefabricated concrete shelters, car bodies, and streetcars off the southern California coast found that quarry rock was the preferred reef material, even though it was second to concrete shelters in attracting fish. The reasons rock was considered a better material are cost, ease of handling, and reduced scouring and sedimentation around the rock reef, as compared to the other reef materials (Turner et al. 1969).

In Florida, utilization of quarried limestone for artificial reef development has occurred primarily in coastal counties located in the southern half of the state. Between 1985 and 2002 in southeast Florida, the following Counties developed limestone reefs on the Atlantic coast: Dade (11), Broward (1), Palm Beach (11), Martin (1). On the southwest Florida Gulf Coast, there was lesser limestone reef building activity, with Collier County building four reefs, Lee building two, and Pinellas County building one limestone reef complex. Of these 31 reefs, four were associated with mitigation projects to replace hard bottom lost due to port expansion dredging, hard bottom burial through beach re-nourishment, or damage to hard bottom communities by placement of fiberoptic cables. The 1996 Port of Miami limestone artificial reef mitigation project was the largest single limestone reef project noted in southeast Florida as of 2003, with 100,000 tons of rock used to build a series of linear artificial reefs. Seventeen of 28 documented south Florida limestone artificial reefs for which project size was noted were built with a boulder tonnage ranging from 148-900 tons; ten were constructed with tonnages ranging from 1,045 to 3,611 tons, and a single reef complex in northern Pinellas County was built using 12,057 tons of limestone in 1999 (Florida Fish and Wildlife Conservation Commission (FWC) 2003).

Florida limestone artificial reef projects typically utilized boulders with a density of 140-145 pounds per cubic foot, ranging from 2-6 feet in diameter (1,000-12,000 pounds) that either originated from existing quarry operations within the counties where the reef projects were undertaken, or were trucked in from adjacent counties. Boulder deployments have been performed using hopper barges where the bottom opens up and the load of boulders is deployed at once, single boulder placement with the use of crane, or through the use of a front end loader pushing boulders off the barge. Crane placement and rapid hopper barge bottom drop deployment have resulted in tight well-controlled placements of boulders. Varying size and shape of boulders create a reef structure of complex habitat with interlocking components that have demonstrated resistance to storm activity (Carmen Vare and Brian Flynn, personal communications).

Florida limestone boulder artificial reefs have been placed in both bay and near shore coastal environments ranging from depths of six feet, where the rock served a secondary function as riprap to protect a bay sea wall (Lee County), to depths of up to 80 feet (Palm Beach County). In this latter project, approximately 2,500 tons of rock were deployed in 1994 to form two linear reef corridor complexes connecting existing vessels previously deployed as artificial reefs (FWC, 2003). Limestone rock has been utilized in conjunction with other reef materials such as modular units to diversify hard bottom habitat in estuarine projects in Palm Beach County. Smaller pieces of limestone rock have been cemented to the surface of modular units utilized extensively off Miami-Dade County in order to increase the surface area for benthic fouling organisms (Virginia Vail and Bryin Flynn, personal communication).

While limestone artificial reefs appear to be very stable habitat even in shallow water environments, placement in high sand transport areas or in areas where the sand coverage over hard substrate is more than four feet thick, may result in boulder burial through sand accretion or subsidence. Off Boca Raton, limestone rock was used to develop a snorkeling reef. The project was developed as a mitigation effort in the Atlantic Ocean 50 feet from shore in nine feet of water and using two to four-foot diameter limestone pieces. It was evaluated nine months after deployment, and revealed 23 species of fish associated with the material (Bill Horn, personal communication). This reef, which was easily accessible from shore, initially was very popular among snorkelers. However, within four years, the reef was completely buried. Experiments with synthetic fabric matting placed under limestone boulder reefs to retard sinking elsewhere in Palm Beach County have been undertaken, but have resulted in mixed success with scouring occurring at the reef edges and some of the boulders rolling off the mats into the scour depressions (Carmen Vare, personal communication).

A four-hundred ton mitigation reef known as the Tycom Reef was placed in 70 feet of water at the Palm Beach Boca Raton Reef Site #1. It was intended to serve as a fish and diver corridor connecting two vessel artificial reefs, the Sea Emperor and United Caribbean. The reef was sampled in May 2001, about four months after deployment. No juvenile or stony corals were visible to the naked eye on the limestone at that point. However, encrusting sponges, bryozoans, hydroids, barnacles, feather duster worms, juvenile rock boring urchins, and arrow crabs had appeared. Fish observed included juvenile and intermediate life states of bluehead wrasses, sergeant majors, tomtates, and schools of herring. Common adult fish included white grunt, striped grunt, French grunt, porkfish, yellowtail snapper, schoolmaster, cocoa damselfish, bicolor damselfish, spotfin butterflyfish, blue tang, yellow goatfish, several parrotfish species, blennies, and gobies. Less common fish observed were two goliath grouper, which were observed during earlier initial baseline monitoring as having moved in from adjacent shipwrecks. Also observed were Spanish hogfish, queen angelfish, blue angelfish, adult and juvenile French angelfish, trumpetfish, great barracuda, ocean triggerfish, scrawled filefish, porcupinefish, and a neon goby at a cleaning station servicing a red grouper in the protected interior recesses of the boulder reef. Numerous southern stingrays were seen over the artificial reef swimming back and forth along the fish corridor between the two ships (Coastal Planning and Engineering 2001).

While quantitative analyses were not conducted, evaluations by the Florida Department of Environmental Protection of dredged limestone placed in 33 feet of water off Miami-Dade County over 75 years ago indicate that vertebrate and invertebrate fauna resembled the fauna found around natural hard bottom sites in similar depths in that general area. The use of limestone boulder artificial reefs is expected to play an increasingly greater role as artificial reefs for use in mitigation as hard bottom resources are impacted as a result of continued population growth in Florida and elsewhere in the southeast. As an example a 744-mile long 36-inch diameter pipeline was constructed in 2001 to transport dry processed natural gas from Alabama and Mississippi across Mississippi Sound and the Gulf of Mexico to Tampa Bay, and make landfall at Port Manatee, Florida. Destruction of hard bottom resources during the laying of this pipe, as a result of trenching, burial, anchorage, and other mechanical damage at shallower depths required mitigation using both limestone boulders and prefabricated modules to create unpublicized artificial reefs. Preliminary evaluations in 2003 suggested that boulder reefs and modules will be successful in providing effective hard bottom habitat for reef fish and invertebrates (Walter Jaap, personal communication).

Texas deployed 50 quarry rocks (irregular size, greater than one ton each, used for testing drill bits) in 1998 in relatively shallow water 23 miles offshore of Sabine Pass. High turbidity levels have prevented divers from accurately documenting fish and benthic attachments. However, all quarry rocks have been shown to be stable on a sandy shell substrate bottom through side-scan and bathymetry studies done in 2001. Landry (2001 unpublished data), conducted fish tagging surveys at this reef site in August-November 2001 and found red snapper populations on the site. In 2002, 74 additional quarry rocks were added to the reef site.

A barge of limestone being deployed by MSDMR to create an inshore reef. Photo Credit: GSMFC.

Due to limited supplies of shells, Alabama has used 34,378 cubic yards of #57 limestone to enhance public oyster reefs, and create inshore artificial reefs since 1999. These materials are usually used in conjunction with concrete pipe forming a retaining border. This material has been found to be extremely effective in producing increased fishing opportunities. Studies are currently underway to evaluate the community development on these reefs.

In 1995, Mississippi deployed 4,500 cubic yards of one to two-inch limestone rocks in various quantities at 11 different inshore, estuarine sites for low profile reef development. These reefs were evaluated at various times between 1996 and 2001. All sites had oyster spat settle on the rocks, later developing into oyster reefs. However, one site, located on the eastern tip of Deer Island, Mississippi, was buried during Hurricane Georges in September 1998.

In Maryland 4,500 tons of limestone were used for estuarine reef construction. DeWitt Myatt, Artificial Reef Program Coordinator for Maryland (personal communication), indicated that the reefs were good fish attractors and supported a good fouling community.

In an effort to deepen New York Harbor for large ship traffic, the COE has been blasting and dredging millions of cubic yards of bedrock from the channels. Over the past 10 years, this vast quantity of dredge rock has been placed on New York and New Jersey reef sites near the mouth of the harbor. The rock is delivered in 5,000 to 10,000 ton capacity scows that open along their keel, dropping the entire load in a pile approximately 300-feet long, 75-feet wide, and 6-8 feet high.

A computerized navigational system allows for precision placement (+ 125 feet of target) of barge loads. Loose rock may be composed of glacial cobbles and boulders. Blasted bedrock ranges in size from chips, to cobbles, to boulders the size of a small car. A primary concern when using dredge rock is that fine sediments, especially mud and silt, must be removed from the channel prior to dredging rock. The fine sediments found in harbors may be contaminated with industrial and chemical wastes.

The type of bedrock will determine its durability and lifespan on the reef. In New York Harbor, bedrock ranges in hardness from granite to soft sandstone. The life expectancy of granite far exceeds that of any other reef material. The large footprint and high relief of dredge rock piles greatly reduces the effects of scouring, ensuring that the reefs will be long-lasting. Dredge rock reefs provide extensive substrate for epibenthic colonization, varied interstitial refuge for mobile invertebrates, and excellent habitat for reef fish. For most applications, large rock is preferred for reef construction since it provides more interstitial spaces. Small stone packs too tightly, and spaces may easily be filled with sand, gravel, and rock chips.

Benefits

- Limestone is comprised of calcium carbonate, the primary component of most natural reefs in the Gulf of Mexico, which is compatible with the environment.

- Quarry rock is a very dense, stable, and durable material, which would be unlikely to move off the reef site except in the most extreme conditions.

- From all indications, quarry rock is a good fish attractant, and provides a good surface for fouling benthos to attach.

- Different size particles of rock can be used to accommodate different life stages of species of interest.

Drawbacks

- Quarry rock is usually not a donated material, so an initial cost would have to be assumed by the reef builder.

- Transportation costs to both the staging and reef sites is expensive, and will require the use of heavy equipment.

Considerations

- Different sizes of rocks provide various sizes of interstitial spaces. These spaces of varying sizes can be important to organisms during different stages of their development.

- Rock may have associated sediments.

### 2.9.4 Electrodeposition

Overview

Electrodeposition is the process of accreting calcium and magnesium salts on a cathode by direct electric current. Hilbertz (1981) used, as a cathode, galvanized iron mesh formed into triangular shaped modules. Iron or lead rods were used as anodes. The electric current was created using wind or solar energy.

In reefs developed using electrodeposition in the Caribbean, fifteen to twenty hours after deployment, the accreted material was visible, and after three days algal growth was observed. Observations of fish utilization of these reefs were infrequent; however, the data indicate that grunts, damselfish, and parrotfish were the most abundant species observed.

Two reefs developed in Texas waters near oil platforms were supplied with wind-driven generators to provide electric current for the electrodeposition process. One site was in Corpus Christi Bay in eight feet of water. The other site was near Mustang Island in 62 feet of water. No determinations were made on the effectiveness of these sites as artificial reefs.

Benefits

- The material used to build a reef with electrodeposition would weigh substantially less than most other reef materials (e.g. concrete) and would presumably cut down on transportation costs.

- Electrodeposited reefs can be repaired in situ if they are damaged, this would not be possible with most modular reef materials (Hilbertz 1981).

- Wire mesh with the accreted material may be useful in developing hard substrate habitat on soft sediments since they would be less likely to sink than heavier reef material.

- The many configurations that can be developed with the wire mesh allow the reef manager to specifically design for the complexity of reefs, which could be useful for particular applications or particular species.

Drawbacks

- Because of its mostly experimental use, it is unknown how stable the reefs would be under adverse sea conditions or what its longevity would be as a viable reef.

