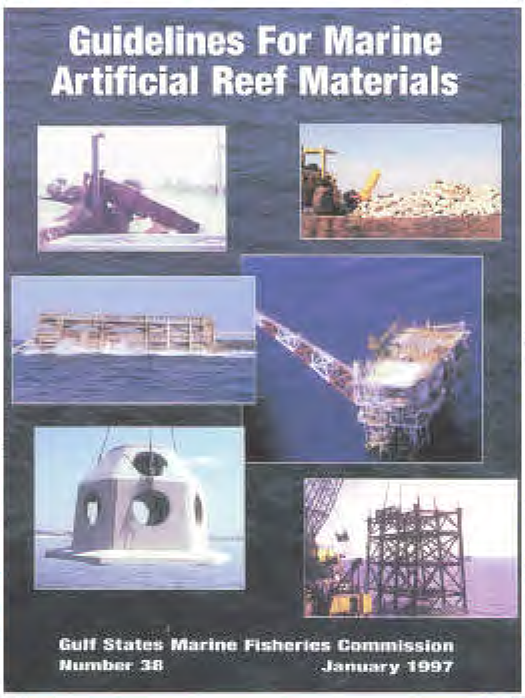
GUIDELINES FOR MARINE ARTIFICIAL REEF MATERIALS

SECOND EDITION



Guidelines For Marine Artificial Reef Materials

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GUIDELINES FOR MARINE ARTIFICIAL REEF MATERIALS

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Compiled by the

Artificial Reef Subcommittees

of the

Atlantic and Gulf States Marine Fisheries Commissions

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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 reef material, 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 subsection represents perceived benefits contributed by state artificial reef managers as a result of their involvement in artificial reef development over many years. The Drawbacks subsection represents perceived 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. Rather it is 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 first 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, P.O. Box 726, Ocean Springs, Mississippi 39566-0726, (228) 875-5912 or the Atlantic States Marine Fisheries Commission, 1444 Eye Street, NW, 6th Floor, Washington, DC 20005, (202) 289-6400.

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 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 the 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 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 are 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 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 (ie. appropriate bottom type, food items, tidal and wave action, etc.).

1.3 *History*

McGurrin et al. (1989) provided an excellent article on 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.

1.4.1 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.

1.4.2 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.

1.4.3 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.

1.4.4 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*

Overview

Concrete, either in fabricated units specifically designed for artificial reefs or imperfect concrete manufactured products, such as culvert or rubble from razed buildings, sidewalks, roadways and bridges, has a demonstrated high success rate as artificial reef material in both marine and estuarine environments. The obvious reason for this high rate of success is the strong compatibility of the material with the environment in which it is placed, and for the purpose for which it is placed. Concrete is generally very durable and stable in reef applications.

Webster's Dictionary defines concrete 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. Limestone is comprised primarily of calcium carbonate, which is 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. 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 predicted, for several reasons. There are significant factors other than cement type, which influence durability. First, concrete reef materials are not load bearing and are not subjected to structural stresses. Second, concrete reef materials are not repeatedly being wetted and dried. During the drying process in Type I concrete, sulfates from seawater react with tricalcium aluminate in the concrete to form needle-like ettringite crystals. It is the formation of these crystals, within the structure of the concrete, during drying that gradually breaks down the structural integrity of the concrete matrix. This is not a problem with reef materials, because they are constantly submerged and there is no repeated wetting and drying. A third 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. The reason for this is that 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, is 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. Pozzalanic materials can help to neutralize the surface pH by combining with the free lime. Such materials include coal combustion fly ash, diatomaceous earth, clays, shales, pumicites, micro-silica, among others. A pozzalanic material reacts with the free lime, lowering the pH and also providing for better bonding between aggregates, thus making the concrete stronger. The majority of concrete used in reef applications is not used 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. An estuarine reef made from concrete culvert in Delaware Bay exhibited the rapid development of an epifaunal community, dominated by the polychaete worm, *Sabellaria vulgaris.* Biomass and species diversity equaled 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 sea water (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.

In a search of the available literature, the earliest reports regarding the use of concrete for artificial reefs was 1962 (Martinez 1964); however, while not reported in the literature, in 1962, 300 tons of concrete pipe were sunk off Perdido Pass, Alabama, in approximately 60 feet of water. Similarly, concrete pipes were utilized for Alabama offshore reefs in 1964, 1970, 1971, and 1977 (Walter Tatum, personal communication). During the 1980s, three bridges were replaced in the Alabama coastal area, and the "scuttled" concrete material was placed offshore for artificial reefs. Culvert constitutes the most frequently used concrete material for artificial reefs offshore Florida (Jon Dodrill, personal communication).

Prefabricated concrete materials have been in use as artificial reefs for over 40 years. "Pillbox" reefs constructed in Japan, Taiwan, and elsewhere have demonstrated the utility of concrete materials. Types of concrete materials, other than prefabricated units, include razed buildings, bridge spans and support columns, replaced roadways and sidewalks, concrete sewage and drainage pipes, concrete blocks from razed buildings, and imperfect concrete materials.

Coal combustion fly ash is regularly used in concrete products manufactured by both private and governmental enterprises (see section 2.10, Ash Byproducts). Fly ash is probably one of the principal additives found in artificial reef concrete materials of opportunity, including bridge rubble, pilings, power poles, culverts, and others. Of the 47.8 million tons of fly ash generated nation-wide in 1993, 6.8 million tons went into concrete products and cement. Benefits of fly ash use can include significant enhancement of compressive strength, improved workability, reduced permeability, increased resistance to sulphate attack, reduced heat of hydration, increased resistance to alkali-silica reactivity, and lower costs (Federal Highway Administration 1995). In Florida, coal combustion fly ash has been used in structural concrete products by the Florida Department of Transportation (FDOT) for 20 years. Fly ash is used to replace cement in the concrete mix at a replacement weight of 18-22% and serves to combine with an activator such as lime or Portland cement to produce a cementitious material. Fly ash batches used by FDOT are checked through independent quality assurance tests based on industry standards for sulfate and organic content, since high levels of both of these materials could reduce concrete durability (Rodney Powers, personal communication).

The coal source of fly ash in concrete products available for reef projects is often unknown. Florida alone 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. There are thousands of tons of scrap concrete placed in the ocean annually off Florida alone, indicating that this is an issue which should be addressed in the future.

The Texas Game and Fish Commission used six foot long concrete pipes cabled together in three separate units for a reef site established 11 miles offshore of Galveston in 1962 (Jan Culbertson, personal communication). The first unit consisted of five sections of 36 inch diameter pipe and five sections of 60 inch diameter pipe placed on natural bottom within a 100 foot by 100 foot area. A second unit consisted of ten sections of 48 inch diameter pipe placed on a one foot thick steel mill slag mat adjacent to the first unit. The third unit consisted of 10 sections of 60 inch diameter pipe on a one foot thick steel mill slag mat adjacent to the second unit. In 1963, the Texas Parks and Wildlife Department (TPWD) increased the size of the "Galveston Pipe Reef" by adding a fourth unit of 300 sections of four foot long, 30 inch diameter pipe cabled together on natural bottom. The two clusters of concrete pipes placed on the metal slag mats were visible with a four foot profile during the side scan sonar survey conducted by a Naval Reserve Mine Sweeping Unit for the TPWD in 1993 (TPWD Unpublished Data). However, the first and fourth units were covered by mud and no longer visible during the survey. Numerous anglers have been observed fishing at this reef site periodically since it was constructed (Bob Bass, personal communication).

The Texas Fish and Game Commission also used 26 sections of five foot diameter, five foot long concrete pipes with 400 sections of 18 and 24 inch diameter, five to six foot long clay pipes to rehabilitate a reef site six miles offshore Port Aransas in 60 feet of water in 1962 (Martinez 1964). The costs to purchase the pipes from the Port Aransas Boatmen's Association and transport this material offshore amounted to $3,496. Recent surveys (1995) of this reef site show that the pipe reef has at least a visible four foot profile and appears to attract fish, especially red snapper (Jan Culbertson, personal communication). In 1994, the Texas Artificial Reef Fund paid for this reef site to be rehabilitated. The TPWD placed 44 square concrete culverts with dimensions of eight feet high by eight feet wide by four feet long. Local anglers have reported several tagged game fish captured on the reef since it was rehabilitated (Terry Cody, personal communication).

The TPWD, with cooperation from the U.S. Coast Guard, is in the process of constructing a reef offshore of Sabine Pass made of 16 concrete “anchor sinkers” in 43 feet of water. Red snapper were observed immediately after deployment at this reef site by divers (Jan Culbertson, personal communication).

Since 1989, Mississippi has deployed concrete rubble in 107 locations within fifteen permitted reef areas. These deployment sites include near shore waters 0.25 miles from the mainland in approximately eight feet of water to sites approximately 30 miles offshore in eighty feet of water. This rubble was obtained from several demolition projects, including military barracks, concrete culverts of various sizes, a cooling tower, and an airport runway. Concrete rubble sizes varied from six inches to ten feet. The larger pieces were placed in offshore areas. Side-scan sonar was utilized to evaluate stability of most of the concrete rubble deployments. In most instances, concrete rubble has proven to be 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 its assumed that this material also subsided.

Since 1984, 200,000 cubic yards of concrete demolition debris, including piers, pilings, bridge spans, block, pipes, and foundations, have been placed on New Jersey ocean reef sites. For each project, the initial barge load of concrete is inspected by state reef personnel. Demolition debris contains dirt, fiberglass, plastic, wood, corrugated metal, and other lightweight materials, along with concrete and heavy-gauge steel. Only the concrete and heavy-gauge steel are allowed. Concrete is usually deployed by pushing pieces off deck barges with heavy equipment; although dump scows, which drop their entire load at once, are also used occasionally. Since concrete is very dense and tends to subside into the sand, New Jersey has placed many barge loads of concrete at the same location in an attempt to facilitate stacking, increase profile, and reduce subsidence. New Jersey’s experience is that concrete provides an effective base for fowling community growth and an intricate maze of hiding places for fish and large crustaceans.

Various forms of concrete, including concrete culverts and bridge rubble, have been used in Alabama's offshore artificial reef building program since the early 1970s. This material is still in place and continues to produce good catches of fish at the time of this writing. Since 1994, concrete culverts, block, and bridge rubble have been used as part of the inshore artificial reef program. This concrete has been used as retaining wall material to hold shell and quarry rock, as well as, alone within the pilings of relic piers. These reefs have all proven to be very productive.

Concrete has been the major reef building material for Delaware's eight estuarine reef sites. Since 1995, over 50 patch reefs have been established on these sites. Culvert and other manufacturer's second quality material is donated to the program. Only new, clean material is used. 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 juvenile habitat for seabass. High profile reefs attract baitfish and species such as weakfish, bluefish, and striped bass.

The California Department of Fish and Game first 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). Over many years concrete has been demonstrated to be a durable material, as well as a good quality substrate. Concrete rubble has been used repeatedly to build reefs off southern California for the last 40 years. Concrete slabs for demolition projects and pier pilings and decking have been utilized since 1986 to build the largest single artificial reef off the California coastline. The Bolsa Chica Artificial Reef off Orange County currently consists of 160,000 tons of concrete rubble, with an actual foot print of approximately 30 acres, in a permitted area of 200 acres. The Bolsa Chica reef supports much of the commercial passenger fishing boat industry activity operating out of Los Angeles and Long Beach Harbors during several months of the year (Dennis Bedford, personal communication). During 1992, the first self-sustaining artificial kelp reef was built by the California Department of Fish and Game off Mission Beach, Dan Diego County, utilizing 9,200 tons of concrete slab rubble from the demolition of a local roadway. Covering approximately 11 acres, this reef supported a kelp bed community for the last 10 years. It was subsequently surveyed as a potential model for a larger mitigation reef planned by Southern California Edison Company (Ecosystems Management Associates, Inc. 1999). During the fall of 1999, Southern California Edison Company built an experimental 22 acre artificial reef off San Clemente, Orange County, designed to support a kelp community. Half of the 48 reef modules are built with concrete rubble.

Benefits

- Artificial reef projects using bridge rubble can 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 consequent need for heavy equipment to handle it. This increases the costs both at the landside transportation stage 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.

- Competition for scrap concrete, for such uses as roadbed construction, as well as the ability to recycle this material is currently reducing the availability of concrete for use as artificial reef construction in some areas.

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 should be used in designed structures and concrete ballasted tire units produced for reef applications.

- 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

In the United States, scrap materials of opportunity, deployed without assembly or much modification, still account for a large portion of reef construction materials. Vessels have served as 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 60 years later.