- The need for an electrical source requires that a platform be at the reef site.

- If the reef builder is going to use platforms that are already in place, such as oil rigs, then there will be limitations on where a reef can be placed, or the reef will have to be floated and towed to the site, increasing transportation costs.

- Utilizing a free-floating platform or a boat to house the electrical equipment will not limit the sites where the reef can be built. However, building the reef could become cost prohibitive if the equipment on the platform was lost in bad weather, or stolen, or if a crew had to be on site to man the boat during the reef building process.

- The electrical equipment must be checked frequently because of exposure to the saltwater environment. For example, in an experimental use of electrodeposition to build a breakwater in Texas coastal waters, the ground was apparently lost to the anodes. The current grounded on several nearby pumps, which were rendered useless and had to be replaced (Bob Colura, personal communication).

- There was also an apparent fish kill associated with the above described electrodeposition experiment. A strong smell of chlorine, which may have been produced by the electrodeposition process, was noticed at the site and is the agent suspected to have caused the kill (Bob Colura, personal communication).

Considerations

- Reef building with electrodeposition is still experimental, and there may be a possibility that the process of electrodeposition could produce harmful byproducts.

- Further research into the overall stability of the accreted material to remain adhered to the wire mesh and not crack and fall off under different environmental stresses needs to be assessed.

- Research into different modular designs for fish attracting effectiveness should be conducted.

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## 2.10 MISCELLANEOUS

The range of materials of opportunity that could be used as artificial reef material is only limited by imagination. If properly applied, the criteria of function, compatibility, durability, and stability will place some limits on material that are suitable for artificial reef application; however, innovation in pre-deployment preparation can render a material suitable that should otherwise be rejected. In that regard, there are miscellaneous materials that should be mentioned, even though there are few to no references in the literature, and experience with them is limited to non-existent. Such materials include miscellaneous metals (poultry transport units, garbage dumpsters, crane derricks, large fuel tanks, construction beams, bridge spans, others), ceramic items (toilets, bathtubs, sinks), among a long list of others. Obviously, not all of these materials will be suitable as artificial reef material; however, with effort, some could be used effectively.

In 2001, approximately 100 steel shipping containers measuring 20-feet long, 8-feet high, and 6-feet wide were donated to the South Carolina Marine Artificial Reef Program. The State decided to utilize the containers on an experimental basis in order to monitor and assess their effectiveness as reef material. It was estimated that the corrugated steel container boxes will function in a manner similar to the steel railroad boxcars which have been used in several states along the East and Gulf coasts, as mentioned earlier in this document (Section 2.6).

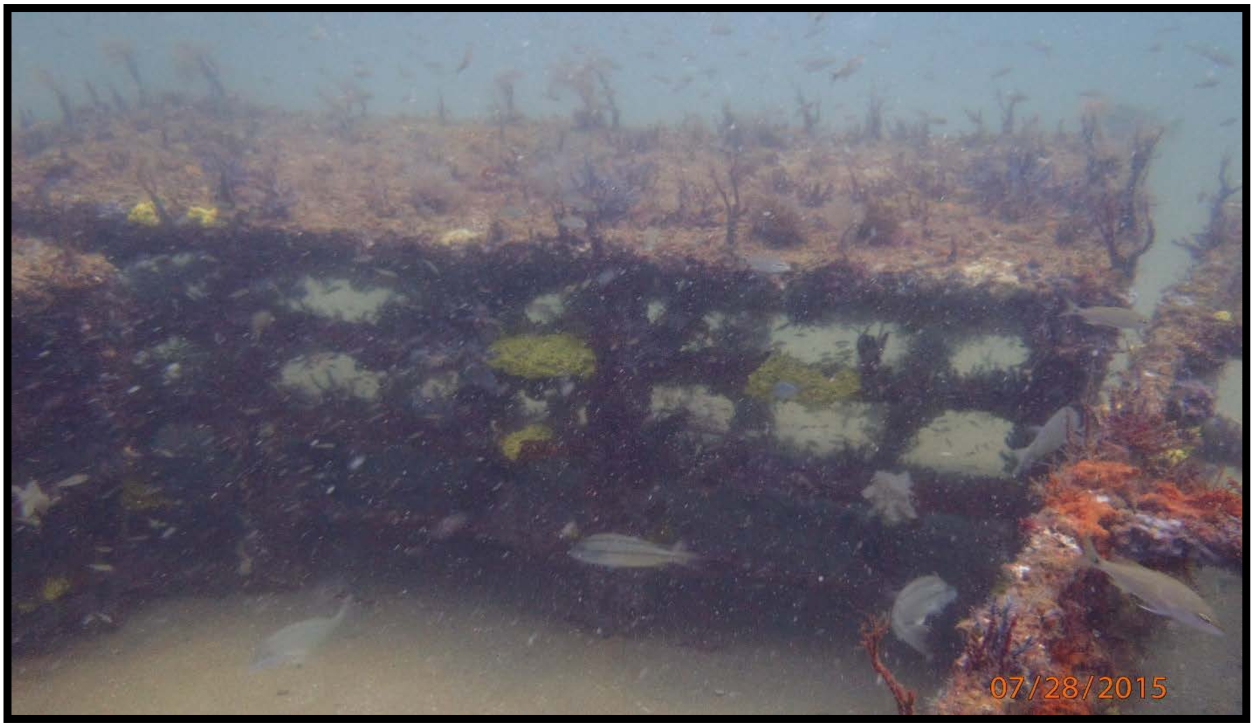
To prepare the containers, end doors were welded open and holes were cut into the remaining sides to allow water flow through the units and, hopefully, reduce the stress of currents on the container walls. The containers required little additional cleaning, since they are nothing more than large steel boxes. They were deployed on three reef sites of 50, 60, and 80-foot depths. Evaluations after one year under water revealed that approximately 90% of the containers remained intact and upright on the bottom. Marine growth was evident on all interior and exterior surfaces and large numbers of gag, scamp and red snapper were in and around the units. Ongoing monitoring will continue to measure durability and stability of the units at different depths, as well as biological colonization and recruitment on the material.

Two fiberglass submarine sonar domes were deployed off South Carolina in 1996. These large structures, the front end of U.S. Navy submarines, measured twenty-feet tall, ten-feet across at the base, and were four inches thick. They were deployed in 85 feet of water to try and minimize the impact of wave energy on them. Although seemingly sturdy and durable due to the thickness of the fiberglass, the domes could not withstand the rigors of the ocean environment. Within two years post-deployment, the fiberglass began tearing and shredding. Within three years there was virtually nothing left of the domes. Due, in part, to this experience, the state of South Carolina will no longer accept fiberglass items of any kind in its artificial reef program.

The Georgia Department of Natural Resources (GADNR) deployed approximately 400 Poultry Transport Units (PTUs) at two estuarine artificial reefs in the early 1990s to enhance inshore angling opportunities. These intertidal reefs were sited according to the inshore program's siting criteria, and PTUs were deployed in groups of four. These PTUs remain intact, each weigh approximately 750 pounds, and are fully colonized with oysters. Decommissioned PTUs have been readily available in Georgia, since Gainesville, Georgia (northeast of Atlanta) is considered the poultry capital of the world. In 2006, GADNR began deploying PTUs offshore at water depths ranging between 45 feet and 55 feet at the DRH reef site. Monitoring indicates PTUs remain stable, do not subside, and quickly become colonized by reef and forage fish species, as well as corals and sponges (January Murray, personal communication). Subsequent assessments of the DRH reef show PTUs providing the basis of a food web where colonies of soft corals and sponges attract saltwater gamefish such as grouper, sheepshead, and black sea bass.

PTUs exposed during mean low water at GADNR's Van Dyke Creek intertidal inshore artificial reef site. Photo Credit: GADNR.


A PTU (8'L x 4'W x 4'H). Photo Credit: GADNR, January Murray.



PTUs providing the basis of a food web at the DRH reef nine years post deployment. Photo Credit: GADNR, January Murray.

In northwest Florida, miscellaneous materials, including PTUs have been utilized by private citizens in cooperation with the local coastal government artificial reef programs off Bay, Okaloosa, and Escambia Counties. These devices were formerly used to cage and transport poultry by truck. At the end of their operating lives they are shipped from various locations, some out of state, and are sold to fishermen in Alabama and northwest Florida. Three western Florida panhandle coastal counties maintain multi-square mile artificial reef sites in federal waters, and have formal reef material inspection programs to assist private citizens and charter captains wishing to deploy private artificial reefs. PTUs and other miscellaneous materials go through a county inspection program. Any fiberglass flooring has to be removed from the PTUs, and at least two units have to be chained or cabled together prior to deployment as reefs. Inspected and approved materials are documented on a signed inspection/cargo manifest which is carried by private individuals who are authorized to transport the reef materials offshore for placement in the county permitted areas. Since the mid-1990s, PTUs have been deployed to northwest Florida Large Area Artificial Reef Sites (LAARS) by private recreational fishermen and charter boat fishing captains. In Okaloosa County during the period July 2001 through September 2002, 44 private reef deployments were made, of which 20 (45.4%) used a total of 240 PTUs. The remaining 24 inspected private reef deployments were dominated by miscellaneous steel items, primarily welded rebar or angle iron frame steel cages, often wrapped with heavy gauge fencing. Also included were concrete mixer drums, heavy steel wire wheels chained together, heavy wire rolls, and an old metal boat trailer.

By late 2002 the privately deployed materials off Okaloosa County were represented almost exclusively by PTUs. From December 2002 through April 2003, of 38 private reef deployment inspections, 35 (92%) consisted mostly or entirely of PTUs and included a total of about 504 PTUs.

Other county approved privately deployed materials included six welded pipe frames, 4 steel rebar open boxes, two welded steel “A” frame structures, four cement mixer drums, seven 20-foot long sections of galvanized steel radio towers, and nine concrete culverts. A single private individual inspection included eight concrete box culverts, and 100 tons of nested concrete pipes. (Okaloosa County Artificial Reef Program LAARS Reef Use Deployment Data Base).

With the exception of the concrete materials, none of the previously mentioned materials are expected to meet the state of Florida standard of 20-year longevity as a functioning artificial reef and are, therefore, not utilized in publicly funded reef programs in Florida. A 10-year life expectancy for PTUs and other comparable steel products was an alternate longevity target. This standard was a compromise to allow charter fleet involvement in reef construction, under modified COE permits special conditions in federal waters in northwest Florida. Material metal thickness of a minimum of 1/8” thick was authorized that enabled the use of PTUs and other scrap steel materials light enough to be hand-loaded onto personal vessels for deployment. All of these materials are deployed at depths greater than 90 feet and in offshore permitted areas where hard bottom constitutes less than 5% of the continental shelf.

The continued use of PTUs over a multi-year period by fishermen suggests they are performing effectively as fishing reefs. Formal documentation of PTU performance off Florida has been limited to word-of-mouth and to video clips showing PTU utilization by such recreationally targeted species as red snapper (Jon Dodrill, personal communication).

PTU resistance to movement and or burial in major storm events at depths of 90 feet or less is in doubt. A commercial reef builder in Alabama reported that in the late 1990s he once deployed 300 PTUs off Alabama for a client who never got a chance to use them. A major storm event hit a week later and the units were lost (David Walter, personal communication). In Alabama, in the wake of Tropical Storm Isadore (September 2002), a storm system that generated 22-foot seas, the loss of PTUs was reported out to depths of 90 feet (David Walter and Robert Turpin, personal communications).

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## 2.11 HISTORICALLY USED MATERIALS: RARELY CONSIDERED FOR REEF DEVELOPMENT

The Materials covered in this section were used early on in state reef programs; however, for a variety of reasons, are currently either not considered, or rarely considered suitable for reef development. These materials are outlined here to provide the history of the reefing programs in the U.S., and could still be considered on a case-by-case basis, or if there is a change in the preparation technology that would make them a more suitable reef material.

### 2.11.1 Fiberglass and Wooden Vessels

Fiberglass Boats and Boat Molds

Fiberglass is now the material standard for small vessel hulls. In 2013, Florida alone had over 896,000 registered boats. As boat designs arrive on the market, the fiberglass molds for the outdated models, as well as the older vessels themselves, become obsolete, deteriorate over time, or are damaged. As the boating population increases, a progressively larger number of recreational vessels become no longer fashionable, seaworthy, or worth maintaining, providing a potential source of reef material.

The owners of these vessels or molds are faced with the dilemma of how to dispose of material for which there is no buyer. There is an expense involved in taking a fiberglass boat to a landfill. As for boat molds, companies must physically cut up thick wood and fiberglass molds reinforced with external metal caging before transporting these molds to a landfill, if they cannot be repurposed or recycled.

Owners of boats and boat molds deal with the fiberglass boat disposal problem in several different ways. Some abandon vessels on land or in inland waterways, after sanding off the registration number and rendering the vessel otherwise untraceable. In 1992, estimates for Florida alone placed the number of derelict vessels statewide at 3,000. Florida has committed millions to dealing with the derelict vessel problem. A December 2014 search of Florida's derelict vessel database identifies only 275 vessels as derelict. Others have been caught hauling vessels offshore to sink without a permit. Boat companies routinely approach reef program managers regarding disposal of boat molds.

In years past, the ready availability of free derelict, fiberglass, recreational vessels was a windfall to charter fishermen in those states such as Alabama and Florida, where, historically, a wide range of materials could be transported offshore in a derelict vessel, and the whole package sunk to create a reef. Landfill expenses were avoided by individuals donating the vessel and materials that went into it and the fishermen obtained a means to deliver materials offshore. The derelict fiberglass boat became a mechanism by which other miscellaneous materials of opportunity, normally classified as solid waste, could be transported offshore and utilized, at least in the short-term, as an artificial reef.

The current legality of using fiberglass boats and boat molds varies with the Army Corps of Engineers District. Currently, the Wilmington Army Corps District no longer permits boat mold use under their 2011 general artificial reef construction permit. Currently, no state reef programs are actively promoting the use of fiberglass vessels in their artificial reef programs. Please refer to past editions for historical use of fiberglass vessels by state.

Stability and durability information relating to fiberglass boats or boat molds used as artificial reefs is sporadic and limited primarily to information on vessels or molds deployed less than 10 years. Anecdotally, information suggests that fiberglass boat molds and vessels may have a limited functional lifespan as a stable artificial reef in waters less than 100 feet deep, even if ballasted and cabled together. In 1985, Dade County, Florida placed fiberglass boat hulls in 47 feet of water, cabled them together, then cabled them to a steel barge. The hulls did not last long. Wave and current action caused the cable to saw through the hulls, splitting them into many pieces. The pieces either drifted into deeper water or were lost completely (Ben Mostkoff, personal communication). In the 1980s, Sarasota County, Florida, deployed hundreds of fiberglass boat hulls and boat molds, distributing them among sites M1 (42 feet), M6 (55 feet), M10 (65 feet), D6 (110 feet), and D9 (100 feet). Despite chaining together and ballasting some of these boats, a decade later, none of the molds or fiberglass vessels could be located, and the county, who once accepted fiberglass boat donations for reef construction, no longer does so (Mike Solum, personal communication). Boat molds deployed off Onslow Bay, NC in 1996 were visually assessed in 2003. Though a number of gag and sheepshead were noted on the mold, little functional profile was available. A side-scan sonar image collected in 2013 demonstrated that of the 12 molds deployed, only five are evident. Broward County, Florida stopped accepting fiberglass boats and boat molds when three boat molds, weighted by metal framing, cabled together, and deployed in over 200 feet of water within 1.5 miles of shore, ended up in the surf zone following an October 31, 1991 storm. The boat molds had been deployed less than a month, and it was found that the new steel cable had broken (Ken Banks, personal communication). Other ballasted and cabled molds off Manatee and Wakulla Counties, Florida were still in place 17 months to three years later, respectively. The Wakulla County boat molds were inspected in 1995 and found to be largely intact; however, observations indicated that numerous patches of the fiberglass surface were not encrusted with epiphytic organisms after three years of exposure (Tom Maher, personal communication). New Jersey’s experience with five fiberglass boat molds was that they broke up and disappeared even with heavy concrete ballast (Bill Figley, personal communication). A former private reef builder who constructed reefs off Gulf County, Florida reported that fiberglass boats filled with miscellaneous materials worked fine as reefs, except for the ones he could not find. Those he assumed were moved by shrimp trawlers (William Koran, personal communication).

Wooden Vessels

Prior to the age of iron clad and steel hulled vessels, sunken wooden vessels were the first to become accidental artificial reefs. Portions of heavy-timbered, old-growth live oak, white oak, cypress, and yellow pine vessels have lasted centuries, buried below the substrate, especially in freshwater, coldwater, or anaerobic environments, as evidenced by the discovery of 1,000-year old cypress and longleaf pine canoes in lake bottom mud, 200-year old live oak logs stored in lakes, submerged 60-year old "dead head" cypress logs salvaged and used for lumber, 19th century river and Great Lakes wrecks, etc. Under temperate marine conditions, exposed remnants of wrecked, heavy-beamed, wooden vessels have persisted from 30 years off Florida to over 100 years off New Jersey (Jon Dodrill and Bill Figley, personal communications).

Wooden vessels represent a small percentage of the total number of vessels deployed in artificial reef programs, and are typically the oldest vessels on a state's registry. The general history of wooden vessel use as artificial reefs shows that only the heavier metal components of the vessels have durability, while the rest of the wreck eventually degrades as the result of storm activity, boring worms, and other marine organisms. The material can then become a navigational hazard or public nuisance as the pieces move to shore. The 80-foot, wooden-hulled, square masted schooner, *Lady Free*, sunk off Dade County, Florida in 1986, began to deteriorate after the first winter, and, by 1991, was unrecognizable except for an engine block. A second wooden boat was scuttled on this same site in 1990, and, within one year, it was observed to be rapidly deteriorating. A wooden motor yacht, *Lewis Marine*, sunk off Broward County, Florida in 75 feet of water in 1986, resulted in scattered rubble around an engine block by 1990 (Berg and Berg 1991). Wooden fishing vessels as large as 40 to 55 feet in length, sunk within a quarter of a mile offshore Cape Hatteras and Cape Lookout, North Carolina, were reportedly scattered along the beach in pieces after one week (Jon Dodrill, personal communication). Old wooden menhaden fishing vessels exceeding 150 feet and intentionally sunk as reefs, have had entire portions of the wooden deck tear loose after a short period of time (DeWitt Myatt III, personal communication). Old wooden ferry boats, employed as artificial reefs in waters off New York, deteriorated very rapidly, while other, more substantial vessels have persisted much longer (Steve Heins, personal communication). The planking and superstructure of a wooden-hull vessel, sunk in the early days of Georgia's artificial reef program, disintegrated within two years, leaving only the ribs, which lasted some time longer (Henry Ansley, personal communication).

Smaller wooden vessels, sunk in deep water, also seem to have a limited life span, at least in subtropical waters. A wooden sailboat, sunk in 200 feet of water as an artificial reef off Broward County, Florida, showed up only as a low mound during a sidescan sonar survey several years later, and further investigation with an ROV (remotely operated vehicle) indicated that it was essentially disintegrated (Ken Banks, personal communication).

In recent years, with the availability of more acceptable and durable materials, artificial reef coordinators have avoided the use of wooden vessels. Threats of lawsuits from beachside communities or major beach cleanup efforts resulting from wooden boat debris washing ashore are experiences that some reef managers choose not to repeat (Myatt and Myatt 1992). USACE regional permits may preclude the use of wooden vessels as well.

<u>Benefits</u>

- Discarded fiberglass boats are readily available and inexpensive.

- Twentieth century vessels with a mixture of wooden and metal components that have sunk intact during storms continue to produce fish after the wood hull has deteriorated. The heavy gauge metal material, such as iron boilers, engines, and metal superstructure, continues to provide some structure after the loss of the wooden hull. As the hulls of wooden vessels deteriorate, the presence of wood boring organisms is reportedly attractive to some fish species.

- Like other small to medium-size fiberglass vessels which have little or no scrap or other market value once their useful work life has ended, wooden vessels may be available to artificial reef programs at little or no cost, and could be used as a means to deploy other, more durable materials.

Drawbacks

- There have been reported instances when fiberglass vessels sunk for private use as an artificial reef did not remain in place because the vessel was insufficiently prepared for sinking. The vessels were found floating just below the surface, or washed up on the beach. This creates a situation where it is not known whether the vessel is derelict and intentionally sunk, or there was an accident and individuals may be missing. This could result in futile search and rescue efforts by local emergency personnel, wasting time and resources, and possibly endangering lives. Fiberglass is a relatively light material requiring substantial ballasting and effort to reduce the potential for movement over time. This additional effort may make the material cost prohibitive.

- Use of derelict fiberglass recreational vessels has been tied to their value as a delivery system for other readily available materials. These transported materials by themselves may have little long-term value as reef habitat due to instability, lack of durability, lack of sufficient individual weight, or the lack of proper preparation. Often, the material transported is poorly secured. Once the boat and its contents are on the bottom, storm conditions may eventually detach and scatter the cargo. Low density fiberglass, sometimes with floatation intact or incompletely removed, is then prone to movement.

- Under turbulent conditions, hulls may break up, with gelcoat, fiberglass fibers, etc. becoming widely scattered. No information is available on the impact of broken up fiberglass, gelcoat, and resin products in the marine environment.

- Derelict recreational vessels loaded with other materials under tow and with floatation fully or partly removed have sunk in navigational channels, and elsewhere enroute to an intended reef site. In Florida, one death occurred when a larger vessel towed by a smaller recreational vessel sank prematurely, pulling the smaller vessel down with it. Clandestine night towing of these vessels, where they are illegal to deploy, results in a navigational safety problem, since vessels are often traveling without running lights to avoid detection.

- Wooden vessels, especially smaller ones, have both stability and durability problems. They may break up in storm situations when placed in shallow water or if not properly ballasted. Floating debris presents a hazard to navigation or may wash ashore as unsightly beach litter, creating negative press and the need to allocate additional resources to cleanup. Increasing water depth for deployment does not appear to improve the longevity of wooden vessels.

- Wooden vessels generally do not comply with the spirit of the 1985 National Artificial Reef Plan, which stresses the use of stable, durable materials for long-term reef enhancement and continuity of reef community structure and development.

- Proper preparation of a wooden vessel for sinking could be complicated by petroleum-soaked wood in the bilge, or some other wood preservative or paint treatment toxic to fouling organisms.

- A best-case scenario is that the wooden parts disintegrate after one to five years, leaving the heavy ribs and keel, and the associated metal components (engines, boilers, metal masts, etc.) to serve as fish and diver attractants, thus providing some short-term economic benefit to some individuals.

- Because derelict fiberglass vessels and obsolete molds are a major solid waste byproduct of the marine boating industry and difficult to dispose of, state and county artificial reef coordinators will likely experience continued pressure to use this material, as well as deal with individuals who have historically deployed this material illegally.

Considerations

- Availability and cost should not be determining factors in accepting fiberglass boat hulls or any other secondary-use material.

- Better follow-up assessment of existing fiberglass boat and boat mold sites, which have been in place for some years but have not been recently evaluated, is needed.

- Fiberglass hulls or boat molds should not be considered appropriate artificial reef material without heavy concrete ballasting, potentially reducing their seaworthiness and increasing the risk of an unintentional sinking and costly recovery.

- With the use of any vessels, it is highly recommended that coastal engineers provide an assessment of the forces to which any vessel would be exposed in a major storm event.