Large Military Vessel Procurement as Artificial Reefs through the U.S. Maritime Administration

The first governmental efforts to provide ships as artificial reefs began with the Liberty ship program. Federal and state government participation in the procurement of steel vessels for use as artificial reefs started with Alabama's initiative to secure Liberty ships from the U.S. Maritime Administration's (MARAD) Reserve fleet in the Alabama River. On August 22, 1972, the 92nd Congress passed and the President signed the Appropriations Authorization-Maritime Programs Bill which became known as the Liberty Ship Act [Public Law (P.L.) 92-402.] This law provided for the transfer of obsolete MARAD owned WWII era Liberty ships, otherwise slated to be sold as scrap, to coastal states for use as artificial reefs. During WWII there were 2,581 Liberty ships mass-produced in production line fashion from component parts shipped to a number of shipyards from all over the U.S. These ships were quickly manufactured (welded not riveted), inexpensively built, slow moving, lightly armed, and expendable. Liberty ships were intended to substantially augment the U.S. merchant marine fleets in efforts to transport all typed of solid cargo to allied forces worldwide during WWII. At that time there were 36 Liberty ships available in Texas, Alabama, Virginia, and California. The majority of the ships deployed under this act were sunk between 1974-78, with 26 of 36 Liberty ships available in 1972 sunk off four Gulf coast states, including Alabama with five, Texas with 12, Mississippi with five, and the Florida Gulf coast with four (Texas Coastal and Marine Council 1973, Lukens 1993, Gregg and Murphey 1994). Two other liberty ships were sunk off the Florida east coast during this period.

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 permitting through the Army Corps of Engineers, coordination with state regulatory agencies, and the Environmental Protection Agency (EPA) as well as addressing navigational issues with the U.S. Coast Guard.

In 1984, P.L. 92-402 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 the Victory class merchant vessels 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 subsequently scrapped. Deployment of P.L. 92-402 ships virtually ceased from 1978 to 1987. Only six (15%) of 42 P.L. 92-623 and 402 vessels sunk as reefs outside of Florida were deployed from 1988 through 1992 (Gregg and Murphey 1994) with none deployed from 1993-2001. In Florida under the amended P.L. 92-623, two 327 foot Coast Guard cutters (*Bibb* and *Duane*) were sunk in 1987 in the Florida Keys and two 460 foot transports (*Rankin* and *Muliphen*) were sunk off Martin and St. Lucie Counties (Southeast Florida) respectively in 1988-89 (Virginia Vail, personal communication).

After six years of no release of ships from MARAD to any state under the Liberty ship program, local citizens, and the Key Largo, Florida Chamber of Commerce in conjunction with Monroe County (Florida Keys), requested assistance from the state of Florida in July 1995 to secure from MARAD the donation of a 510 foot long ex-navy Landing Ship Dock, *U.S.S. Spiegel Grove (LSD-32)*, to be sunk as an artificial reef off Key Largo, Florida within the Florida Keys National Marine Sanctuary. Environmental, legal, logistical, administrative, contractor and fiscal issues delayed title transfer of the ship to the state (and subsequently to Monroe County through Memorandum of Agreement) for nearly seven years until May 30, 2001. On June 13, 2001, nearly 13 years after the last MARAD donated vessel was sunk, the *Spiegel Grove* was towed from the James River Reserve Fleet in Fort Eustis, VA to begin undergoing cleaning and pre-sinking preparations at a Virginia ship yard. Following delays stemming from the national disaster of 9-11-01 and switching shipyards and contractors, the vessel preparation was completed, final environmental clearances were given the U.S. Coast Guard, Environmental Protection Agency, the Florida Fish and Wildlife Conservation Commission, and the Florida National Marine Sanctuary. The vessel was towed to Key Largo, Florida and sunk on its permitted site on May 17, 2003 and open to the public for fishing and diving three weeks later. As of 2003, the *Spiegel Grove* was the largest vessel intentionally sunk in the U.S. as an artificial reef. Two other MARAD artificial reef vessel projects, already over five years into the planning process as of 2003, are currently being pursued as artificial reef donation projects through MARAD. The 600 foot long *Texas Clipper* in the Beaumont, TX reserve fleet is being sought as an artificial reef by Texas Parks and Wildlife and the 520 foot long former missile tracking vessel *Hoyt Vandenberg* will be requested by a nonprofit diving organization in conjunction with the City of Key West working cooperatively with the Florida Fish and Wildlife Conservation Commission who will make formal application to MARAD.

Current Procurement and Preparation Issues Related to Large Military Vessels

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 State 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 nonflammability, 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 non metallic 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 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," (Interim Final Policy, November 30, 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 also commenced laboratory PCB leach rate studies, and deepwater PCB studies on military ships sunk in 6000 feet or greater, as well as risk analysis on environmental and human health effects of PCBs . Findings and recommendations from the Navy studies will be available by the summer of 2003 and are expected to verify the results of South Carolina's preliminary testing (Frank Stone, personal communication).

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”. (Stuart Perry, personal communication). 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 abraiding (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. (Carolyn Salmon, personal communication).

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. Elizebeth 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. Elizebeth Stanley said, “The owner/operator would need to remove the regulated asbestos containing material (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 asbestos in 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 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 in recent years. 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 of 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 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 PCB and other hazardous waste and pollutant material removal will be incorporated into a document entitled "National Guidance: Best Management Practices (BMPs) for Preparing Vessels Intended to Create Artificial Reefs." This document, authored by a multi-agency federal working group is anticipated to be available in the summer of 2003 (Elizabeth Freese, personal communication).

MARAD Navy Vessel Cleaning and Preparation Cost Issues

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, and 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 feet long, 57 feet wide, and 80 feet from the top of 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 ship was 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).

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. Scrap steel values are low as of 2002. 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 2002 range from 1-2.2 million dollars per vessel. For example the *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 *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 2002 substantially exceed the annual operating budget of a typical state artificial reef program. Without major private, and local government financing and 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 remained prohibitively expensive for most state reef programs.

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. These remaining inactive ships constituted 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 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. 16 USC 1220c-

1(a) now 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 reefs, 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 feet long, 34,881 ton Korean War/Viet Nam era ex-Navy aircraft carrier, *U.S.S. Oriskany (CVA 34)* would be available as an artificial reef pilot project through a turn key 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).

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 vessels used as artificial 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 non combatant 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 112 decommissioned oil and gas structures as of 2003 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).

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 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). Bank loans of several hundred thousand dollars incurred by the Key Largo Chamber of Commerce as a result of providing financial assistance to the *Spiegel Grove* project in the Florida Keys are on track to be repaid within two years through the sales of souvenir medallions to thousands of divers who are diving the wreck (Spencer Slate, personal communication).

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 ship wrecks (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 a107 reef artificial reefs system that included 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 ship wrecks (54%), and 921 (38%) were on artificial reefs, which included some intentionally placed ship wrecks. Only 8% of the reported dives were on live bottom areas or rock jetties (Rhodes et al. 1992).

The popularity of wrecks as reef destinations for divers is evidenced by the number of diving accidents occurring at shipwreck sites during the period 1989-93. In that time frame, 552 diving accidents occurred during wreck dives in the U.S., representing 24.4% of the 2,258 freshwater and saltwater diving accidents reported to the Divers Alert Network. Thirty-two of these accidents were fatalities. According to the Divers Alert Network Database managed by Duke University, the doubling of the annual injury rates for divers in general and for wreck divers suggests greater diver participation in the sport rather than a relaxation of safety standards (Divers Alert Network Database).

Utilization of vessels as diver attractants in a recreational activity that has some associated level of risk should be carefully evaluated by managers. However, some charter dive operators believe that smaller vessels at depths of 60-80 feet in low current environments are actually safer to dive on than putting divers with basic skills on natural bottom where orientation and return of the diver to the anchor line may be more difficult for a novice open water diver. Multiple divers placed in the water at the same time and able to orient to a small wreck are less likely to wander off and are able to safely move around the wreck exterior and back to the anchor line for ascent back to the boat. (Steve Parks, personal communication).

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.

When interactions of both human and physical variables are combined, no vessel dive site, no matter how well planned is immune from accidents. Three vessels over 320 foot long placed at depths of 110-130 feet in a moderate current environment off Key Largo, Florida and exposed to thousands of recreational and tourist divers per year had the following safety records: Coast Guard Cutter *Bibb* oriented on its side had one fatality in 16 years of moderate diving pressure as a result of an inexperienced diver penetrating the wreck and running out of air. No fatalities have been recorded in 16 years on the heavily dived sister ship, 327 foot long cutter *Duane* oriented upright. The 520 foot long ex-Navy vessel *Spiegel Grove* oriented on its side after 10 months on the bottom and 12-14,000 successful dives, recorded a diving fatality on April 2003, the result of a 48 year old female out of state diver incurring an embolism after rapid ascent seven minutes into the dive(Maher 2003).

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 1 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).

Table 1. 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; stem section torn off.
Belcher Barge	barge	195	57	Several steel plates torn off barge.
Belzona One	tug	80	73	Wheel house 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; stem 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, pilothouse torn from hull.

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

During Hurricane Gordon (August 1994), a 600 foot long vessel loaded with concrete and sunk off Bimini, Bahamas in 80 to 100 feet 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, a tug, the *Paul Main*, deployed off Jacksonville, FL in 70 feet of water in 1968 still remains a popular dive site in 2003 though 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 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 1 and Jon Dodrill, personal communication).

Vessels require a significant amount of care to insure 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, so they can move on to the next job, have resulted in vessels sinking offsite and outside permitted areas.

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 *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 insure 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).

The perceived advantages of explosive use 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 as artificial reefs vessels less than 150-200 foot long (i.e. tugs, auxiliary vessels, coastal freighters) that do not have the complexity of large numbers of water tight compartments and other voids. 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 foot 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 1500 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 insure 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 moment. 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 side off NW Florida, 1995), 460 foot troop ship Mullephin (sank on side off SE Florida in 1988); the 327 foot coast guard cutter *Bibb (*sank on 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).

The value of vessels as fishing habitat, from a management perspective seems to be a double-edge 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 the vessel as a fishing reef is seriously compromised. 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 fully 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 on the narrow band of continental shelf (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. All things being equal, anglers exhibit a preference for fishing on natural habitat. 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).

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 site holding dense concentrations of fish. In January of 1986 during a cold front, a barge carrying 7000 tons of crushed granite enroute from Savannah, GA to Nassau, Bahamas sank in heavy weather in 80 feet of water in off Cape Canaveral. When the Space Shuttle *Challenger* blew up over the Atlantic shortly after take off 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 ship wrecks 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.

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 dollars 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 SawyerAssociates 2001).
- Steel-hulled vessels, when selected for sound hull integrity, are considered durable artificial reef material when placed at depths and orientations that insure 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 over-fished such as warsaw, black, 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 life, 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.

- 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).

- 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.

- 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.).

- Removal of hazardous materials, pollutants, and other material not authorized for artificial reef disposal under the permit requires 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, void spaces, and overall complexity increases.

- 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, hazards associated with wreck penetration into a multi-level labrynth of compartments by divers exceeding skill levels, 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, especially those in marginal condition, are at greater risk of sinking off site while under tow, either to the salvage site or the permitted area itself, than other reef materials carried on or in more seaworthy vessels.

- Salvage efforts may weaken the structural integrity of a vessel or result in significant reduction in its vertical profile and complexity, due to loss of the superstructure.

- 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 is 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.

- On older government vessels, treatment of contaminants such as asbestos, and PCBs, and other materials that are considered hazardous wastes under other scenarios, as of spring 2003 have not been aggressively addressed by the EPA in any well-publicized, formal policy statement or guidelines.

- 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.

Considerations

- 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.

- Some contractors or other organizations tasked with cleaning vessels, or their hired laborers and volunteers have historically not always followed proper hazardous materials and other waste handling and disposal, and/or general OSHA safety protocols due to lack of expertise or training, inadequate facilities ,equipment and manpower, desire to reduce project time and expenses, or insufficient guidance or over sight provided by the contract or project manager, and focus on removal of salvageable material to the detriment of meeting other cleaning and preparation objectives (Kurtis Gregg, personal communication; Jon Dodrill, personal communication). Examples would be failure to test air quality in enclosed compartments prior to extended work in the compartment or utilizing cutting equipment therein (air quality testing normally requires a marine chemist), failure to utilize a certified asbestos inspector to identify and make recommendations regarding securing or removal of asbestos on a vessel, no PCB testing on vessels where such materials are suspect, improper disposal of waste materials (throwing materials overboard, utilizing a ship's compartment as permanent central waste/trash disposal area, sealing up fuel tanks without thoroughly cleaning them, etc.).

- Recommendations for vessel siting, cleaning, preparation, standards, and consistency.

- 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 a 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. Identified 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.

Federal Vessel Reefing Program Development Recommendations

- Gulf and Atlantic Marine Fisheries Commissions and Councils should investigate possible federal programmatic alternatives to the multi-year drawn out process of securing piecemeal 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 turn key 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 the 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 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 *Oil and Gas Platforms*

Overview

Offshore oil and gas platforms first began functioning as artificial reefs in 1947 when Kerr-McGee completed the world's first commercially successful oil well out of sight of land. It is recognized that oil and gas reserves are often associated with salt domes on land, so it made sense to geologist Dean McGee that they would also be in Louisiana's shallow waters off Ship Shoal. Early in 1946 Kerr-McGee acquired the first leases 43 miles South of Morgan City, Louisiana. The leases covered some 40,000 acres in fairly shallow waters.

One year later Kerr-McGee decided to drill its first offshore well in Ship Shoal Block 32. The problem was that the technology and equipment to drill in 18 feet of water 10 ½ miles from shore did not exist. Armed with a new technology which resulted in the development of Louisiana's brand new offshore industry, Kerr-McGee begin drilling operations on September 12, 1947. Twenty two days later on the morning of October 4, they struck oil. To date, as technology improved, offshore oil and gas development has expanded into waters well over 7,000 feet (U.S. DOI MMS 2000).

There are approximately 3,992 petroleum platforms in the Northern Gulf of Mexico as of 2001 (Figures 1a-b). In addition to supplying oil and gas, these platforms provide an important source of hard substrate or reef habitat (Reggio and Kasprzak 1991). The Gulf of Mexico Fishery Management Council (GMFMC 1989) estimated the total natural reef habitat in the Gulf of Mexico 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 of Mexico exist. 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%. This particular habitat is important in the northern Gulf of Mexico. Bottom habitat in the Gulf of Mexico is typically dominated by clay, silt and/or sand with little to no relief. The addition of these 3,992 petroleum platforms and the hard bottom substrate they provide has undoubtedly had some effects on fish populations, although their effects are not completely understood (Stanley 1994).

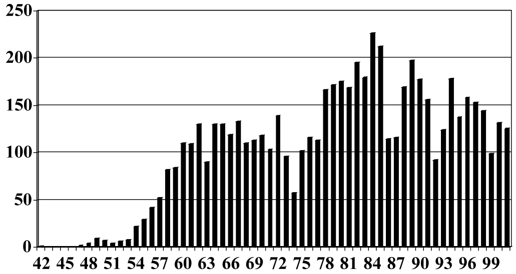


Figure 1a. Platforms Installed: 1942-2001.

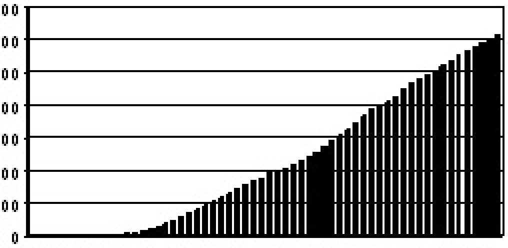


Figure 1b. Cumulative Platforms Installed: 1942-2001

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). Stanley and Wilson (1996, 1997, 1998, 2000b) documented species composition and abundances of fishes at several platforms and concluded that each standing platform seasonally serves as critical habitat for 10-29,000 fish, many of which are commercially and recreationally important. Reggio (1987) estimated that petroleum platforms were the destination of over 70% of all recreational fishermen fishing off Louisiana. Furthermore, it has been determined that anglers who fished around platforms caught more, bigger, and more desirable fish than marine recreational fishermen who fished other areas (Witzig 1986) of the Gulf. Avanti, Inc. (1991), using data from the NMFS' Marine Recreational Fisheries Survey, estimated that 30% of the recreational fisheries catch, a total of approximately 15 million fish, were caught near platforms off Louisiana and Texas. Dimitroff (1982) conservatively estimated that 112 snapper/grouper fishermen from the panhandle of Florida landed approximately 450,000 pounds of reef fish annually valued at approximately $2 million from around oil and gas platforms. However, sampling fish populations from around these is particularly difficult with traditional fishing gears due to gear bias, limited visibility, diver/ROV avoidance, and lack of standard survey techniques (Stanley 1991). To date, most of the research on oil and gas platforms has centered around environmental impacts and composition of discharges such as produced waters, drilling fluids and spills (Boesch and Rabalais 1987).

Despite these difficulties, investigators have found that fish abundance near a platform ranges from a few hundred to several thousand individuals depending on platform, size, location and time of survey (Continental Shelf Association 1982, Putt 1982). 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. The combined species in water depths between 10 feet and 60 feet included red snapper, bluefish, Atlantic spadefish, blue runner, grey triggerfish, grunts, greater amberjack, sheepshead, and groupers (Gallaway 1980, Continental Shelf Associates 1982, Gallaway and Lewbel 1982, Putt 1982, Stanley and Wilson 1990). Putt (1982) found that from June through September fish populations were variable, with fish abundance varying by a factor of two, while species composition remained constant. Stanley and Wilson (1990 and 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. 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. In a study conducted between September 1990 and June 1992, Stanley (1994) estimated approximately 12,000 fish, as a monthly average number 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.

Dokken et. al. (2000) studied three types of biofouling communities on seven 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 bluewater zone were located in deeper, clearer water over 60 miles offshore, which had only moderate temperature changes all year round. They found 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. They reported that bluewater platforms had the highest diversity of all platform communities. Sponges and algae dominated these platforms with soft corals, bryozoans, and sessile hydrozoans as secondary dominates. Dokken et. al. (2000) also reported that vertical zonation on platforms was the most important factor in determining what biofouling communities dominated the structure. They also discussed rugosity as a measure of thickness of the biofouling community on the platform. Rugosity appeared to be affected by the platforms distance from shore. They also reported that one to four separate communities developed with depth on these structures.

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. These three 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 undoubtedly influenced by a number of factors including 1) the distribution of turbid layers; 2) seasonal extremes in temperature; 3) primary productivity of the surrounding water column, and 4) the degree and extent to which platforms are exposed to Caribbean water masses (Gallaway and Lewbel 1982).

As of December 2001 there were approximately 2,643 platforms classified by Gallaway and Lewbel as Coastal in Federal outer continental shelf waters, in addition to approximately 900 found in Louisiana state waters (beach to three miles), and 297 in Texas state waters (beach to nine miles). Offshore and bluewater communities accounted for 792 and 554 platforms, respectively. Continental Shelf Associates (1982) also studied fishes associated with oil and gas structures in Louisiana. They described species diversity around platforms and showed how environmental factors such as depth and current affected the location of specific fish in relation to vertical and horizontal support legs.

It did not take long for fishermen from Louisiana and neighboring states to recognize the bountiful fishery resources beneath these platforms. Since these platforms are so commonplace in coastal Louisiana and Texas, many citizens and management groups believe that they are permanent and will always be available for fishing. This, however, is not the case. From 1973 to 2001 over 2,000 structures have been removed from the Gulf of Mexico, as required by federal law. At present, there are 2,259 platforms in the Gulf of Mexico which are greater than 25 years old, and it is anticipated they will be removed over the next 10 years. Pulsipher et. al. (2000) estimated by the year 2023 over 4,645 platforms will be removed assuming an installation rate of 142 platforms per year and a removal rate of 186 per year. This will represent a decline in the number of operating platforms by an estimated 29% to a total of 2,612. Of the platforms that are being installed, most are in deep water and far from shore making them practically inaccessible to the average angler. This does not include platforms which need to be removed because of damage, regulatory requirement due to lease abandonment, or economic circumstances. This projection raises serious questions about the impacts of the potential loss of valuable habitat to a variety of marine life (GMFMC 1989). The reduction in available habitat by the removal of these structures may have long term impacts on reef fish populations and at a minimum will disperse these populations away from traditional fishing locations.

Many coastal states, recognizing the potential of these structures as artificial reefs, began securing the platforms for their coastal waters as fish habitat. 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.

In 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. On October 2, 1985, Tenneco towed two additional structures from Louisiana 920 miles to a site 1.5 miles off Dade County, Florida.

The Louisiana legislature passed enabling legislation entitled, The Louisiana Fishing Enhancement Act (Act), signed into law on June 25, 1986, to take advantage of the availability of obsolete oil and gas platforms that provide valuable reef fish habitat. The Act set up a mechanism that transferred ownership and liability of the platforms from the oil and gas company to the State when the platforms ceased production. Normally these production platforms are removed, towed to shore and cut up for scrap, resulting in a loss of reef fish habitat. Removal costs to operating companies are also substantial. It has been estimated that cumulative removal costs will reach $1 billion by the year 2000 (Lee 1985). When the deck portions are used, all the processing equipment is either removed or cut open and the piping and vessels flushed clean. The residue and contaminants are then packed in drums and shipped ashore for disposal. Certification that the decks are clean is then generally performed by a third party and a certification report provided (Maher 1993).

Under the program, administered by the Louisiana Department of Wildlife and Fisheries, the oil companies may deposit obsolete structures at state-designated sites, preserving the habitat and substantially reducing removal costs. These savings realized by the participating companies are shared equally with the state for assuming liability and maintenance of the reef (Reggio and Kasprzak 1991).

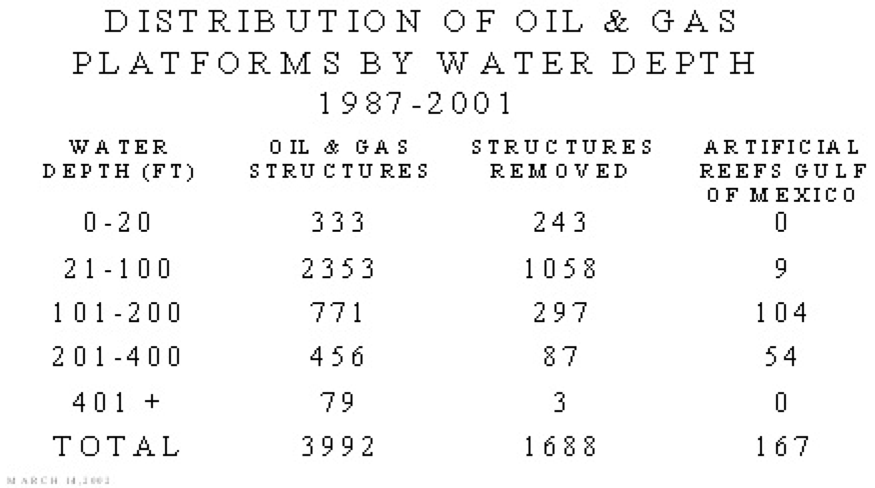
In 1989 Texas passed similar legislation that directed TPWD to promote, develop, maintain, monitor, and enhance the artificial reef potential in state and federal waters adjacent to Texas. This legislation also directed TPWD to "actively pursue acquiring offshore platforms for use as artificial reefs in the Gulf of Mexico, in deference to other structures" (Stephan et al. 1990). To date, more than 167 platforms have been deployed as artificial reefs in the Gulf and East Coast of Florida.

The Texas Artificial Reef Program, like the Louisiana program, requires oil and gas companies to donate to the program a portion of the savings realized by utilizing structures as artificial reefs, rather than transporting them to shore for salvage. These donations are reviewed by a citizen's advisory committee, composed of ten interested user groups. The advisory committee provides a forum for minimizing conflicts between user groups before the permitting process begins.

In 1999, Mississippi passed legislation similar to that of Louisiana and Texas, which allowed them to accept obsolete platforms as well as the associated donations into their program with the ownership of the platforms transferred to the state. Early in 2000, Mississippi received its first two donations. These platforms were transported to a site located east of the Chandeleur Islands.

California recently attempted to pass similar legislation in 2000 by a bill introduced by Senator Albert (SB 241). Although the bill passed both the House and the Senate it was vetoed by the Governor.

However, it is not always economical to convert a platform into an artificial reef. The size of the structure, water depth, distance from shore, proximity to final reef site, and potential resale value will dictate whether or not an obsolete platform becomes a reef (Pope 1988). From 1987-2002, of the over 1,688 platforms removed from Louisiana and Texas waters, only 167 platforms, or approximately 10 percent, became artificial reefs (Kasprzak 1994). However, when the required 50 ft. of clearance is considered, which is achieved in water depths of 100 to 400 feet, 158 of 384 or approximately 50% have entered artificial reef programs (Table 2).