### 2.11.2 Ash Byproducts

<u>Overview</u>

Several categories of ash byproduct material have been proposed as artificial reef materials. Ash byproducts from the combustion of coal, oil, and municipal solid refuse have been combined with cement or other bonding agents and pressed into pellets or blocks for use as oyster or benthic substrate since the 1970s (Woodhead et al. 1981a, Baker, et. al 1995a, 1995b; and 1995c). However, some important distinctions between these ash by-products must be realized before they can be considered as potential artificial reef materials.

The ash residues produced from the incineration of different energy resources or fossil fuels are considered separate substances under the Resource Conservation and Recovery Act (RCRA) 42 U.S.C. 6901-6991 of 1976, and the 1980 Solid Waste Disposal Act Amendments by EPA. RCRA establishes a comprehensive "cradle to grave" system for regulating hazardous wastes. Subtitle C of RCRA and its implementing regulations impose requirements on the generation, transportation, storage, treatment, and disposal of hazardous wastes. Wastes which are not considered hazardous are “exempt” from Subtitle C regulations, fall under Subtitle D, and are subject to regulation by states as solid wastes.

The RCRA exempted some fossil fuel combustion wastes from hazardous waste regulation until EPA completed a Report to Congress in 1993 (Federal Register 40CFR Part 261: 42, 466. 530-Z93-009, FRL-4689-8, August 9, 1993). In a Final Report to Congress on May 22, 2000, EPA (2000) determined that all large volume coal combustion wastes generated at electric utility and independent power producing facilities are exempt from hazardous waste regulations under RCRA Subtitle D (EPA 530-F-00-025). These regulatory determinations addressed all remaining co-managed coal or fossil fuel combustion wastes from electric, or industrial utilities, and non-utilities, subject to RCRA Sections 301 (b)(3)(A)9i) and 8002 (n).

While RCRA is the principal Federal law affecting the regulation of ash byproducts, there is a larger statutory framework of Federal laws that is integrated with state and local statutes including: the Clean Water Act of 1974; the Toxic Substances Control Act of 1976; the Safe Drinking Water Act of 1974; and the Comprehensive Environmental Response, Comprehension, and Liability Act of 1980 (the Super Fund Act). All these statutes address the control of toxic substances, and rely on environmental testing and risk assessment to establish regulatory criteria.

Currently, almost one quarter of the coal combustion waste generated each year - about 28 million tons - is beneficially used in areas such as construction applications (EPA 530-F-00-025, March 2000). In this Report to Congress, EPA stated that they did not identify any significant risks associated with these types of beneficial uses. EPA also stated that they did not wish to place any unnecessary barriers on the beneficial uses of these wastes because they conserve natural resources, reduce disposal costs, and reduce the total amount of waste destined for disposal.

Solid Municipal Incineration Ash Byproduct

On May 2, 1994, the Supreme Court issued an option interpreting Section 3001(I) of RCRA, 42 U.S.C. 6921(I) City of Chicago versus EDF, No. 92-1639 (EPA 1994a) concerning the disposal of ash generated at resource recovery facilities burning household wastes and non-hazardous commercial wastes. The court ruled that Section 3001(I) does not exempt this type of ash from the hazardous waste requirements of Subtitle C of RCRA. The Court’s decision became federal law after May 27, 1994.

EPA immediately issued a memorandum (EPA 1994a) to all regions concerning the implementation strategy for bringing “waste to energy” facilities affected by the Supreme Court's decision into compliance with RCRA Subtitle C as quickly as possible. EPA also published in the Federal Register a “Notice of Extension for Date of Submission” of Part A Permit applications for waste to energy facilities affected by the Court's decision. EPA has also published a Draft of “Sampling and Analysis of Municipal Refuse Incineration Ash” (EPA 1994b), which gives guidance to resource recovery facilities on handling these ash materials.

Large quantities of municipal refuse incineration ash are primarily localized problems for such states as New York and Florida, where there is decreasingly available space for public solid waste landfills. Consequently, there have been relatively few studies investigating the use of this type of ash as an artificial reef substrate (Schubel and Neal 1985; Park 1987; and Breslin et al. 1988). The results of these studies indicate that stabilized ash blocks made from municipal solid refuse and Portland cement retained their structural integrity over time. The metal concentration analyzed in the tissues of attached benthic organisms and fish found nearby were not significantly different from background concentrations in the environment.

These studies were conducted before the Supreme Court decision in 1994 concluded that incineration ashes from municipal solid refuse should be regulated as a Class D hazardous waste material. Based on these recent regulatory changes, the use of this type of ash material for artificial reef substrate is not recommended.

Coal Combustion Ash Byproduct

There are several types of ash, which are produced from the coal combustion process called fly ash (CCB), bottom ash, boiler slag, flue gas desulfurization (FGD) emission material and fluidized bed combustion by-products (FBC). Jagiella (1993) summarizes the distinction between these types of ashes by:

“Fly ash is the powder-sized CCB, which is transported in the flue gases from the boiler and collected by devices such as electrostatic precipitators and baghouses. Bottom ash and boiler slag are the heavy, course CCBs, which are collected from the bottom of the boiler. FGD material is produced by subjecting flue gases to scrubber lime, an environmental control process, to remove sulfur emissions from the air. The FGD material, when oxidized, chemically forms calcium sulfate, a synthetic gypsum. FBC material from coal combustion byproducts are generated in the boiler unit during the sulfur removal process, without benefit of a scrubber unit at the end pipe.”

Some ash materials such as FBC materials generally have a high sulfur content and high amounts of residual alkalinity, which would make them less suitable for artificial reef material. However, some features of these types of ashes make them excellent material to construct artificial reefs (Baker et al. 1995b). CCBs, such as fly ash has “pozzolanic” properties and may have “cementitious” properties, which are advantageous for engineering, construction and waste remediation applications. The term “pozzolanic” refers to the chemical binding reaction that can be produced from coal ash because it contains silicon oxide and/or iron oxide. The term “cementitious” refers to the self-hardening property of coal ash because of its calcium content.

The American Society for Testing Materials (ASTM) in ASTM C-618 has created two classifications of useful and quality coal ash, which are categorized as Class F ash and Class C ash. Each class of coal ash has different pozzolanic and cementitious characteristics.

- Class F ash results from burning anthracite or bituminous coals (eastern coals). This type of ash has high pozzolanic material content and a low calcium content.

- Class C ash results from burning lignite or subbituminous coal (western coal). Class C ash is both pozzolanic and cementitious. Most Class C ashes have high calcium content.

In a report to Congress, the U.S. Department of Energy (1993) identified coal fly ash's most important feature is that “it reduces permeability while increasing durability and long term strength of the material.” Coal fly ash can be utilized in many manufacturing, mining, agricultural, engineering, construction and waste remediation applications. Organization such as ASTM and the American Association of State Highway and Transportation Officials (AASHTO) have established over 60 standard specifications for utilization of coal ash.

As electricity generating plants increasingly convert from burning oil to coal, large volumes of CCBs and FGD ash materials are produced. Both ash materials require disposal in permitted landfills. According to Department of Energy's report to Congress (1993), they stated “approximately 80 million tons of ash and 20 million tons of flue gas desulfurization wastes have been generated ... and the amount of ash waste generated is expected to increase by about two percent per year.”

Although one-fifth of these ashes can be recycled as cement additives, high volume road construction material and blasting grit, the remaining four-fifths are transported to permitted landfills. Ninety-five percent of the raw ash in this non-recycled portion have been determined to contain oxides of silicon, aluminum, iron, and calcium. However these ashes also contain small quantities of heavy metals such as arsenic, barium, selenium, cadmium, chromium, mercury, manganese, zinc, copper, and lead in “varying trace amounts” depending on the source of coal and the desulfurization treatment process. The metals in the raw ash (if improperly contained in acidic landfills) have the potential to leach over time into groundwater and may affect natural resources and contaminate public drinking water supplies (Dvorak and Lewis 1978).

There has been increasing demand from both electric utility companies and the Federal government to investigate more feasible recycling methods in order to conserve valuable natural resources. The Presidential Executive Order No. 12873 “Federal Acquisition, Recycling, and Waste Prevention” was published in the Federal Register on October 20, 1993. The intent of this order is to establish the Federal Government at the forefront of efforts to conserve our nation's natural resources by maximizing waste prevention and recycling in the Government's operations, and increasing markets for recovered materials through greater Federal government preference and demand for such products.

Beginning in 1976, scientists at the Marine Sciences Research Center, State University of New York at Stony Brook, N.Y. investigated the feasibility of using stabilized solid blocks of coal combustion byproduct (CCB) as potential construction material for artificial reefs in seawater systems (Woodhead et al. 1979). Once additives such as cement were mixed with these wastes, any toxic substances were “bound” in a stable aggregate form and could be hardened in the shape of pellets or larger blocks. The stabilization reactions which take place during these hardening formations are similar to the pozzolanic reactions which occur in the curing of concrete. Early mixed designs (Woodhead et al. 1979) varied from 1:1 to 1:5 ratios of fly-ash and bottom ash with up to 15 percent Portland cement additive. These initial studies tried to obtain a compressive strength of at least 300 psi after 14 days.

Mix designs used in Texas, using Class C coal ash (Belleman 1989; Baker et al. 1991), have used higher concentrations of lignite bottom ash as an additive to solidify and strengthen the substrate used for artificial reef blocks. Baker et al. (1991) reported several mixed designs of fly ash and lignite bottom ash (1:1, 2:1, 1:2) with additions of hydrated lime (5.00%) or Portland cement (4.40-5.04 %), which had compressive strength test values ranging from 350-730 psi after 14 days. Water only contributed 10.71-21.83% by weight depending on the mixed design ratio. However, compressive strength testing these design mixtures after a year submerged in an estuary, showed the average compressive strength of these blocks ranged from 2942-3418 psi. These test results indicate the submerged CCB blocks become stronger over time and are stable, durable materials.

Early studies at the Stony Brook Laboratory in New York examined the potential leaching of major chemical components such as dioxin and heavy metals from fly ash blocks in seawater in the laboratory (Seligmann and Duedall 1979). Using cultures of sensitive marine diatoms in bioassay tests of the seawater elutriates from the stabilized ash, they determined there were no toxic effects from the leachate of the ash. These long-term studies showed that the experimental blocks contained the same amount of chemical components as initially found in the blocks, and no significant leaching was found in the seawater elutriate. They also determined the stabilized blocks increased in compressive strength over time in seawater, and did not break down into less stabilized material with the potential for leaching the unbound chemical components of the ash.

Following these laboratory results, several progressive studies (Duedall et. al. 1981, 1982, and 1985; Hayward and Rothfuss 1981; Parker et. al. 1981; Woodhead et. al. 1981b and 1982) were started by placing larger blocks in the shallow estuaries of Long Island Sound and then later in the Atlantic Ocean off the New York Bight. They determined that the rough texture of bottom ash and, therefore, the proportion of bottom ash used in the mixture was a critical factor in the settlement rate of benthic organisms on these blocks. Both studies conducted in a shallow estuary area over a two-year period, and at a 20 m depth ocean area over a three-year period, provided consistent results that no leachable substances were found in the tissues of benthic organisms attached to the substrate. The stabilized ash material was also found to have increased compressive strength over time. For the results of more studies examining the utility of using CCB in artificial reef modules, please refer to the Guidelines for Marine Artificial Reef Materials 2nd edition (http://www.gsmfc.org/pubs/SFRP/Guidelines_for_Marine_Artificial_Reef_Materials_January_2004.pdf).