DISTRIBUTION OF OIL & GAS PLATFORMS BY WATER DEPTH 1987-2001

WATER DEPTH (FT)	OIL & GAS STRUCTURES	STRUCTURES REMOVED	ARTIFICIAL REEFS GULF OF MEXICO
0-20	333	243	0
21-100	2353	1058	9
101-200	771	297	104
201-400	456	87	54
401 +	79	3	0
TOTAL	3992	1688	167

MARCH 14,2002

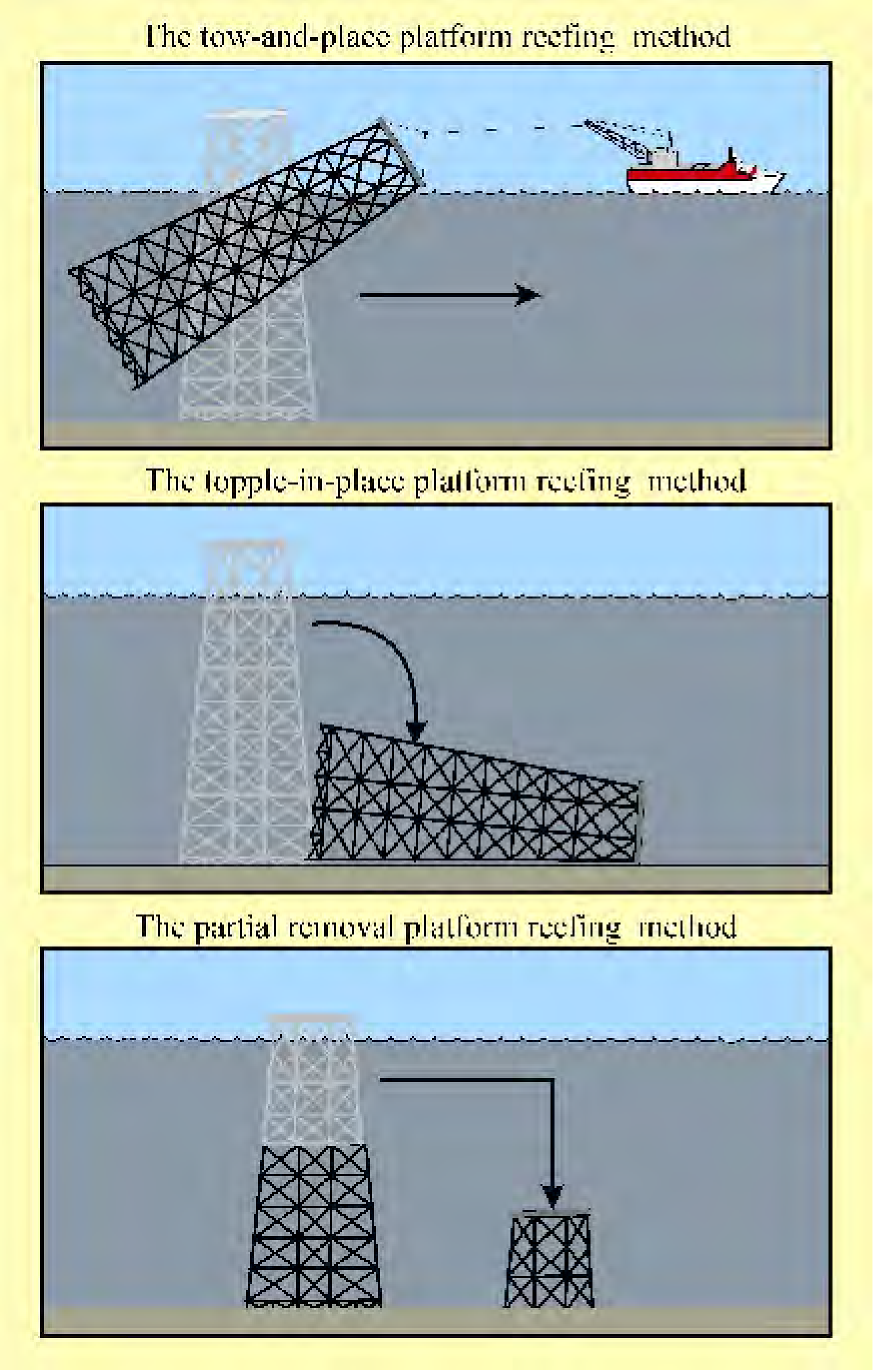
Table 2.

Once an oil or gas structure is properly plugged and abandoned, there are three removal options available when donating a structure (Figure 2) (Dauterive 2000). The most common removal method, in deep water applications, involves the use of explosives inside the jacket legs, 15 feet below the mudline. Once the jacket legs are severed by the explosives, the structure is toppled over in a horizontal position on the bottom. This method offers the donor lower costs and time savings. The disadvantage to the use of explosives is the potential mortality of sea turtles, marine mammals, and fish that might be associated with structures. Gitshlag et al. (2001) studied the effects of explosives on fish populations during the removal process and found that though large numbers of fish are killed, the overall impact to the population was relatively small.

The second removal option involves divers cutting the jacket legs below the mudline using explosives. Once the legs are severed, the entire structure can be lifted from the sea floor using a derrick barge, towed to a new permitted location, and placed on the bottom in a horizontal or vertical position. Mechanical or abrasive cutters can also be used to cut the legs. This method is typically only used in water depths less than 100 feet. Water depths in excess of 100 feet would significantly increase the risks to divers. There however, would be no adverse impacts to associated living marine resources. This method is also expensive, labor intensive, and time consuming. The Texas Artificial Reef Program has been able to receive six jackets that were mechanically cut below the mudline and transported intact to two separate reef sites. Although there was no monetary savings using this method, instead of using explosives, the turtles, fish, and encrusting organisms were transported along with the structures to the new reef site (Jan Culbertson, personal communication).

The third removal option involves the partial removal of the upper portion of the jacket and placing it on the sea floor next to the standing bottom portion of the jacket. This method is particularly beneficial with deep water structures that are converted into reefs. The standing vertical portion of the structure, which must provide at least 85 feet of navigable clearance, remains in place and continues to provide beneficial habitat for a large number of pelagic and other reef fish originally associated with the platform. Also, the upper portion that is removed provides an equal or slightly lower profile to compliment the standing section, and increases the overall surface area of the structure for habitat enhancement. This type of removal requires a wavier from the Minerals Management Service. The waivers are required, since existing regulations require severing of the jacket legs 15 feet below the mudline. For deep water operations, this method significantly reduces the removal costs and risks for divers (Jan Culbertson, personal communication).

Figure 2. Dauterive 2000.



To study the effect reefing a platform plays on the surrounding fish communities, Wilson et. al. observed the communities associated with a toppled, partially removed, and standing platform. The standing platform, HI A350, was characterized by the same type of community of fish that Stanley and Wilson (2000a) observed at other structures in similar water depths such as GI 94. Time of day and depth stratum affected the fish community, as had been reported previously (Stanley and Wilson 2000a); however, the density patterns exhibited at different times of day do not follow a predictable pattern and are likely site-specific. Fish density and size are greater near the surface than the bottom of standing oil and gas platforms. Results revealed approximately 12,000 fish around HI A350, which is consistent with the estimates of fish communities reported by Stanley and Wilson (2000b, 1997) for platforms in similar water depths. They reported 10,000 to 20,000 fish inhabited each of the four oil and gas platforms they had studied. Species composition at HI 350 was also similar to that reported by Stanley and Wilson (2000a) and included important to recreational and commercial species such as amberjack, red snapper, creole fish, triggerfish, and almaco jack.

Density at the two artificial reef sites ranged from 0 to 0.7 fish/m^3. The partially removed platform had a slightly higher fish density than the toppled platform with overall mean values (within 20 m of each site) of 0.002 vs. 0.0015 respectively. This translates to approximately 1,978 and 1,742 fish at the two sites. Both sites had highest fish densities near the bottom, which is opposite the pattern at the standing platform. However, the partially removed platform, HI A355, also had higher estimated densities near the surface resembling fish distribution at a standing platform. There was little difference in species composition between the two reef configurations. ROV surveys of HI A355 in June 1999 and in June 2000 indicated that red snapper and amberjack were the two most abundant species both years, and together they made up over 70 percent of the fish community. Similarly, the survey of WC 617A, conducted in June 1999, indicated that amberjack, almaco jack, and red snapper were the most abundant species. Species composition at the two reef sites was similar to species composition at the lower portion of HI A350 and to previous studies by Stanley and Wilson (1997, 2000a). It is of interest that the red snapper and amberjack populations at the two reef sites were similar in number to the populations estimated to be at the standing platform in similar water depths. These artificial reef sites, like their platform predecessors, have significant fishing value since majority of the species associated with these reef sites are targeted by commercial and recreational fisherman. When a standing platform is converted into an artificial reef, it appears that pelagic planktivores make up the greatest biomass that is lost while the more desirable recreational species are retained.

Target strength data revealed information on the size distribution of fishes associated with these sites. In general, slightly larger fish are associated with a standing platform, particularly near the middle water column, compared to a partially removed or toppled platform, where they are larger over the reef sites and near the surface (Stanley 1994). The larger species were shown to be pelagic planktivores and piscivores by Stanley and Wilson (1997).

Results revealed there were significant effects of orientation and distance at both artificial reefs. The probability of finding a fish at WC 617A was highest over the platform and within 30 m of the reef; which is similar to the survey of EI 366 done by Wilson and Stanley (1994). This is similar to a reported 16 m area of influence by Stanley (1994) at platforms from 50-100 m depths. Platforms appear to have a finite reef effect that does not extend beyond visual range of the associated species. The probability of finding a fish at HI A355 was highest around the sides of the platform and within

30 m of the structure, although fish biomass, and therefore density, were highest directly over the reef site. Wilson and Stanley (Unpublished) reported higher numbers of fish directly over another artificial reef (EI 366), and reported the same high fish densities within 30 m of the artificial reef. The difference in orientation (north, south, east, and west) at HI A355 could be related to a section of the jacket being placed roughly 90 feet away from the partially removed platform on the southeast side. It is also possible that the small foot print of HI A355 confounded analysis.

Though Alabama does not have legislation creating a Rigs-to-Reefs program similar to Louisiana, Texas, and Mississippi, the state has arranged for the deployment of four additional platforms since the Marathon platform was deployed in 1983.

<u>Benefits</u>

- Oil and gas platforms have proven to be excellent artificial reef material. The National 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 (Stone 1985), and oil and gas platforms appear to 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 well 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). The steel members of the platform provide the necessary hardbottom 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, since generally only the submerged jacket of the structure or that portion of the platform that has never come in contact with hydrocarbons is used.

- Oil and gas platforms are also very durable and stable, rarely if ever moving from where they were placed. Side-scan sonar surveys of two oil platform artificial reefs in areas offshore Louisiana affected by Hurricane Andrew, a category 4 storm, were conducted by Louisiana State University in 1993, and indicated no detectable movement (Wilson and Stanley 1994).

- These platforms also appear to be relatively durable. 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 approximately 300 years.

- These platforms are also readily available, with over 3,992 in the Gulf of Mexico alone. However, it is not always economical to convert a platform into an artificial reef. The size of the structure, water depth, distance from shore, proximity to final reef site and resale value will dictate whether or not an obsolete platform should become a reef (Pope 1988). From 1987 to 2001, of the over 1,600 platforms removed from Louisiana and Texas waters, only 167 platforms, or approximately 11%, became artificial reefs (Kasprzak 1994). However two-thirds were in waters less than 100 feet and were unavailable to reef programs (Kasprzak 1994).

- Partial mechanical removal methods using divers or abrasive cutting tools have provided a method for transferring platforms into reefs with the highest profile in the water column with the least impact on the natural resource, and decrease the dangers to sea turtles and marine mammals.

Drawbacks

- There are several disadvantages to using oil and gas platforms as artificial reefs. Individual Coast Guard districts are responsible for developing marking guidelines for obstructions to navigation under 33 CFR 64.30. For instance, the 8th Coast Guard District, with jurisdiction from western Florida to the Texas/Mexican border, requires a minimum of 85 feet of clearance over the obstruction to be exempt from maintaining expensive lighting requirements. An exemption of the lighting requirements may be granted on a case-by-case basis if at least 50 feet of clearance is maintained. Since many of these structures have a maximum relief of at least 50 feet, a minimum of at least 100 feet of water is required to properly site and maintain oil and gas platforms as reefs. In Louisiana, the 100 foot contour exists between 30 to 75 miles offshore, making some reefs inaccessible to many fishermen. In Texas, the 100 feet contour exists between 30 and 75 miles offshore along the upper coast and 15 miles along the lower coast.

- Another disadvantage is the expense in removing these structures. Derrick barge rates currently run between $50 thousand to $100 thousand a day depending on the lifting capabilities of the barge. The size of the structure to be removed determines the size of barge required. This however, may be turned into a benefit if the savings realized, by not having to take it to shore, can be shared with the entity accepting the ultimate responsibility for the structure. To date, however, the oil and gas industry has dealt only with established state recognized reef programs. In some areas permitting and meeting state law requirements and the ability to satisfy liability requirements have prevented fishing clubs and private individuals from acquiring platforms as reefs.

- A third disadvantage is the method of removal. Currently, state-of-the-art techniques required to sever these structures from the sea floor involve the use of explosives. The concern over the use of explosives stems from their potential impact on endangered sea turtles and marine mammals. To address this issue, MMS and NMFS require a review of the operators' abandonment plan that is required under Section 7 of the Endangered Species Act. Recently the Gulf of Mexico Fishery Management Council became concerned about the impacts of the use of explosives on red snapper.

Considerations

- Developers of artificial reefs should check with local Coast Guard districts for marking requirements and evaluate their coastal bathymetry to select sites of sufficient water depth to obtain appropriate clearances. In some cases the water depth needed to deploy these structures may be too far offshore to achieve desired results. Since these structures should be considered permanent (lasting up to 300 years) when placed on the bottom, consideration should be given to selecting sites where the Coast Guard may consider waiving the buoying requirements once the site is plotted on a navigation chart.

- Distance towed plus size of the structure must be evaluated to determine cost effectiveness of the project.

- A mechanism should be established to clearly transfer title from the donor to donee. The transfer of ownership must absolve the donor of all liabilities once possession is taken, otherwise the oil and gas industry would be unlikely to participate. In addition, a portion of the savings realized by the oil and gas company's participation should be placed in a dedicated fund for the long-term maintenance and monitoring of the reef.