However, not all studies have shown the consistent results of New York and Texas. Studies done on CCBPs in Mississippi (Homziak et al. 1995) have found specific instances where increased elevations of heavy metals in the leachate are a source of environmental concern. The Mississippi Power Plant study on the leachate from mixed substrate used for oyster cultivation in the laboratory reported elevated levels of hexavalent chromium in oyster tissues. The results of this study are in direct contrast to no significant findings from previous studies testing heavy metal bioaccumulation in oysters (Parker et al. 1985 and Price et al. 1991). Homziak et al. (1995) indicates that hexavalent chromium is difficult to analyze, especially in high salt matrices such as oyster tissue. He indicates that previous studies by New York scientists evaluating the leachate from ash substrate may have underestimated hexavalent chromium. However, the coal source evaluated in the Mississippi study, contained high levels of chromium (37 +/- 14 ppm by x-ray fluorescence), which Homziak indicates directly contributed to the elevated levels in the oyster tissue. However, the actual source of the coal and the sulfur treatment process are not documented in this study.

Oil Combustion Byproduct Ash

Very few studies of oil combustion byproduct as an artificial reef substrate are found in the literature. Most of the work available has been done in Florida, where a reef site constructed of stabilized oil incineration ash was placed offshore of Vero Beach in the Atlantic Ocean (Mazurek 1984; Kalajian et. al. 1987; Metz and Trefry 1988; and Nelson et. al. 1988). These scientists investigated this oil combustion ash substrate for biofouling potential and fish recruitment to the reef. The results of the biofouling test show that oil combustion ash substrate was not significantly different from the concrete control blocks. Barnacles studied over a four month period, showed no significant difference in settlement density on the ash reef versus the control blocks. Results of the tissue analysis of the benthic organisms recruited to the reef site did not indicate any bioaccumulation of metals. Further testing of this type of ash substrate may show that it is similar to coal combustion ash in providing artificial reef substrate.

Benefits

- Individually analyzed pellets or blocks from one source of coal, from a specific combustion and treatment process, which has no adverse effects on the marine environment can be used to make oyster substrate in estuarine environments and larger habitat areas in offshore waters.

- Non-toxic rough textured substrate for oyster cultch material may provide important habitat for both recreational and commercial fishing interests as natural shell material is declining.

- The chemical/physical process first defined by Hockley and Vander Sloot (1991) as “pore refinement”, which hinders minor elements from diffusing past an impermeable boundary layer formed in fly ash substrate exposed to seawater, makes stabilized coal ash an appropriate artificial reef substrate.

- Compressive strength tests made by all studies since the 1970s have shown that the CCB substrate hardens and becomes stronger over time while submerged in seawater. This physical characteristic of the ash material bound in cementitious additives insures decreased levels of potentially toxic material from leaching out of the substrate and bioaccumulating in oysters, other benthic organisms and fish. By decreasing the potential leachate, there is less bioaccumulation of metals and other toxic substances in oysters or fish; and therefore decreased human health risks from eating oysters and fish exposed to the ash substrate.

- Construction of artificial reef substrate with a stable, durable, and impermeable substrate made from CCBs decreases the demand for disposing of massive quantities of potentially leachable material in the decreasingly available spaces of permitted landfills. These landfills may provide inadequate containment and could impact primary drinking water supplies.

Drawbacks

- Not all ash materials are considered exempt under Subtitle C of RCRA. EPA determined that all large volume coal combustion wastes generated at electric utility and independent power producing facilities are exempt from hazardous waste regulations under RCRA Subtitle D. However, the ash generated from incineration of municipal solid waste refuse is no longer considered exempt under Subtitle C of RCRA. On May 2, 1994, the Supreme Court ruled that Section 3001(i) does not exempt this type of ash from the hazardous waste requirements of Subtitle C of RCRA. The Court's decision became federal law after May 27, 1994.

- Oysters accumulate metals far in excess of ambient concentrations (Lytle & Lytle 1982; Eisler 1981; and Eisler 1986), and potential leaching and bioaccumulation of metals may be important public health concerns where ash-cement aggregates are being considered for oyster cultivation.

- Stabilized CCB ash reef substrate, which are constructed of undocumented sources of coal and undocumented treatment processes have the potential to leach unknown levels of toxic substances in the environment.

- Variable leaching rates may occur with different environmental conditions, particularly in saline environments, which may contribute to underestimates of the bioaccumulation of metals in marine organisms.

- Ash characteristics, particle size and composition, and bioaccumulation rates also vary in response to site specific factors.

- Materials which are not properly investigated prior to deployment in the natural environment are costly to remove and present a potential liability to both state and federal agencies.

- Testing of fly ash for toxic components is expensive and may be cost prohibitive to programs.

Considerations

- Potential reef material constructed of ash from CCB have already been designated by EPA as non-hazardous materials. However, these ashes must be analyzed to meet the criteria established by state and local agencies in order to obtain authorization to be used as an artificial reef substrate.

- Regulations concerning the reuse of non-hazardous ash materials vary from state to state. Each state now has the ability to develop their own protocol for evaluating CCBs as a potential artificial reef substrate. A protocol for evaluating these ashes as potential artificial reef materials has been created for the Gulf States Marine Fisheries Commission.

### 2.11.3 Vehicles

Overview

The composition of automobiles has changed considerably over the past fifty years. Through the early 1960s, ferrous metals comprised a much greater percentage of the total materials in an automobile than today. Fiberglass, rubber, and plastics became more prevalent in the automobile manufacturing process during the decade of the 1960s, and in the early 1970s unitized car bodies started replacing the previously used ferrous-metal frames.

The objective of artificial reefs as a habitat altering process is to place material into selected areas that will enhance the development of a total reef ecosystem. The ability of encrusting or fouling organisms to colonize the deposited material is one of the most important considerations in the material selection process. Certainly, automobiles which were manufactured prior to 1960 accommodate colonization by macroinvertebrates to a greater degree than those manufactured subsequently. The sheer weight of attachment and encrusting organisms on plastics and fiberglass tends to break the organisms loose from the ultra-smooth surface. This does not occur with ferrous metals, except in situations where corrosion is advanced.

A search of the available literature indicates the earliest use of automobiles as artificial reefs to be in May 1958 (Carlisle et al. 1964) ; however, while not reported in the literature, the Alabama Department of Conservation and Natural Resources (ADCNR) constructed artificial reefs of car bodies in 60 feet of water off Baldwin County, Alabama in 1953. In 1957, the ADCNR placed additional car bodies off Dauphin Island, Mobile County, Alabama.

The Texas Fish and Game Commission constructed three car body reefs in the Gulf of Mexico near Freeport, Port Aransas, and Port Isabel in 1958 (Benefield and Mercer 1982). These reef sites were located within six miles of shore in 50 to 60 feet of water. Initial surveys showed these reefs were very productive and had numerous encrusting organisms attached to the metal surfaces. Biologists observed Goliath grouper, red snapper, blennies, butterflyfish, moonfish, Spanish and king mackerel, wahoo, barracuda, blacktip sharks, remoras, and cobia on these reef sites (Wier 1959). However, subsequent inspections of these reefs after storms related to Hurricane Carla showed the car bodies broke loose and were washed away by strong currents (Martinez 1964).

According to the National Plan (Stone 1985), "...although materials such as automobiles and appliances are readily available, these are not dense and their durability and stability are poor." Interviews with artificial reef coordinators from the Atlantic coast revealed a consensus that automobile bodies as artificial reefs are unstable in the marine environment and have a useful life expectancy of only one to three years (Bill Figley, Mel Bell, Steve Heins, and Jeff Tinsman, personal communications).

Reports from anglers offshore Alabama indicated that following Hurricanes Frederick and Elena in 1979 and 1986, respectively, there was little movement of automobile bodies deployed as artificial reefs in Alabama’s large general permit areas. Hurricane Opal, which skirted the Alabama Gulf Coast in October 1995, had a devastating impact on the automobile bodies in that area, with many artificial reef builders reporting the loss of over 80% of their sites. Months later, approximately 50% of the lost automobile bodies were found approximately 900 feet northwest of their original location. Some of the automobile bodies were discovered in their original locations, but were buried under three to four feet of sand. It is interesting to note that, prior to 1992, automobile bodies deployed as artificial reefs offshore Alabama were not required to have the engines removed. The engines certainly provided additional weight, which could have been a factor in reducing movement of the material during earlier storms (Walter Tatum, personal communication).

Monitoring of sites with automobile bodies, sponsored by the Florida Department of Environmental Protection, has revealed mixed results. August 1995 video footage of the remnants of four automobile bodies, in place for seven years in 81 feet of water off Escambia County, indicates that about 30-40% of the original structure of the vehicles remained. The vehicles offered minimal habitat, only about two feet of relief, and were not immediately discernable as automobile bodies. The roofs were gone, and those sheet metal panels which still remained attached to the frame were flimsy and badly corroded, such that they could easily be punctured. Associated with the four automobile bodies were 17 fish species, including juveniles of vermilion and red snapper, juvenile amberjack, and several tropical species. A loggerhead turtle was also resting on the bottom, partially sheltered under a vehicle frame. The metal remnants were heavily encrusted with fouling organisms, including some representatives of the hard coral genus of Oculina (Horn 1995).

In the context of ecosystems management, automobiles, like other metallic materials, may be of greater benefit going into the recycling process, especially if there are available artificial reef materials which can effectively substitute for automobiles. When reused, recycled steel requires on average half the energy and a fraction of the water needed to make steel from iron ore. Recycled aluminum requires 90% less energy to produce than aluminum made from bauxite. At present, more than 94% of the Nation's annual automotive waste stream of 10 million junk cars are recycled into new products. On average, vehicles consist of 70.4% ferrous metals, 5.6% non-ferrous metals, and 24% miscellaneous materials, including plastics, rubber, glass, fluids, among others. At least 75% of a vehicle can be effectively recycled

<u>Benefits</u>

- Automobile bodies are readily available, inexpensive, and are relatively easy to handle, not requiring heavy equipment to move.

<u>Drawbacks</u>

- Automobile bodies require a great deal of preparation and removal of material prior to being ready for deployment. This activity can be labor-intensive.

- Automobile bodies are not durable, lasting for one to five years in the marine environment. Considering that about one year is required to establish an encrusting or fouling community, along with a relatively stable population of fish, and considering that significant deterioration has likely begun to take place at about year four, automobile bodies may have about three years of useful life as an artificial reef.

- Automobile bodies are not stable, and likely can be moved easily by storm surge or a boat pulling a trawl, resulting in the material being moved from its original location.

- Fiberglass, rubber, and plastics attached to automobile bodies, if not removed when deployed, may become unattached and free in the water column after the metal corrodes away.

- Recycling of the steel may be a more economically beneficial use of automobile bodies than allowing them to corrode within a few years on the ocean floor.

Considerations

- Automobile bodies must be carefully inspected prior to deployment as artificial reefs.

- Fuel tanks must be drained and perforated to prevent flotation.

- Oil must be removed from the engine block.

- The engine should be steam-cleaned or removed.

- The brake lines should be removed from the brake cylinder, and the line and cylinder should be drained.

- Plastics that are not attached securely to the automobile body must be removed.

- Electrical components capable of emitting PCBs must be removed.

- The rear axle differential on rear-wheel-drive automobiles must be drained of oil or should be removed.

- Steering sectors, both power and standard steering, should be drained of fluids or removed.

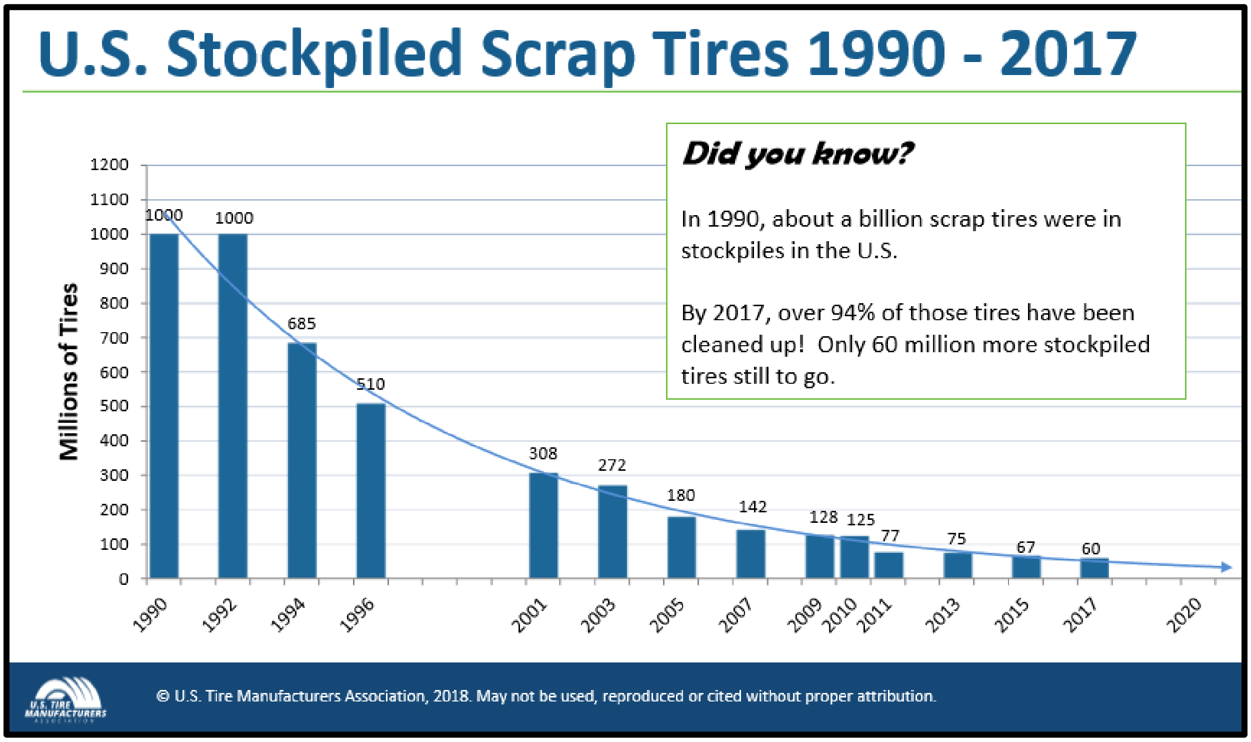
- Transmissions, both standard and automatic, should be drained of fluid or removed.

- The coolant system should be drained of fluid, mostly antifreeze, or removed.

### 2.11.4 Vehicle Tires

Overview

A typical tire rubber compound consists of 41% rubber (14% natural, 27% synthetic), 28% carbon black, 14-15% steel and 16-17% fabric, filler, accelerants and anti-ozonants (Rubber Manufacturer's Association, 2016). There are two basic types of tire construction: bias-ply and radial. The bias-ply tire is made of layers of rubber-coated plies composed of textile cords, usually nylon, placed upon each other at approximately 30-degree angles. These plies are then wrapped around the bead wires - which anchor the tire to the rim - to form the casing, or air chamber. The plies are then covered with more rubber to form the tread pattern. The radial tire is constructed in two parts. First, a single layer of rubber-coated steel cables arch from one bead to the other to form the tire casing. Second, numerous rubber-coated steel belts are placed in the crown, under the tread, to form a strong stabilizing unit (Michelin Earthmover 1999).




A waste tire, also referred to as scrap tire, is any used or processed tire that has been removed from a motor vehicle and has not been retreaded or re-grooved (Chapter 62-701.200, Florida Administrative Code, Florida Department of Environmental Protection). By the early 1970s, the U.S. was generating 200 million scrap tires a year (Minter 1974). With increased tire generation, the number of stockpiled scrap tires increased through the 1980s and was estimated to be 2 billion by 1988 (Ryan 1988). Along with tires discarded in other environmentally questionable ways, stockpiled tires created associated fire hazard, mosquito breeding, and esthetic problems. Due to landfill space limitations combined with the tendency of buried auto tires to migrate to the surface of landfills when trapping released landfill gases, state and local governments investigated other scrap tire disposal alternatives (Jessie Carpenter, personal communication). The use of waste vehicle tires as artificial reefs began in the United States in the late 1950s or early 1960s (Mathews 1983). The utilization of scrap tires as artificial reef material was undertaken to develop fishing reefs by utilizing an abundant material source and to provide a possible solution to the growing solid waste disposal problem (Stone and Buchanan 1970, Stone et al. 1974). Tire reef construction during the 1960s, 1970s, and early 1980s was seen as an acceptable low-cost alternative disposal option capable of handling millions of stockpiled tires. The idea of using tires to create three-dimensional habitat for public fishing reefs was originally embraced by a number of coastal states, local governments, the tire industry, and citizens groups.

In 1990, there was a dramatic shift in scrap tire management as new markets for scrap tires emerged. In 1990, approximately 25% of tires were reused or recycled (Rubber Manufacturers

Association, 2002). Currently all 50 US states regulate scrap tire disposal. Scrap tires can be recycled a number of ways, including as a fuel source, playground mulch, rubber modified asphalt, and civil engineering; accounting for approximately 3.4 million tons of tires in 2017 (U.S. Tire Manufacturers Association, 2018). In addition, technological advances have significantly increased the average tread life on a passenger tire, requiring less frequent tire changes per automobile. Today, most illegal tire stockpiles have been abated and regulations on tire stockpiling, transport, and disposal have been established across the nation. Nationwide, 96.9% by weight of the scrap tires generated are utilized by end-use markets (U.S. Tire Manufacturers Association, 2018). Today's scrap tire market has proven to be an effective way to manage scrap tires. Scrap tires have been gaining increased value in the marketplace, and the industry no longer views artificial reef deployment as a low-cost disposal alternative.

Un-ballasted Tire Artificial Reefs and Their Legacy

Throughout the 1970s and into the early 1980s, millions of un-ballasted tires were systematically placed in marine waters as artificial reefs off both the U.S. Gulf and Atlantic coasts. Tires were deployed by county governments, state programs, fishing and civic clubs, and private individuals. The average un-ballasted automobile tire, weighing 20-24 pounds (9.3-11.0 kg) in air but only three pounds in water, was generally sunk in bundles that involved roping, chaining, wiring, or strapping the tires to each other. Initially tires were left intact with holes punched in them or sliced to allow air to escape. Later, cutting, compressing, and baling equipment began to be used to bundle many tires together (Minter 1974, Prince and Brouha 1974, Briggs 1975, Loudis 1978, Tolley 1981, Benefield and Mercer 1982, and Crowe and McEachron 1986). For additional information on the historical use of un-ballasted tire usage in artificial reef construction, please refer to the Guidelines for Marine Artificial Reef Materials 2nd edition (http://www.gsmfc.org/pubs/SFRP/Guidelines_for_Marine_Artificial_Reef_Materials_January_2004.pdf).

Many states where un-ballasted tires were utilized continue to deal with tires moving off site during storm events or high surf. Tires continue to wash ashore in North Carolina, though numbers have abated considerably in the last few years (Gregg Bodnar, personal communication). North Carolina has never had an issue with estuarine tires moving off station. Tire bundles located on an estuarine reef site in 12 feet of water near Hatteras, NC still have the 1-inch polypropylene line intact as late as 2007 (Gregg Bodnar, personal communication). North Carolina no longer utilizes tires, in any configuration, as artificial reef material.

Between 1967 and 1973, an estimated 1-2 million tires were deployed as an artificial reef (Osborne Reef) near Ft. Lauderdale (Sherman 2001, Raymond 1981). The initial creation of the reef occurred when a fleet of nearly 170 private recreational boats transported the first tires to be sunk at the reef site (Good Year Tire and Rubber Co. 1974). Later, barges stacked with thousands of tires were utilized (Pamela Fletcher, personal communication). A 1974 report details an additional deployment of 240,000 scrap tires at the Osborne Reef (D.E. Britt & Associates 1974). In this report, a number of problems faced during tire deployment were documented. Tires were dispersed over a wide area due to depth of water (65 feet), strong currents, and haphazard dumping. Inaccurate navigational controls resulted in placement of tires on top of the outer (third) reef tract. Many plastic bands were broken when the bundles were lifted. Tires unable to be hole punched (steel belted tires) trapped air upon descent and were found floating nearly submerged towards the shore. By 1975 (two years after placement) cylindrical modules were documented to have rolled 1.25 miles north of the original deployment site, and loose tires along the third reef had migrated westward halfway to the second reef. As of 1975, tires covered an area approximately 600 ft. x 1000 ft., located between the second and third reefs east of Sunrise Boulevard in Ft. Lauderdale.

The estimated size of this tire reef in 2001 was 1,050 feet by 1,450 feet (34.95 acres), which was significantly larger than estimated in 1975 (D.E. Britt & Associates 1975) and 450 feet larger in both directions than the estimated size of this reef in 1974 (D.E. Britt & Associates 1974). The footprint more than doubled in area from 1974 to 2001, from 13.77 to 34.95 acres respectively. The further spread of tires east to west was confined to natural reef lines, with resultant impacts to the border of these reefs by tires moving against or over them (Horn and Mille 2001). Very few fish were associated exclusively with these tires. Only when the tires were near natural substrate did fish appear in significant numbers. This indicates that individual tires lying flat on the bottom do not make good fish habitat (Horn and Mille 2001). The minimal benthic growth on all sides of each loose tire is likely more a function of tire instability resulting in flipping over, flexing and/or abrasive contact with sea floor sediments, rather than anti-fouling properties of the rubber itself. Overall the tires were not making good habitats and were extremely unstable (Horn and Mille 2001).

Directed efforts to clean up the tire reef off Ft. Lauderdale were initiated in 2001 by Dr. Robin Sherman of Nova Southeastern University. With $30,000 funding from NOAA and a crew of 86 volunteer divers, 1,600 tires were removed and recycled at a cost of $20 per tire. The process involved volunteer divers collecting and bundling tires with polypropylene line for towing and removal by commercial divers. More than one million tires are believed to remain off Fort Lauderdale. At the recovery rate of $20 per tire, the complete clean-up cost may run into tens of millions of dollars, although a larger endeavor is expected to be more cost-effective than the relatively small-scale demonstration project coordinated by Dr. Sherman over the course of four weekends (Sherman 2001).

In 2006, funding was obtained through the NOAA Marine Debris Program to conduct a feasibility study to determine the best course of action for removing and disposing of the tires. In 2007 a study was conducted to test diver retrieval methodology, transport and processing. Divers lifted the tire bundles to the surface with lift bags, where a crane transferred the bundles onto an Army landing craft. Tires were then disposed of in the Wheelbrator Ridge Energy plant in Auburndale, FL. Major recovery operations began in 2008 and continued through 2009 with the efforts of Coastal America, US Navy, Army, Coast Guard, Florida Department of Environmental Protection (DEP), Broward County Environmental Protection and Growth Management Department, and Broward County Port Everglades Department. Funding was provided by the Department of Defense's Innovative Readiness Training Program, Florida Department of Environmental Protection and Broward County. As of 2009, approximately 73,000 tires have been removed from the reef.

Un-ballasted Tires as Midwater FADS (Fish Attractor Devices)

The minimal negative buoyancy of tires has also been used to construct floating vertical tire reefs. A 1967 publication depicts strands of cabled tires floating along the shoreline (Edmund 1967). In

1976 floating tire reefs were constructed off Jacksonville by running a cable through 10 tires stacked end-to-end, with three propane tanks bolted to the end of the cable to keep them afloat, and anchored with tracks from a bulldozer (Alex Waters, personal communication). The same approach was also used offshore of Panama City during the late 1970s (Danny Grizzard, personal communication). In both cases the floating tire reefs only lasted as long as the propane tanks remained afloat. FAD durability can vary, which can severely affect its lifespan. In some areas extensive fouling can render the unit inoperable. As the unit remains underwater, fouling organisms attach themselves and add weight to the unit. Once the attached biofouling weight overcomes buoyant force, the unit sinks and becomes marine debris. When the unit no longer serves as an aggregating device it becomes a hazard to boaters and marine life. In addition, operational units can become a hazard to trolling gear, boat propellers, and bottom gears. If a FAD is damaged or loses buoyancy due to vessel interactions it again becomes marine debris. USACE permits may not authorize the use of FADs.