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2.4 *Aircraft*

Overview

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 video 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 bank 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).

Individual plane wrecks, at least on a temporal basis, may attract a large biomass of pelagic fish. An A-7 jet, attempting a carrier landing in 1982, crashed and landed upside down in 110 feet of water with tail hook and landing gear extended. Large grouper were seen under the wings, and red snapper were immediately above the wreck. A loggerhead turtle and a barracuda were also seen. Circling higher in the water column above the wreck were scores of large amberjack (Mike Hendrix, personal communication).

References to other aircraft wrecks appear in several fishing "hot spot" publications targeting recreational fishermen and divers. Three aircraft wrecks off northeast Florida (Duval, St. Johns Counties) in 70 to 106 feet of water are listed in Pybas (1991). Rhinehart (1991) lists 17 known aircraft wrecks for Florida concentrated primarily in central and northern Florida Gulf waters. Stebbins and Stebbins (1990) lists 22 wrecks or partial aircraft wrecks out of 2,916 wreck and reef sites from Texas to Maine, mostly in Florida. Tierce (1990) lists 11 aircraft wrecks out of 732 fishing "hot spots" located off Destin, Okaloosa County in northwest Florida. The highest number of local aircraft wrecks is found in Tierce (1991) where 40 aircraft and four additional possible aircraft wreck sites are listed out of 589 fishing locations between Pensacola, Florida, and Gulf Shores, Alabama. The aircraft wrecks in the above references were chiefly in 60 to 155 feet of water and apparently identified by divers. Other aircraft wrecks exist beyond diving range but are not specifically identified as such in the popular literature. At least two WWII aircraft sit in 515 to 518 feet of water off Key Biscayne in southeast Florida (Mitch Skaggs, personal communication). Although the aircraft wrecks were largely unidentified as to type or noted as "World War II plane wreck" or "old fighter", some were listed as PBY's, Hell Cats, Trainers, torpedo bombers, Corsairs, A-4 and A-6 jets, P5M seaplanes, C-47, B-27, C-54s, F-84s and F-4 Phantoms. Ocean crashes of more modern military aircraft (F-16 fighters) in more recent times on both the Gulf and Atlantic coasts of Florida are known to some members of the recreational fishing and diving community (Kent Smith and Larry Beggs, personal communications).

Publicly documented aircraft wrecks off other Gulf and Atlantic Coast states in less than 175 feet of water are apparently uncommon. Some un-salvaged private plane crashes have occurred in areas like Long Island Sound in New York, but locations of these sites remain closely guarded since they attract fish (Steve Heins, 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.

As of 2002, 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 15 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

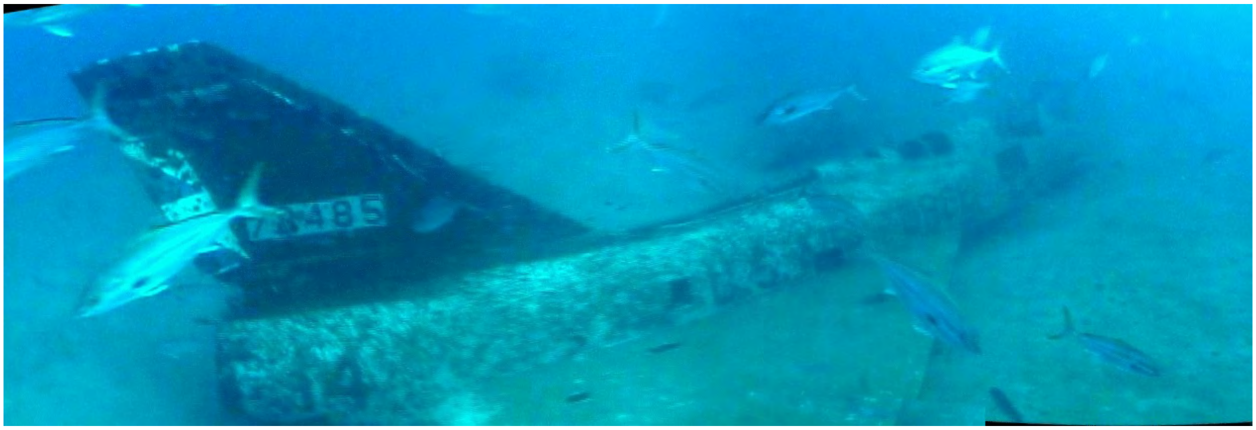
There are some records of aircraft placed in less than 100 feet of water that have survived at least a decade. F-101 and F-102 jets, a navy T-33 trainer, and a Sikorsky helicopter, all placed off Bay County, Florida in 60 to 70 feet of water, survived as fishing and diving sites at least 10 years (Danny Grizzard, personal communication). The current 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). As of 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).

First hand accounts are currently unavailable on the status of two F-4 Phantom fighter jet fuselages sunk in 80 feet of water off Miami-Dade County, Florida in 1981. Technically, the status of these planes is unknown. However, second-hand information received by Miami-Dade County Environmental Resources staff, but unconfirmed by the County, suggests that the planes still exist, and may have shifted location during a storm event. They reportedly are being utilized as private fishing and diving sites, but no longer can be located at the publicly advertised coordinates (Tim McIntosh, 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 June 1995. An additional two A-4 fighters were deployed during the same time frame in 53 feet of water. One A-4 North Carolina aircraft was substantially damaged when a load of concrete material was deployed on top of it (Kurtis Gregg, personal communication). As of summer 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 ft. 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 ft, *in situ* observations to verify individual aircraft locations are few, and limited to qualified technical divers. As of 2002, many of the 26 aircraft have 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 around the aircraft 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. As of 2002, the aircraft are still in place. Due to shallower depths and closer proximity to shore, the aircraft are more frequented by divers and fisherman than the deeper water aircraft off Jacksonville (Edward Kaulakauskis, personal communication).

Commercial and Military Cargo Aircraft and Bombers

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).

In 1992 a cargo plane was forced to ditch intact in shallow waters several hundred yards offshore of Broward County, Florida. A small storm moved through before salvage efforts could be completed. The sunken plane broke up and scattered its load of brassiere straps across the adjacent live bottom seabed (Ken Banks, 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 recent evaluation. The independent pieces continue to provide some degree of fish attraction. Miami-Dade County Department of Environmental Resources Management (DERM) staff report that as of 2000, the nose section and majority of the fuselage were still on site with the detached wings also in the general vicinity. The current whereabouts of the tail section are 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.

Current Status (2003) of the Use of Aircraft as Artificial Reefs in the United States

No known state sponsored and funded aircraft deployments for purposes of artificial reef construction occurred in the U.S. between 1996 and 2001. Between 1997 and 2001 only one aircraft deployment, locally funded and privately sponsored, (P2V-3 bomber fuselage) took place (Florida) over the misgivings of the Florida state reef program based upon prior experiences as outlined in an earlier version of this document. Despite the extensive volunteer time, money, effort and good intentions involved, the local project was a dramatic failure. Between November 1999 and May 2001, Florida's artificial reef program turned down separate offers to donate to the state reef program a stripped out DC-9 fuselage, three civilian twin turboprop aircraft fuselages, and two Boeing 747 commercial aircraft fuselages.

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 overland 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 who 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 individuals 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 life span 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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2.5 Railroad, Subway, and Street Cars

Overview

During the 1980s, North Carolina, Florida, Alabama, Mississippi, and New Jersey experimented with the use of obsolete railroad boxcars 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 boxcars (10 each at 21 different sites) at depths between 35 and 85 feet (Steve Murphey and Kurtis Gregg, personal communications). In 1987 and 1988, Lee and Sarasota Counties, Florida sank 48 and 40 boxcars, respectively, for a total of six sites. During June 1988, in northern Gulf waters off the western Florida panhandle, Okaloosa County deployed 16 boxcars in pairs 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 boxcars 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 boxcars, eight each at two 100 foot locations (Guy Hunt and CSX Reefs, personal communication) off its coast (Walter Tatum, personal communication and Lukens 1993). During the same year Mississippi sank at least four box cars at the FH-1 reef site in 65 feet of water (Lukens Consulting 1995). Following a five-year hiatus in boxcar deployment, Lee County, Florida, in January 1994 as part of a $65,000 project, procured 60 steel CSX railroad hopper cars placing 20 in 70 feet of water and 40 in two groups at 86 to 90 feet. Twenty-four of these were stacked, and 16 were not (Steve Boutelle, personal communication). No railroad cars are known to have been deployed as artificial reef material nationwide since 1994.

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 was 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 railroad hopper cars discussed above. 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 the observations, an hypothesis was developed that the 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 visually inspected by Lee County artificial reef staff in December 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. In early March 2002, the Lee County reef coordinator fished the site and caught his bag limit of 14-18 inch long gray snapper (Chris Koepfer, personal communication). The “Charlies #1” 90 feet deep hopper car pile was inspected on April 21, 2003, nine years post deployment. Gaping corrosion holes had appeared in the metal sides of the cars, resulting in the physical loss of about 50% of the side plating surface area of cars 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 boxcars (due to compartment dividers) may provide longer lasting vertical structure. The North Carolina hopper cars continued to provide some fish attraction 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 were attractive to large numbers of bait fish. Lobster, grouper, vermilion snapper, and amberjack were noted on the north Florida box cars (Danny Grizzard, personal communication). In the initial six months after an August 1989 deployment of box cars in 100 feet of water off Alabama, remote video from the NMFS showed box cars intact after six months (Walter Tatum, personal communication); however, recent anecdotal observations indicate that these boxcars have likely collapsed (Steve Heath, personal communication). Box cars deployed off Sarasota County, Florida supported mangrove snapper, lane snapper, goliath grouper, white and tomtate grunts, juvenile amberjack, and queen angelfish (Jon Dodrill and Tom Maher, personal communication).

From the perspective of the marine contractor engaged in the Okaloosa County boxcar deployment, "the boxcars were an extremely efficient item, from the standpoint of time required to process and deploy. The boxcars arrived at the city docks, were lifted onto a barge, and deployed in the Gulf in a very short period of time, which translated into low transportation costs" (W. Ted Brown, 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 boxcars in North Carolina occurred within two years post deployment resulting in only about half of the sites ultimately 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 boxcars were wood and steel and, at present, provide little or no profile. As of this writing, a few end panels were still standing. The remaining 10%, which were steel hopper cars, have remained intact as of 1997. Finding groups of ten boxcars after collapse has, however, proven to be worthwhile, if difficult, for North Carolina fishermen, since demersal target species are usually larger and more abundant on boxcars 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 boxcars were placed in 72 feet of water in eight sets of six cars each. Six months after the boxcar deployment, Chuck Listowski, the Lee County Artificial Reef Coordinator at that time, wrote: "Until an investigation or study can be done to determine that boxcars are, in fact, a viable artificial reef material, we will not advocate their use at this particular site" (Lee County Department of Community Services, Division of Marine Sciences, personal communication to Virginia Vail). A 2003 status report on the Lee County CSX box cars were 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 boxcars in both the Lee County and North Carolina projects. Similar degradation of the wood components was noted in the case of a wood and steel tram car deployed in Moreton Bay, Queensland, Australia, in 1986. The tram was reported as badly deteriorated (no time frame given), with only the steel portions of the structure remaining intact (Branden et al. 1994).

Aware of North Carolina's experiences with collapsed box cars, New Jersey's Division of Fish, Game, and Wildlife cut the horizontal side walls and end panels off 31 army ammunition boxcars prior to the their deployment in 75 feet of water in 1997. They deployed only the chassis and wheels as reef material. Boxcars used in New Jersey did not require additional concrete ballasting of the chassis, since concrete decks existed. No follow up monitoring was conducted and no further box car deployments are anticipated for New Jersey. The time and labor expended on this project was not worth the effort (Bill Figley, personal communication).

After six years, some steel boxcars off Sarasota County, Florida experienced collapsing roofs and long walls, while the end panels remained standing (Jon Dodrill, personal communication). One set of 10 boxcars in 50 feet of water at the M-7 reef off Sarasota, Florida were fully collapsed with walls, providing no relief. Only parts of the chassis were visible (Mike Solum, personal communication). Another pair of Sarasota County boxcars were noted to have only an end panel of each still standing after six years. Depending on how the sides collapsed, they provided a lean-to shelter for large fish (Goliath grouper) or resulted in fish as small as 10 inch long lane snappers having to turn sideways to slip under one of the walls lying nearly flat on the substrate. Nevertheless, even the nearly flat wall was 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 are now disappointed that the cars all 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.