<u>Individually Unmodified and Un-ballasted Tires Incorporated into Designed Concrete Reef Modules</u>

One designed module in use in Alabama since 1998 is a 10-foot tall concrete tetrahedral frame with ten individually un-ballasted automobile tires slipped over each of six legs of the module prior to joining the individual legs together (Walter 1998). The stability of the un-ballasted tires is dependent upon the durability, stability, and overall longevity of the concrete module frame upon which a total of 60 tires per unit are strung. The total dry weight of the module with and without tires was estimated at 2.4 and 1.8 tons, respectively. The module's submerged weight with and without tires was estimated at 1.1 and 1.0 ton, respectively. An engineering evaluation of the structure found that the module without tires is generally more stable than that with tires. For a 20-year storm event, the study recommended placement of modules with tires at depths of 75 feet or deeper, and placement of modules without tires at depths of 50 feet or deeper to avoid movement (Paul Lin and Associates 2000).

<u>Tires Ballasted in Concrete</u>

Foster and Fowler (1992) reported that several mid-Atlantic coast states, including New Jersey and Maryland, used tires that when properly ballasted, yielded positive results. They remain relatively stable in the marine environment, encourage fouling, or epiphytic communities, and attract fish species. The functional life expectancy of strapping materials (rope, cable, metal bands, and plastic) has been shown to be significantly less than the long life expectancy of the tires themselves. Data on the predicted lifespan of tires in sea water based upon chemical analysis was not available. While both concrete (in piers and bridge material) and tires (on vehicles in holds of vessels sunk in WWII) have demonstrated lifespans in seawater of greater than sixty years, there remain concerns that ultimately concrete ballasting material may deteriorate prior to the tires themselves. Therefore, the predicted longevity of tires relative to concrete should be further researched. Alabama does utilize tires embedded in concrete on their offshore reef sites only. Their standard procedure is to embed the tires at least one third of the tire diameter (Craig Newton, personal communication). Delaware has had good success with large diameter off-road tires ballasted with 3,000 lbs. of concrete. They report that the tires remained stable even after several years post-deployment and that a high abundances of flounder are present at the reef site (Jeff

Tinsman, personal communication). For additional information on the historical use of tires ballasted in concrete by individual states, please refer to the Guidelines for Marine Artificial Reef Materials 2nd edition
(http://www.gsmfc.org/pubs/SFRP/Guidelines_for_Marine_Artificial_Reef_Materials_January_2004.pdf).

Chipped Tires in Concrete

Tire chip aggregate/concrete products for artificial reefs have recently been proposed as an alternative to whole tires imbedded in concrete. Two experimental projects utilizing tire chips mixed with concrete have occurred in south Florida. One project compared two patch reefs composed of solid concrete tetrahedrons with two patch reefs composed of a similar size and number of concrete/tire chip aggregate tetrahedrons. These units were comprised of 20 pounds of two-inch by two-inch chips per 104 pounds of concrete. Both tetrahedron types were deployed at the same time in March 1993, at a depth of 20 feet, on sandy substrate off Broward County, Florida. After 17 months of monitoring, and recording 90 species of fish and 116 taxa of invertebrates, there were no specific differences observed in the biotic communities between the two types of reefs (Spieler 1995). Nine years later (Florida FWC 2002 unpublished data) both material types remain in place. However, the absence of a major hurricane in the vicinity of the project site during this period limited conclusions that could be drawn concerning the stability of this artificial reef construction material at shallow depths.

The second project used Sarasota County waste tire grant funds to incorporate four to six-inch pieces of steel-belted radial tires into concrete Reef Balls™ (patented product). These reefs were placed in Sarasota Bay in September 1996 on a pilot project basis (Mike Solum, personal communication).

The density of tire chip/concrete aggregate reef modules is less than solid concrete or limestone boulder materials, due to the lower density of rubber. As a result, the overall stability of such artificial reef units is potentially affected. Wave tank tests comparing solid concrete tetrahedrons, limestone boulders, concrete Reef Balls™, and tire chip/concrete aggregate tetrahedrons showed the tire chip/concrete structures to be the least stable of the four designs, and not suitable for use in shallow water, high wave energy environments. The study recommended their use be reserved for offshore deep water artificial reef application. For example, the wave tank models indicated that the unit weight of a tire chip/concrete tetrahedron would have to equal or exceed 3,000 pounds to remain stable in 40 feet of water in a storm event generating 12 foot waves. A solid concrete tetrahedron, under the same conditions, would only have to weigh 1,500 pounds (Zadikoff et. al.1996). Some environmental concerns have been raised about the long-term persistence of tire chips in the marine environment. The time span after which concrete may break down in the marine environment is not known; however, once that time has passed, the embedded tire chips would be released into the surrounding environment.

Fish and Epifauna Associated With Tires

Tires do not appear to make good habitats for fish based on fish census data from the FWC (Horn in press). Between 1992 and 2000 FWC divers completed 152 fish census dives on artificial reefs of all types, sizes, and ages. Two tire reefs assessed off Wakulla and Broward counties during this time period showed only six and eight species observed, yet were among the oldest and most mature reefs at 35.2 and 19.7 years old, respectively. Out of 24 reefs assessed older than 10 years, the two tire reefs had the fewest species recorded of all older reefs (Horn in press). A recent second assessment of the tire reef in Broward County again found very few fish associated exclusively with the loose tires. Only when the tires were near natural substrate did fish appear in significant numbers (twenty more species observed than on tires without surrounding natural reef) (Horn and Mille 2001). The tire reefs observed in each of these assessments in Florida were comprised primarily of single, loose tires, lying flat on the bottom. Low fish density can likely be attributed to the lack of structural complexity associated with loose tires.

Very little data has been published on epifauna associated with tires. In 1994 a comparative study was conducted between two different 8-year old tire unit reefs off New Jersey (Steimle and Figley 1996). Fauna scrape samples were collected using scientifically and statistically accepted methods from the flaps of stacked, split rubber automobile tire units. A total of 35 taxa were identified, dominated primarily by barnacles and blue mussels, although a relatively high degree of variability was observed between samples and between sites. The authors stated that while there is a great need for information on the ecology and fishery-forage productivity of artificial reefs, their data are too limited in quantity or temporal/spatial coverage to reliably answer any questions about the ecological function of reef epifauna (Steimle and Figley 1996). In North Carolina, tires have been observed with Oculina corals and various species of sea whips (Gregg Bodnar, personal communication). Epifaunal growth appears to be regional. In Mid-Atlantic States, epifaunal growth is possible, though not so in waters off Florida (Jeff Tinsman, personal communication).

Epifauna observations in Florida consist primarily of observations recorded from tire reefs now lying loose on the bottom. Overall, these tires were unstable (could easily be lifted and tossed through the water column with one hand) and showed very little invertebrate growth after up to 26 years in the ocean (Horn and Mille 2001, Mille and Horn 2001). Mille and Horn (2001) showed that there was some evidence of prior barnacle and epibenthic growth on the loose bare tires, indicating that abrasion or siltation and not the tire surface themselves are impeding epibenthic growth. Even the underside of some tires showed signs of previous epibenthic growth, indicating that the tires had, at one time, been upright before flipping upside down. On the other hand, at these same Florida sites, tires that had been stable for long periods contained more diverse epibenthic communities, indicating that epifaunal growth may be proportional to tire stability. Most notable were observations of a concrete filled tire unit at the Osborne tire reef in Broward County, Florida which showed a 15-inch diameter Diplora spp. coral encrusted across two tires within the same unit (essentially cementing the tires together). This was the only stable tire unit in the area; no other tires contained hard coral cover (Horn and Mille 2001). Additionally, observations in Manatee County, Florida, also found that some tires embedded in stable concrete slabs had greater densities of scleractinian corals than the cement slabs themselves (Rick Spadoni, personal communication).

A study of artificial reef benthic community development in Hawaii tested concrete, coral based rock, painted steel, and car tires (Fitzhardinge and Bailey-Brock 1989). This study found that of the materials tested, tires were the least suitable for epifaunal development, particularly for corals. The authors provide references to additional publications with similar results (Alcala et al. 1981; Downing et al. 1985) and speculate that poor epifaunal growth could be explained by toxic components that either prevent corals from settling on the tires or cause mortality to new recruits. The authors observed that recruitment of other sessile organisms to the tires was also lower compared to other materials. The authors reference another paper, which indicates that epifaunal larvae may be actively avoiding the tires since fouling of dark materials is usually greater than light-colored sub-strata (Long 1974).

Epifaunal communities associated with tires appear to be variable. Some variability may be attributable to stability, while other variability may be attributable to adverse chemical influences on larvae and new recruits. Regardless, tires must be stable in order for fouling, or epiphytic, communities to attach to tires. Loose, mobile tires do not allow for invertebrate growth due to abrasion, chafing, and flexing.

Tire Leachate Concerns

Tires contain various chemical compounds including paraphenyldiamines, oil based plasticizers and pigments; and trace metals such as copper and zinc are also present (Hartwell et al. 1998). Studies concerning tire leachate resulted in mortality of rainbow trout (Kellough 1991 and Anonymous 1992). While these studies were conducted in fresh water, the results are cause for some concern. Stone et al. (1973) reported on a study using pinfish (*Lagodon rhomboides*) and black sea bass (*Centropristes striatus*) where 40 seabass and pinfish were placed in a 2,000-liter circular flow through seawater tank as controls and another 40 fish were placed in a tank of the same size, except that six waste auto tires were also placed in the tank. Beginning on day 21, and by day 36, all black sea bass in the tire reef tank had died of unexplained causes, but those in the control tank were apparently unaffected. All pinfish in both tanks survived the full 101 days of the experiment. No changes were noted among either fish species in control or reef tanks with respect to PCB levels, insecticides, or trace metals. However, since this was a flow through seawater tank setup, the experiment would have necessarily limited any buildup of leachates in the tank. Hartwell et al. (1998) observed in tire leachate experiments using various salinity concentrations that toxicity decreased with increasing salinity. Hartwell et al. (2000) furthered the study by determining the toxicity degree is primarily due to an interaction between the toxin and salt, rather than an effect of leachability.