More recent information received from charter diving operations in Bay and Okaloosa Counties (Northwest Florida) indicates that as of 2002, all box cars visually observed have fully collapsed (Nancy Birchett, Mark Christy, Mike Eller, and Danny Grizzard, personal communications). By 2002, 14 years post deployment, local divers reported that very little remained of Okaloosa County box cars placed in 70 to 90 feet of water. In January 2002, Okaloosa County contracted a charter dive operator to go to box car sites and provide an assessment. In his report, Christy (2002a) stated: "I searched on four different sites for the box cars, and no luck. Prior to 1995 these sites had very little profile left and all the ones that I did dive on, the sides had fallen in. So it is no surprise that they are no longer visible. Inshore box cars off Fort Walton and Destin (Okaloosa County, FL) continue to serve as fishing sites but have such low relief that they are undetectable to the average boater. They must be fished with very precise GPS readings. Few people apparently utilize the collapsed box car sites. They yield large snapper and gag but low numbers at any one time. Only the collapsed frames remain with the fish moving in and out from under the frames (Mike Eller, personal communication)."

A 2001 inspection of a 14 year old boxcar in 73 feet of water off Bay County revealed the boxcar 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).

Boxcars 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 boxcar 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 sea floor, but all four sides were still attached (Jack Spey, personal communication). Anecdotal 2002 reports from fishermen occasionally fishing on some Okaloosa County Florida box cars at depths of 115 feet suggest that there is some vertical relief after 14 years, and that the end walls may still be standing. (Mark Christy, personal communication). This was not born out by actual observation of boxcars at slightly shallower depths. Christy (2002b) reported on an April 2002 investigation of a box car in 98 feet of water and one in 112 feet of water off Okaloosa County. Video film footage he shot 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.

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 of box cars in Northwest Florida at depths of 70-112 feet 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 boxcars deployed inside a barge offshore Mississippi in 1986. As the barge was sinking, it overturned, spilling the four boxcars out onto the sea bed. The first measurements of the height of the boxcars were taken in 1989, and the second measurements were taken 2.5 years later. Those data indicate that the boxcars 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 boxcars still on site, with some minor movement of the boxcars to the east. The side scan sonar data indicate that the boxcars sides have still not collapsed as of 2001.

Subway Cars

Subway cars have not been used extensively in the past as reef material, though they may be offered to state reef programs increasingly in the future, as cars built in the 1950s and 1960s are retired from service. In 1990, five subway cars were placed on a New Jersey reef at a depth of 65 feet. Only the car bodies were deployed; wheel trucks were 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. The NYCTA offered to clean and transport the cars. 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 to include 1,100 cars. As of 2003, 517 cars have been deployed in 85 feet of water on one Delaware site. The cars support an invertebrate assemblage and dense populations of seabass and tautog.

South Carolina has deployed 200 NYCTA subway cars on reef sites ranging from 90 to 120 feet deep. After only three months in the water, divers found a diverse array of fish species inhabiting the cars. Other states that have also recently received subway cars from New York City include Virginia, with 150 cars, and Georgia, with 50. The 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, has shown 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.

Streetcars

During September 1958, six wooden streetcars 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 streetcars within the first 25 months. In 1960, two additional streetcars were placed on reefs at Malibu and Santa Monica, both in Santa Monica Bay. Subsequent surveys conducted four and one half 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

- Boxcars can easily be cleaned compared to other materials, in contrast to some steel hulled vessels where petroleum products and other hazardous materials may require more complex and costly cleanup procedures. Some cutting of holes for air vent purposes or lifting by crane may be required. These holes will also provide for better water circulation in the boxcar's interior.

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

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

- Boxcar vertical profile that exceeded 10 feet appeared, at least initially, to be attractive to both pelagic and demersal fish species. Loss of vertical relief through side wall collapse may continue to provide some minimal low relief, hard bottom/ledge habitat for as long as 14 years, the extent of which is dependent on how the side walls randomly collapse and fall on each other and whether the structures lying flat on the bottom become buried. 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 boxcars.

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

- Subway cars have shown 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 are available in large numbers.

- Subway cars are 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

- If the objective of box car deployment is to provide vertical relief to attract pelagic fishes, an interesting dive site, or an easily locatable public fishing site, then the achievement of these objectives with box cars is not sustained over an extended period. Most of the vertical relief on steel walled boxcars appears to be lost within four years with complete wall collapse and loss of most nearly all vertical relief at depths of 90 feet or less occurring by 14 years. The initial structural failure appears to begin with the collapse of the roof and one or more of the side walls, usually the long horizontal walls, which have less structural reinforcement and thickness than end panels. The collapse of the walls may be due to weld-joint failure resulting from surge/current activity (divers have reported seeing boxcar walls flexing in a current), or physical impact with the bottom if allowed to free fall from the barge.

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

- Boxcars 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 begun, and the car can no longer keep cargo dry. The heaviest gauge steel (wheels, axles, wheel frames) is normally removed from the boxcar for further use by the railroad.

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

- Availability of boxcars may be unpredictable. Access to surplus boxcars is dependent on the proximity of the rail line and a railhead near a marine staging area. Some railroads, like CSX, may have thousands of surplus boxcars, while others may have none available or no cost effective means to transport the surplus box cars they do have to a prospective reef builder.

Considerations

- Combination wood and steel surplus boxcars 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 boxcars (more than 30 per site with close spacing) may still provide years of fishing opportunity, even following boxcar 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 boxcar. 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, after nine years in the marine environment.

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

- The use of subway cars is relatively new, and monitoring of the associated asbestos, durability, and associated organisms should continue.

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2.6 *Designed Structures*

Overview

Although secondary use materials still predominate artificial reef development efforts, 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 began directed 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'x4' log huts built and deployed by South Carolinians in the late 1830s to improve fishing for sheepshead (McGurrin 1988) and bamboo frames filled with sand bags and other materials to improve catches of grunts off the Japanese coast (Vik 1985).

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 (Hickson and Beets 1989; Kruer and Causey 1992; Bortone et al. 1994; Eklund 1996; Lindberg and Loften 1998; Sherman et al. 2002). Beginning in the early 1990s, Florida's state artificial reef grants-in-aid program began to fund designed modular alternatives to the use of other materials of opportunity such as washing machines, fiberglass boat hulls, and auto bodies, whose use was being phased out in that state. Some of the early prototype structures with lighter weight plastic or PVC components did not hold up in ocean conditions. Failures included delamination and movement of plastic corrugated sheeting from AquaBio units (Turpin, 2001b), breakup and movement of recycled plastic frame modules (Horn 1995; Maher 1996; Turpin and Bortone, in press), and disassembly and loss of PVC pipe structures, possibly due to activities by vandals removing stainless steel hardware (Roger Schoefield, personal communication)

Experimentation with the use of secondary use material fabricated into modular units continues. 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.

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 (Grove et al. 1991). Designed, prefabricated reef units began to be developed and used in the early 1950s (Sheehy 1982). In contrast to earlier structures, these engineered configurations no longer incorporated secondary use materials for construction, but rather used pre-stressed 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 are also selected for resistance to corrosion/abrasion and other durability considerations, as well as strength, structural/design demands, and biological compatibility (eg., 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 service, 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 (1985).

Experimentation and small-scale deployment of specifically designed artificial reef structures began in the United States in the late 1970s, remaining 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), the use of Japanese designed artificial reef structures in the United States also remained limited, largely due to the high costs associated with the acquisition of the units, the low availability of units and unit suppliers domestically, and the continued abundance of secondary use materials. Despite the lack of sales, however, interest was generated within the United States regarding Japanese and Asian artificial reef technology and designed structures. Both 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 in the majority of artificial reef construction projects, coastal states have, in recent years, begun utilizing designed reef structures at increasing levels to carry out artificial reef development objectives. This expanded reliance upon designed reef materials is due, in part, to the development of more readily affordable and seemingly dependable designs, as well as recent increases in funding levels of some artificial reef programs, and the loss of previously relied-upon supplies of certain materials of opportunity.

In 2001, Maher surveyed several Atlantic, Gulf of Mexico, and Caribbean artificial reef development programs on their use of designed "modules" and similarly designed structures 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) have never used designed artificial reef modules within their public artificial reef programs…..albeit a number of various module types have been deployed through the private reef-building program in Alabama." In addition, Alabama has conducted comparison studies using several module designs to determine if some perform better than others.

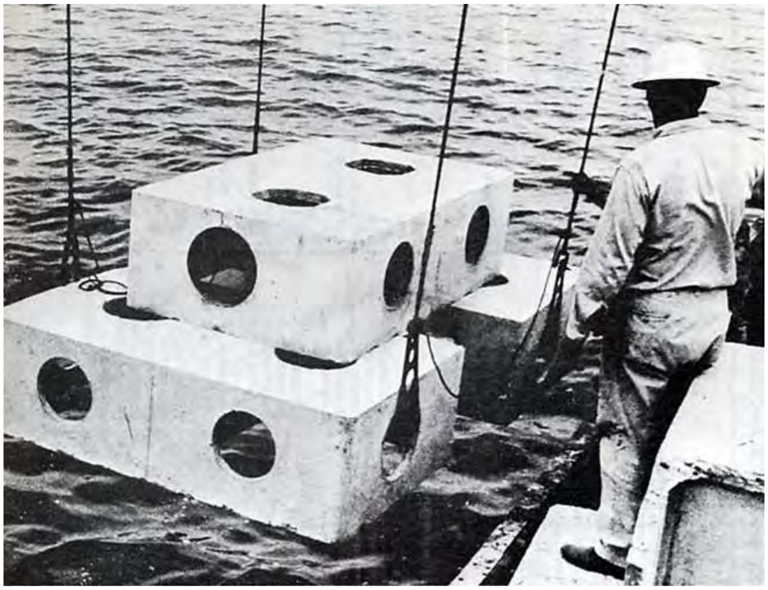
The rapid increase in the utilization of designed artificial reef structures is likely due to a number of factors. The most important of these has been the programmatic and commercial manufacture of several designed artificial reef structures that are affordable and readily available, both important considerations in reef development program planning and budgeting. 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 loss of previously dependable sources of reef materials (eg., 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.

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).

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).

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 off 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 (eg., vessels).

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 limerock boulders, and backfilling with carbonate sand to reestablish 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).

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 1994; Gregg 1995; Florida DEP 1996; Turpin 2001a; 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.

Benefits

- 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, steel, or heavy-duty plastics 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.

- Currently there is a relative shortage of well-engineered, tested, and affordable designed reef structures available to reef managers; although, with competition, the variety of manufactured units may increase and associated costs decrease.

- 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.

- Available designed structures have not been uniformly tested and their performance proven/documented under adverse physical conditions, on varying substrates, and throughout offshore and estuarine waters along the U.S. Gulf of Mexico and Atlantic coasts.

- Without documented performance applicable to local conditions, reef programs may not be able to justify additional expenditures for designed structures.

- 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 nation-wide 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 followup 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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2.7 *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 REEFEX. REEFEX ,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 REEFEX 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.

REEFEX '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 sea water was an acceptable method of partial demilitarization. A major U.S. Army surplus property depot, located, in northeastern Alabama at the Anniston Defense Depot, held more than 3,000 of the 6,000 decommissioned MBTs in inactive status in the Continental U.S. These tanks, now vulnerable to new anti-tank weaponry technology, had been replaced by the larger, faster, more maneuverable 120mm 70 ton M1 Abrams MBTs. The obsolete 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 decommissioned tanks included some M48 tanks but were mainly M60A1-A3 Patton tanks built as the Cold War MBT mainstay between 1960 and 1983. The M60 MBT was deployed to Vietnam but first saw formal extensive combat when used by Israel in the 1973 Yom Kippur War. M60 MBTs were also effectively used as a front line combat tank by U.S. Marines during Operation Desert Storm against Iraq in 1991. As of 2002, twenty allied countries around the world still utilized the M60 MBT (Popular Science 2002).

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. In 1993, the average scrap value of excess MBTs was less than $2,000 per tank. Four inch thick hardened steel tank armor made the MBTs difficult to cut up and required demilitarization and shipment by rail from Anniston, Alabama to distant specialty scrapping facilities in the Midwest (Currie 1994). The DLA 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 that had been permitted by the Army Corps of Engineers (COE) pursuant to its responsibilities under 33 USC Section 2104. 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, REEFEX '94 a military program, was organized.

REEFEX '94 Environmental Planning

In a January 13, 1994 meeting at the DLA on REEFEX, the EPA committed to preparing the federal requirements for placement of MBTs in the marine environment. EPA followed this up with a February 10, 1994 letter to the DLA discussing banned and restricted materials to be removed from MBTs 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 tank (Muir 1994a). Based upon the guidance provided in this letter, a detailed cleanup checklist was developed. The list had to be certified 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; 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 originating from Anniston were to be individually inspected at Anniston 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).

Following a March 15, 1994 on site meeting and inspection of representative MBTs at Anniston Army Depot prior to REEFEX '94, the EPA reiterated its position on National Environmental Policy Act (NEPA) Requirements: 1) EPA is opposed to dumping of anything in the ocean that would harm or endanger the marine environment; 2) EPA opposes dumping of anything, harmful or not, just for the purpose of waste disposal, and 3) the EPA takes a very strong stand on the need for replacing waste disposal with recycling as part of the Administration's pollution prevention strategy (Muir 1994b).

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. A properly located reef having long-term viability was necessary for the latter requirement. 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. However, 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 second 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 REEFEX ’94 an Environmental Assessment, *Environmental Assessment for Use of Obsolete Military Tanks for Artificial Reef Construction*, was prepared by DLA and the Army Materiel Command for the deployment of 106 MBTs in federal waters off Alabama. This was later followed by a 1995 Environmental Assessment for the expanded Gulf and Atlantic coast-wide national REEFEX 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 REEFEX 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 REEFEX 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 1995). Joint Task Force 310 was formed to implement REEFEX ‘94 and was commanded by Col. Thomas M. Ogles, Jr. Col. Ogles stated that the Army’s objective was to provide individual and collective training, including joint training with other services and military personnel from other countries. REEFEX ‘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 in the cleaning, demilitarizing, transport, and deployment of obsolete military hardware for artificial reef development (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).

REEFEX ’94 culminated in three phases of multiple successful deployments of 106 MBTs in groups of 1-3 off Alabama. The initial phase was a pilot deployment of six tanks placed individually by crane on the sea floor in early June, 1994. The expense of using an 800 ton crane ($2,500 per hour) 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 “on the fly” without the barge having to anchor. (Snyder 1994).

REEFEX ’95

The planning and operational success of REEFEX ’94 in the Gulf of Mexico off Alabama provided the impetus for a national REEFEX ’95 effort. Gen. Leon E. Salomon, commanding the U.S. Army, Materiel Command, stated in a REEFEX press release: “Headquarters, Department of the Army approved the plan for fiscal year 1995: AMC will prepare and transport approximately 500 excess battle tanks/combat vehicles from selected Army depots to designated CONUS seaports, for sea movement to off-shore artificial reef sites, not later than 30 September 1995. AMC will also develop plans and coordinate funding for the continuation of this mission in fiscal years 1996-1999.” Approximately 1.5 million federal dollars was available for REEFEX ’95 through the Civil-Military Cooperative Program. State supplemental assistance was strongly encouraged (Walter Tatum, personal communication). REEFEX ’95 was initiated off Florida’s Gulf coast with 40 M60 MTBs evenly distributed in units of 1-2 off Escambia, Okaloosa, and Bay Counties in the Florida Panhandle on December 18-20, 1994. This was followed by another 40 tanks evenly distributed ten to a county in a variety of configurations among four southwest Florida gulf coast counties of Hernando, Pasco, Pinellas, and Sarasota on April 21, and 22, 1995.

During this initial phase of REEFEX ’95, Florida contributed $190,000 to assist the Army with this 80 tank gulf coast deployment effort at a cost of $2,375 per tank (Florida Fish and Wildlife Conservation Commission Grant Contract Database). In an October 28, 1994 letter from DLA chief of the Storage Policy Team, James Sanchez, to Florida Governor Lawton Chiles, Mr. Sanchez reported that the cost to the Army to clean, transport, and deploy an MBT to Florida was approximately $8,000 per tank, excluding Florida’s contribution. Another $29,372 was expended by Miami-Dade County on two MBTs for cleaning, transport by rail from Alabama to Miami, FL and subsequent deployment in late July 1994. The DLA charged Dade County $2,500 per tank for cleaning and loading the tanks onto a railroad car, and the commercial rail carrier charged $2,086 per tank for the shipping. In contrast, Alabama was required to pay no costs for tanks originating from the same army depot during the same time period. (Jon Dodrill, personal communication).

All tanks prepared for Florida were jointly inspected at Anniston 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 COE. REEFEX activities then bypassed Florida east coast counties with proposed pending projects, and shifted activities to other states. In addition to MBTs, two additional armored vehicle types, armored personnel carriers (APCs) and Sheridan tanks, were subsequently deployed.

First used in REEFEX '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 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 introduce the foam into the marine environment. The foam flotation, along with an inflatable collar, allow 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, which is before the aluminum side walls corrode. 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. Table 3, provides a breakdown of the distribution of military hardware made available to the Atlantic and Gulf states through REEFEX '94, '95, and subsequent independent state initiatives. When the federal REEFEX component of the Civilian-Military Cooperative Program was terminated September 30, 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. The state of South Carolina initiated its own version of REEFEX through the use of surplus armored vehicles from the South Carolina Army National Guard (SCARNG). From 1997-1999 obsolete armored vehicles, including M60 battle tanks and M113 armored personnel carriers, were de-militarized, cleaned, and transported by

SCARNG and deployed on eleven South Carolina artificial reef sites (Robert Martore, personal communication). New Jersey and other mid-Atlantic states engaged in similar independent activities where the obsolete combat equipment and willing National Guard units were available. In 1998, as part of a program called Civilian-Military Innovative Readiness Training (CMIRT), the Department of Defense released over $1.45 million to New Jersey's National Guard and other guard units to continue cleaning and deployment of M60 MBT's, M113s, and half a dozen tank salvage vehicles off mid Atlantic coastal states. Where the original REEFEX program was intended to train Army reserve units, this program was designed to train national guardsmen to increase skill levels beyond their normal weekend training while at the same time providing a benefit to civilian agencies. The funding was only available to interested National Guard or other military units (Col. William Lowe, Department of Defense, Personal Communication with Jon Dodrill).

Table 3. Type and distribution of military hardware used by the states as artificial reef material (1994-2003).

STATE	MBT[1]	APC[2]	SHERIDAN
Louisiana	0	40	0
Alabama	106	0	0
Florida	82	0	0
Georgia	55	0	0
South Carolina	18	190	0
Virginia	0	8	18
Maryland	2	24	20
Delaware	2	25	19
New Jersey	26	44	48
New York	0	8	18
Total	291	339	123

[1] MBT = Main Battle Tank

[2] APC = Armored Personnel Carrier. Some of the APCs are also missile launchers.

In northwest Florida in 2001, Okaloosa County artificial reef staff partnered with Eglin Air Force and deployed multi-ton MBT turrets from tanks destroyed in hard target weapons practice. MBT turrets with cannon barrels intact were deployed upright in groups of three, with 24 placed at a depth of 120 feet and 21 deployed at a depth of 75 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).

Military Hardware Monitoring

Storm Impacts

M60 MBTs are 10.75 feet tall, 27 feet long, and 11.9 feet wide. They weigh about 42 tons empty with the engine and other material removed. They are proven to be stable on the ocean bottom. For example, in June and July of 1994, 106 MBTs were sunk in 85-110 feet of water in the general permit areas offshore Alabama. During October 1995, Hurricane Opal hit the Florida panhandle, just to the east of Alabama. A number of small artificial reefs, located in the Alabama general permit areas, were moved by the storm surge. No longer able to rely on their traditional small reef sites, because of their displacement, the fishermen turned to the tanks that had been deployed in the same areas and found that not only had they not moved, but they had abundant fish populations. This was particularly significant for the charter boat fishery, which was able to use the REEFEX 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 (October1995) 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) on November 9, 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 tanks 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. A nearby 1.5 ton, hollow, four-sided, concrete prefabricated artificial reef unit deployed in 1993 at the same depth as the tank was observed flattened from a vertical relief of five feet to about six inches (Horn et al.1995).

Observations of MBTs and APCs on the sandy sea floor off New Jersey indicated that all vehicles are stable and their tread base resists subsidence. Vehicles are also colonized by large numbers of fish and lobster (Bill Figley, personal communication). Upright MBTs off Sarasota County (SW Florida) in an April 12, 2001 roving diver fish census revealed twenty species of fish that included such grouper species as gag, red grouper, scamp, 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).

The earliest M60 tank deployments off the Florida Panhandle indicated that all MBTs did not land in an upright orientation. The seventh tank deployed off Pensacola on December 18, 1994 was spot checked 20 minutes later and found to be lying upside down on its turret with about two feet of the turret and the barrel buried in the sand. Bank sea bass, lane snapper, and sand perch were already present at the tank after only a few minutes. This tank was deployed close to some recycled plastic "wood" frame modular units and automobiles, both deployed as state grant study projects one to two years previously. A washing machine of unknown deployment date was also visible from the tank (Maher and Horn 1994). None of these materials except for the tank were in existence as of 2000. This tank and six others deployed in 80-82 feet of water with it were documented intact in 2000 without movement. One tank, 7G4, was recorded in 2000 to be upside down with turret substantially buried. Four other tanks were upside down on their turrets but in good condition with about 20% subsidence. Tank 7M2 was on its right side sticking straight up and 20% buried. A single tank, 7G2, was upright and in good condition, with subsidence reported at about 10% (Turpin 2001). Some undersize recreationally important fish species like amberjack and red snapper were present on the tanks but not in numbers or sizes anticipated. This was believed to be the result of the high level of summer and early fall fishing pressure the tanks and other artificial reefs in the immediate area received (Robert Turpin, personal communication).

An analysis of video taken topside combined with visual observations of the initial Florida tank 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 REEFEX '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 (Maher and Horn 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 let a two-year contract to conduct monitoring on military equipment deployed during REEFEX in less than 100 feet of water. Beginning in the spring of 1999, consultants with the firm Aquabio (Sheehy and Mathews 2000; Sheehy et al. 2001) 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" (Sheehy and Mathews 2000; Sheehy et al. 2001) also experimented with enhancing some southwest Florida shallow water MBTs with tennis net fish attractor devices (FADs) attached to the tanks and held up by floats. They reported that differences between military armored vehicles without FADs and those with FADs were highly significant, with FAD enhanced vehicles having more midwater species and grouper, but not total bottom fish. However, the tennis net FADs became rapidly fouled within a year and sank to the bottom (Hayward Mathews, personal communication). Additionally the Florida Fish and Wildlife Conservation Commission expressed some concern that the Department of Environmental Protection and COE permitted sites authorizing the use of armored equipment did not authorize the use of FADs. Sheehy et al. (2001) did have the caveat in their paper that FADs should be applied only when their use is consistent with guidance from appropriate state and federal fisheries management agencies.

Feedback (Sheehy and Mathews 2000; Sheehy et al. 2001) 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. In response to the last complaint, Jon Dodrill (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 REEFEX 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.

Benefits

- Selected military surplus armored equipment is typically of high quality, built to engage adversaries, 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, spiny oysters, among others. Sea urchins, grazing on the encrusting organisms, were abundant.

- Video tape analysis revealed that the most prominent species associated with the Alabama tanks was red snapper, while in South Carolina red snapper, black seabass, 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 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.
- REEFEX 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

- Each artificial reef manager should evaluate the suitability of military hardware for their program.

- 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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2.8 *Natural Materials*

2.8.1 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, including bamboo, log cribs, and palm fronds, is 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

- Many of the same problems in using wooden vessels would be inherent in using natural wood resources as reef material.
- Wood generally has a short life span in the marine environment~~s~~, 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.
- 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.

<u>Considerations</u>

- 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.

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

2.8.2 Shell

<u>Overview</u>

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 seabass 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 seabass 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 Colorado River (Bob Bass, Galveston District, personal communication). The COE plans to construct 118 acres of shell reef in Galveston Bay in the future, using shell material dredged during the widening and dredging of the Houston Ship Channel (Bob Bass, 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 insure 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 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 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). Recently oyster shell has been utilized to create small offshore experimental reef sites. These experimental shell reefs have been effective in providing habitat for 0 and 1 year old red snapper (Steve Szedlmayer, personal communication) and have management implications about recruitment (Workman and Foster 1994).

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.

- 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.

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.

- 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.

- Reef profile high enough to avoid siltation of shells is important for reef permanence.

- 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.

2.8.3 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 of 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 (cpf), ranging from two-six 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 his latter project, in 1994 approximately 2,500 tons of rock were deployed 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, easily accessible from shore, initially was very popular among snorklers. 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 on May 23-24, 2001, about four months after the January 18, 2001 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 blue head wrasses, sergeant majors, tomtates, and schools of herring. Common adult fish included white grunt, striped grunt, French grunt, porkfish, yellowtail snapper, schoolmater, cocoa damselfish, bicolor damselfish, spotfin butterfly fish, 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 ship wrecks. 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 effective 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. Further studies may be continued after 74 additional quarry rocks were added to the reef site in 2002.

In 2000 and 2001, Louisiana created two reefs composed of limestone rocks in Lake Pontchartrain and Lake Pelto. Both reefs will be evaluated by researchers from the University of New Orleans and Louisiana State University (Rick Kasprzak, personal communication).

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 six to eight 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 life span 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 its development.
- Rock may have associated sediments.

2.8.4 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 salt water 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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2.9 *Fiberglass, Ferro-cement, and Wooden Vessels*

Overview

2.9.1 Fiberglass Boats and Boat Molds

Over the last four decades, there has been a major shift in composition of recreational boating materials from wooden hulls to fiberglass hulls. In Florida alone there are over 710,000 registered boaters. The majority of vessels engaged in saltwater recreational fishing have fiberglass hulls. As newer boat designs arrive on the market, the fiberglass molds for the old 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.

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. In some cases boat companies must physically cut up thick wood and fiberglass boat molds reinforced with external metal caging before transporting these molds to a landfill.