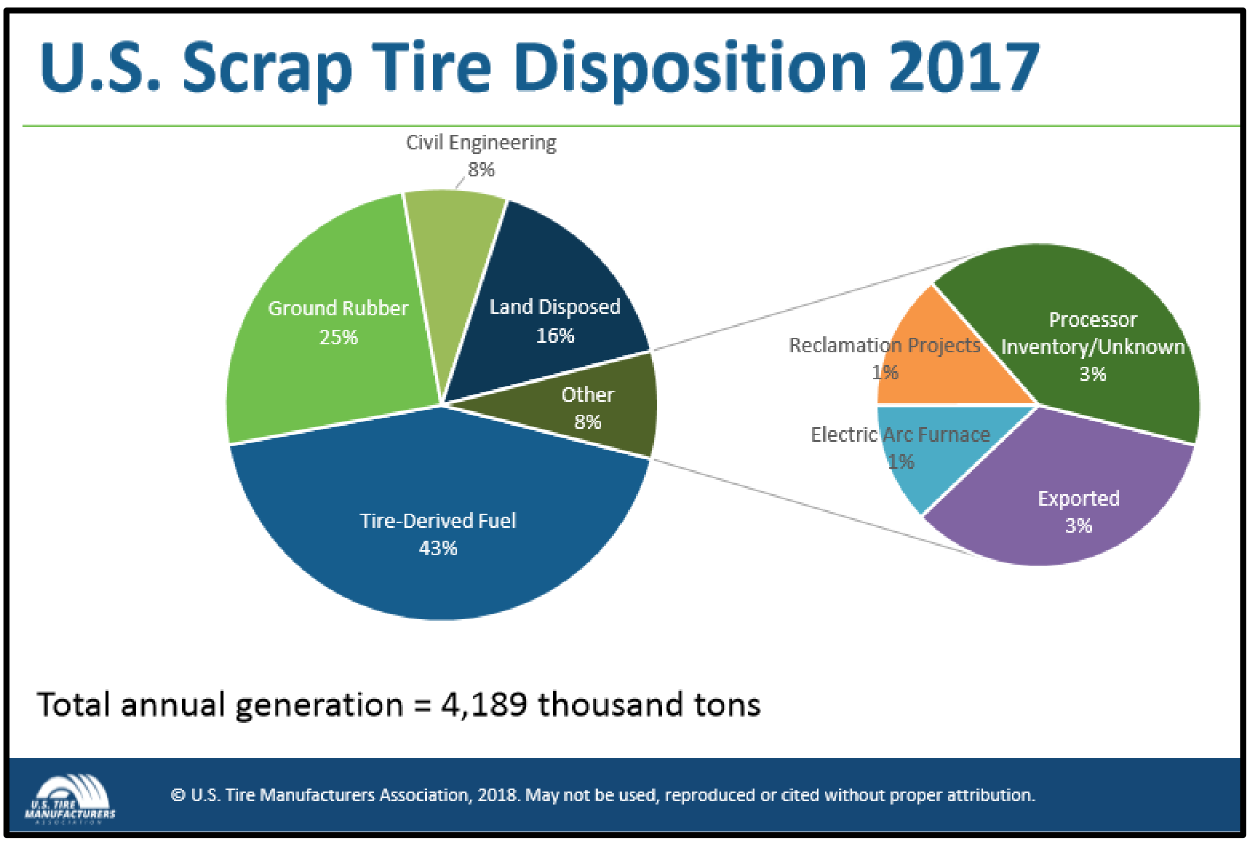
While studies indicate that toxicity decreases with increasing salinity, other studies provide more information on specific chemical leachate from scrap tires. To evaluate the risk of leachate from potential alternative scrap tire utilization projects (i.e., chipped tires for use in septic drain fields, playgrounds, etc.), the Florida Department of Environmental Protection, Division of Solid Waste contracted a report summarizing the results from several tire leachate experiments (T.A.G. Resource Recovery 1999). The report is based on a comprehensive review of over 15 identified leaching studies conducted in the United States and Canada between 1989 and 1999. The study compiled data from a list of up to 52 compounds, including metal ions and organic compounds, leached from scrap tires and tire shreds. The study summarized that "batch leaching tests conducted in laboratory reactors confirm that tires are capable of leaching inorganic and organic materials when continuously submerged in water." Specific leached compounds and quantities depend upon pH, soil, and other specific conditions. In general, leaching of inorganic metals increases at lower pH and organic compounds increase at higher pH. Leached compounds do not generally exceed Maximum Concentration Limits (as defined in Florida Drinking Water Standard

62-550, F.A.C.) or Guidance Concentrations for materials with primary standards. However, secondary standards for iron, magnesium, aluminum, manganese and zinc were significantly exceeded in some tests (T.A.G. Resource Recovery 1999). It should be noted that these studies tested tire leachate under extreme conditions compared to drinking water quality standards. The majority of these studies used small pieces of tire chips in freshwater, not whole tires in seawater, as might be expected in artificial reef use. Also, since seawater is at a neutral pH, generally more chemically stable conditions are provided than the extreme pH conditions used in the freshwater tests. It should also be noted that water quality standards in the marine environment are much less stringent than drinking water standards, none of which would have been exceeded in the referenced studies.

The studies note that tires do leach inorganic and organic compounds and heavy metals while submerged. Ocean salinity and the sheer volume of water may dissipate these compounds to a point where accumulation may be non-fatal. Careful consideration should be taken to determine if leachate of any concentration is acceptable.

Current Tire Use and Recycling

Coastal governments previously mandated to dispose of tires at sea through their artificial reef programs no longer have to do so. During the 1990s dramatic achievements were made in finding alternative solutions for managing disposal of waste tires. Until 1989, almost all waste tires in Florida were landfilled or stockpiled (Florida Department of Environmental Protection, Waste Tire Program). Since that time, state tire programs have made major accomplishments in the utilization of waste tires through burning as fuel and the creation of crumb for playgrounds, road beds, etc.



Nationwide, less than 10% of scrap tires generated in the U.S. were being used or recycled prior to 1990. Currently, 81.4% by weight of the scrap tires generated nationwide are utilized by end-use markets (U.S. Tire Manufacturers Association, 2018). All tires, including the massive earth moving vehicle tires, are available for recycling. Illegal stockpiles of waste tires have also been significantly reduced during the last ten years.

During the 1960s and 1970s, tire manufacturers such as Goodyear provided bundling machines, strapping material, and public relations brochures to promote tires as artificial reefs. Today however, with improved scrap tire management in the United States, a variety of economically viable markets for scrap tires have been developed, essentially eliminating industry interest in scrap tire disposal as artificial reefs.

Most coastal states have restricted or formally banned tire use in artificial reefs, beginning with the banning of tire use in reefs by the states of California and Washington in 1985 (Stone 1985). As mentioned earlier, New Jersey, a former leader in the use of ballasted tire reefs, has revised the New Jersey Artificial Reef Plan that not only bans the use of tires, but also prohibits any lightweight components in artificial reef construction (Figley 2002). In 1992 the Gulf States Marine Fisheries Commission passed a resolution, subsequently modified in 2002, expressing concern about the use of automobile tires as artificial reef material. As of 2019, the only states currently allowing deployment of tires as reefs are Delaware (large diameter off-road tires ballasted with concrete) and Alabama (tires ballasted in concrete).

Public Perception

Many decisions are driven by public perception, from politics to food additives. Artificial reef materials are no exception. Tires have gained a negative perception in the public due to their makeup, leachate, and movement events of various scales. Artificial reef programs are perceived by the public as a positive endeavor, creating both habitat and fishing and diving opportunities that can have a positive effect on fisheries, tourism and local economies. Careful consideration should be taken on the necessity of tire use in future artificial reef enhancements.

Benefits

- Vehicle tires are lightweight and easy to handle, particularly un-ballasted tires on small boats.

- Vehicle tires may be readily available in large quantities, depending on regional scrap tire market value, and alternative government incentives.

- Vehicle tires may be acquired free or at low costs, depending on local regulations and regional scrap tire market value.

- Tires will last indefinitely in the marine environment (Parker et al. 1974, Tolley 1981, Mathews 1983). This is considered a benefit in the context of the material durability.

- Tires used as artificial reefs can be effective in attracting and holding fish and invertebrate populations (Stone et al. 1974, Briggs 1975, Stone 1985).

Drawbacks

- Handling and access to waste tires is no longer unregulated. The storage, handling, and transportation of scrap tires are carefully managed by all states (EPA.gov). Tire collection sites must be permitted, and vehicles transporting tires must be registered with appropriate cargo manifests.

- Tire recycling alternatives are common. Large scale deployment of tires at sea as a waste disposal activity under the umbrella of artificial reef construction is no longer viewed by management, regulatory agencies, and the public as environmentally acceptable.

- Leaching of petrochemical or heavy metal toxicants from tires into the marine environment may occur under certain conditions, causing adverse effects to fish and epibenthic organisms.

- Un-ballasted tires are unstable in open water marine environments. As a consequence, they must be properly ballasted in order to assure that tire units do not move in response to currents or storm wave forces.

- Properly ballasted tire units are more expensive, bulky, heavy, difficult to handle, and difficult to transport without heavy equipment.

- The expense and labor involved in creating a stable and durable tire unit may not make them as cost effective as other materials that can accomplish the same objective.

- Tires must be spatially stable in order for fouling or epiphytic communities to attach, although there is some disagreement. Loose, mobile tires do not allow for invertebrate growth due to chafing and flexing.

- Single tires lay flat on the bottom and provide little or no habitat value for fish.

- Assuming that tires will last indefinitely in the marine environment, tire units will last only as long as the connectors or binding material holding them together remains intact (even when ballasted, multiple tire units that use steel reinforcement rods as a connector will separate after several years due to corrosion of the rods). Each tire used in multiple tire units must be ballasted. Once multiple tire units come apart, the remaining single tires will provide little or no habitat value.

- Most states have regulations in place that no longer allow use of waste tires as artificial reefs.

- Some managers express concern that structural ballast (concrete ballast, with steel reinforcement) may not have the longevity as a stable unit for the life of the tire, and they do not wish to leave behind a detrimental legacy that may have adverse impacts decades or centuries into the future.

- Tires will last indefinitely in the marine environment (Parker et al. 1974, Tolley 1981, Mathews 1983). This is considered a drawback in the context of tires being unstable in salt water.

Considerations

- If used, tires should be clean and free of petroleum or other environmentally incompatible substances prior to deployment.

- Tires should not be deployed under environmental conditions expected to cause leaching of toxicants. This includes low salinity areas where leaching has been shown to increase.

- Each tire used should be ballasted in concrete. Compressing tires and connecting them with steel reinforcement rods can result in tires breaking free due to corrosion of the steel rods.

- Tires should not be deployed if they are not properly ballasted. Tires deployed without being ballasted have been documented to move off site (Figley 1991).

- Tires can be chipped and incorporated into concrete as an aggregate; however, an engineering study has shown that this approach can reduce the density, thus the stability, of the units when compared to the same unit without the chipped tires (Zadikoff et al. 1996).

### 2.11.5 White Goods

Overview

For this discussion, white goods include clothes washers, dryers, refrigerators, and other household appliances. Although white goods have been used as artificial reef material, their use is not referenced in published artificial reef literature.

Benefits

- White goods are readily available and are easy to handle, both onshore and at sea.

Drawbacks

- White goods are thought to be short lived in the marine environment. If that is true, sites would have to be replenished regularly, in order to maintain habitat.

- White goods are thought to be unstable, and may easily be moved offsite by storm surge or being dragged in a shrimp net.

- According to Stone (1985), material such as appliances, while readily available, are not dense, and their durability and stability in the marine environment is poor.

Recommendations

- The use of white goods should be avoided, unless they can be used in compliance with the standards and criteria established in the National Plan as cited earlier. Ballasting or chaining several units together may increase stability; however, this practice will not increase the durability of the material.

- Motors and compressors should be removed or drained of all lubricants, where applicable.

- All plastic knobs, valves, and wiring should be removed.

- Removing the compressors and motors during predeployment preparation would eliminate the heaviest component of the materials, thus contributing to their instability.

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## 3.0 CONCLUSION

It is expected this will be a living document, now in its third edition, and will serve as useful guidance to artificial reef programs and developers. The authors restate the intent that this document is to be used for guidance only and has no direct regulatory application, unless adopted by a regulatory agency for that purpose. We welcome reader suggestions for improving the document. In addition, the authors invite anyone to report any materials known to be used in artificial reef development that are not included in this document. This will allow inclusion of such materials in the next edition of these guidelines. Please direct any suggested improvements to the document, additional information regarding positive and/or negative experiences with specific artificial reef materials, and any recommendations for addition of specific materials to either the Gulf States Marine Fisheries Commission, 2404 Government Street, Ocean Springs, Mississippi 39564, (228) 875-5912 or the Atlantic States Marine Fisheries Commission, 1050 N. Highland Street, Suite 200 A-N, Arlington, VA 22201, (703) 842-0740.