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. The 1992 estimates for Florida alone placed the number of derelict vessels statewide at 3,000. Over the last 10 years, Florida has committed $2,500,000 to dealing with the derelict vessel problem (Dale Adams, personal communication). Others have been caught hauling vessels offshore to sink without a permit. Boat companies routinely approach reef program managers regarding disposal of boat molds. South Carolina was recently offered, but declined, 370 boat molds for use in their artificial reef program (Robert Martore, personal communication).

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. The fisherman obtained a materials delivery system. 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 Philadelphia and Jacksonville Army Corps Districts no longer permit fiberglass boat or boat mold use under their 1995 general artificial reef permit. However, private use of fiberglass boats as a delivery system for other miscellaneous reef materials continues at night in Florida. Fiberglass boats, as an artificial reef material and a delivery system for other materials, were used legally in Alabama under a formal inspection program; however, as of this writing, there is a moratorium on that activity. Currently, no state reef programs are actively promoting the use of fiberglass vessels in their artificial reef programs.

In the past, state funding has been provided to use fiberglass boat hulls or molds as artificial reefs for projects in five different counties, including Manatee (molds, 1987), Dade (boats, early 1980s), Gulf (boats, 1993), St. Lucie (boats, 1988), Wakulla (molds, 1992). They have also been employed in formal county reef programs in Sarasota and Broward Counties. In 1985, a local fishing club placed 30 to 40 fiberglass boat molds secured to each other with heavy chain in 45 feet of water off Georgia.

In Mississippi, in 1994, a fiberglass shrimp boat, was deployed as an artificial reef. The boat, approximately 50 feet in length, was cut in half and sunk in two pieces. The foam floatation between the inner and outer hulls was not removed, resulting in half of the boat eventually sinking offsite, and the other half drifting away just under the surface (Ron Lukens, personal communication).

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. Preliminary 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. Dade County, Florida, in 1985, 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). Sarasota County, Florida, in the 1980s, 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 can be located, and the County, who once accepted fiberglass boat donations for reef construction, no longer does so (Mike Solum, personal communication). 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 June, 1995 and were 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). The status of 22 fiberglass boat hulls ballasted with concrete and sunk off St. Lucie County, Florida in 33 feet of water on March 3, 1988, is unknown (Brad Keene, 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).

While a Georgia fiberglass boat hull reef, deployed in 1985, has not been visually examined, it still shows up on the depth recorder, and it is reported that fish are still being caught there (Henry Ansley, personal communication). A Miami charter boat captain reported that he was catching warsaw and snowy grouper on fiberglass wrecks in 250 to 300 feet of water off Dade County, Florida. That reef had been deployed since the 1960s (Joseph Evans, personal communication). Similar reports from the local reef coordinator also state that fiberglass boats in water up to 600 feet deep continue to hold fish after many years (Ben Mostkoff, personal communication).

Fiberglass boats sunk in shallow water without ballasting and/or anchoring will move. A sunken or scuttled 32 foot fiberglass sailboat was observed to actively shift positions off Broward County, Florida before it disappeared following a storm (Ken Banks, personal communication).

Attachment of fouling organisms on fiberglass boat molds may not be as rapid as on concrete materials, as evidenced by underwater video footage taken 16 months after a January 1992 deployment. Six groups of eight cabled and ballasted boat molds placed in 55 feet of water off Wakulla County, Florida, showed minimal fouling of the interior surface of the molds (Jon Dodrill, personal communication). Exterior surface benthic fouling was noticeably less diverse and well developed than growth on bridge span concrete 30 feet away and placed on site within days of the molds. After 16 months the molds were observed still cabled together; however, those on top had shifted position by as much as 20 feet relative to each other since they were first deployed. Boat molds were observed and videotaped three years after the 1987 deployment off Manatee County, Florida. Benthic fouling was reportedly slow to commence but was beginning to become established (Dan Ramsey, personal communication).

Benefits

- Discarded fiberglass boats are readily available and cheap.

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.

- 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, 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.

2.9.2 Ferro-cement Vessels

Little information is available on the use of ferro-cement vessels as artificial reefs. 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 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).

2.9.3 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 drydocks 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 drydocks, New York no longer accepts them in their program. The existing drydock reefs, however, continue to function effectively as fishing and diving reefs (Steve Heins, personal communication). In the early 1980s, wooden dry docks were sunk off Virginia Beach, Virginia and are still intact with no 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 has not disassociated to any great degree and is still a viable reef structure and popular fishing site. Alabama has been pleased with the performance of this material and deployed another dry dock in 1999. They are currently trying to obtain another wooden dry dock for reef deployment in the future (Ralph Havard, 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, and it was sunk as an artificial reef off Jacksonville, Florida. 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).

2.9.4 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 limbs 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. Gregg and Murphey (1994) list 53 of 414 vessels (11%) deployed in artificial reef programs as having wooden hulls. The use of wooden vessels as artificial reefs needs to be evaluated in the context of their short-term economic return as fish attraction devices versus long-term stability and durability as reef habitat. Larger wooden vessels (greater than 60 feet in length) are valued by some commercial bottom fishermen. If a commercial fisherman paid several thousand dollars for such a derelict vessel, towed the vessel offshore and sank it at a private location in the Florida panhandle, a commercial grouper/snapper fisherman could more than double his investment fishing on this wreck within four years (Cris Koenig, personal communication).

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 falls to pieces as the result of storm activity, boring worms, and other marine organisms. 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, 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).

Benefits

- Oceangoing wooden vessels that are longer than 60 feet with heavy wooden frame structures, such as shrimp boats, are valued by some commercial bottom fishermen, because value of the landings over the fishable life of the vessel, when deployed as an artificial reef, exceeds the cost of securing and deploying the vessel.

- 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

- 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. 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.

- Fiberglass boats seem to be the preferred secondary use material for the private reef developer since these boats can serve as vessels in which to transport other materials of opportunity offshore. Most state-run programs no longer use fiberglass boats, due to their low density, and potential to move offsite. Some COE districts no longer permit their use under the general reef construction permit.

- 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 should not be the determining factor 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.

- 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.

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2.10 *Ash Byproducts*

Overview

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 1970's (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 recent 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). However, this report (Bevill Amendment; Exclusions (RCRA) 65FR 32214 Part 261; Subpart A; Section 261: 4(b)(4); May 22, 2000) stated that although large volumes of coal combustion wastes disposed in surface impoundments, landfills, and used in minefill have been determined to be non hazardous wastes under RCRA Subtitle D, national regulations are expected to be established for the disposal of these solid wastes in these types of impoundment areas in the future.

While RCRA is the principle 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 1999). 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.

2.10.1 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.

2.10.2 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 have "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 2 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 ground water 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 between 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.

Recent mixed 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 substrate. 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 breakdown 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.

In addition to these initial studies done in New York, Hockley and Van der Sloot (1991) cut open the sample blocks used in the biofouling studies done by Duedall et al. (1985) to investigate the chemical/physical factors creating an impermeable barrier in the fly ash substrate with seawater. When the block was analyzed for major elements (Ca, Mg, SO4, CO3, and pH), a sharp discontinuity or dark region was noticed 10-20 mm from the outside surface of the block. This dark region was enriched with Mg, but without distinct crystals present. They concluded that Mg was present as a precipitate of the amorphous Mg phase or from substitution of Mg into other phases such as calcite. The pH profile showed two chemically different regions, which implies a chemical reaction occurred. A pH of 9-10 was found in the material near the outer surface of the blocks and a pH of 11-12 was noted in the darker layer located inside the block. Some minor and trace elements (Na, Cl, Br, and Mo) had discontinuities within this dark layer. As, B, and Sb had discontinuities at the surface, while Zn, Cu, La, and W remained constant except near the surface. Soluble calcium phases in the block (Portland cement and calcium sulfite) disappeared from the surface of the blocks. When the Portland cement dissolved, it released hydroxide ions, which were believed to form precipitates with the Mg ions diffusing into the block. While the pH of 9-10 at the surface supports the presence of hydroxides, some calcium was released into the sea, and some precipitated with the carbonate ions diffusing into the block. This dissolution and diffusion process set up a moving boundary, which is limited because ion products are equal to or higher than solubility products. Hockley and Van der Sloot (1991) concluded that due to the precipitation in the block pores, the rate of contaminant movement was slowed and the block matrix was strengthened. They called this chemical/physical process “pore refinement.” The Na and Mo profiles were mirror images of each other, indicating the process which hinders Na from diffusing past the boundary layer is the same process which hinders Mo from leaching out from behind the boundary layer. This “pore refinement” process provides the necessary characteristic which makes stabilized coal ash an appropriate artificial reef substrate.

In addition to the New York study, several other studies were initiated in other states. Delaware scientists (Price 1987; Price et al. 1989; and Dinkins 1987) evaluated stabilized ash material for oyster substrate in the laboratory, and later in both Delaware and Maryland bays. The Delaware studies (Price et al. 1991) found that a higher proportion of bottom ash in the design mix provided a rougher textured surface and increased attachment of benthic organisms. They also found that the oblong shapes of the fly ash substrate caused increased interstitial space and flow, and higher settlement rates in oysters.

The Delaware study (Price et al. 1991) also found that although most of the tissue metal concentrations found in oysters grown on the fly ash substrate were within acceptable levels, there was a significantly greater accumulation of iron, manganese, and zinc in the oysters. The long term effects of these higher concentrations have not been evaluated.

Several studies were done in Florida (Florida Power Corporation 1990; and Livingston et. al. 1991) on a coal ash artificial reef demonstration project in 1988, where 28 stacks of 100 block sections were placed 9 miles offshore of Cedar Key, in 20 feet of water. Dimensions of these 2800 blocks for this construction project were 8 inches wide by 8 inches tall by 16 inches long, with two-holes in each block. The design mix for these blocks was 57% bottom ash, 34% fly ash, and 9% Type I Portland cement. This demonstration project included the following testing: laboratory testing of the leachate using standard EPA Toxicity testing and modified seawater EPA Toxicity testing; bioassay testing of the leachate; benthic and fish tissues analysis for metals; and biological evaluation of the habitat by core analysis, photo-transects, scrapings of the blocks, traps, and trawls.

No significant leaching was detected from the fly-ash elutriate testing. The 96-hour bioassay tests were conducted on *Pagurus maclaughlinea, Hippolyte zostericola, Tozeuma carolininenesis, Mysdiopsis bahia*, and *Poecilia latipinna*. There were no overall toxic effects from the block elutriates on the species tested, with the exception of *Tozeuma carolinesis*. This species of diatom had an lethal concentration (LC 50) of 38.22% of the block elutriate, which is a moderate level of toxicity for this sensitive organism.

Biofouling and recruitment of fish at this Florida ash reef site was rapid on both fly ash and concrete control blocks. There were no noticeable differences in abundance or recruitment at the reef site or control areas. Tissue analysis of two fish species (flounder and black sea bass) captured near the ash reef showed some bioaccumulation of arsenic. However, there was no consistent relationship between metal concentrations found in fish and proximity to the reef. Other reef fish species taken from the fly ash reef showed comparable levels of metals with species taken over reference areas.

Since 1988, Houston Lighting and Power Company (HL&P Company), JTM Industries, and Texas A&M University (Baker et al. 1991; Baker et al. 1995a, 1995b and 1995c; Landry et al. 1995; Ray et al. 1995) have spent several years planning, obtaining the appropriate permits, and developing an acceptable protocol for evaluating CCBs as an artificial reef substrate. This protocol has involved extensive evaluation of the fly ash, lignite bottom ash for metal toxicity, and organic toxicants such as dioxin. Their protocol requires that the analysis of fly ash/bottom ash mixture used in the artificial reef substrate be from only one source of coal or specific sources of coal, where the proportion of coal sources remains the same.

They have developed a design mixture for large blocks and smaller sized pellets from fly ash, lignite bottom ash, and hydrated lime, which has a compressive strength of 3587 psi after one year submerged in seawater. These scientists have emphasized the importance of knowing the source of the coal and the desulfurization treatment process before starting the expense of testing the leachate from the substrate and bioassay tests.

Houston Lighting and Power Company (now Reliant Energy Company), with Port of Houston and National Marine Fisheries Service, and approval from Texas and Federal resource agencies summarized for EPA the results of extensive testing and monitoring on seven oyster reefs constructed of CCB in the Galveston Bay estuary system (Baker et al. 1995b). This report documents that there were no significant levels of toxic substances in the leachate from the ash material in the bioassay tests and EP Toxicity tests. No organisms were affected in the bioassay test and no significant concentrations of metals were found in oyster tissues in the laboratory or the field samples. This report also documents the oyster reefs in the Galveston Bay estuary system have had significant recruitment and spat survival. Fish survey results using traps, nets, and visual census techniques of the estuarine reefs show there has been significant biological recruitment of fish and invertebrates at these artificial estuarine reefs.

The results of this time consuming documentation of the coal source and the low levels of toxicity present in the ash before construction begins has been an extremely important factor in the recruitment success at these reef sites and the promotion of future reef sites in Texas.

In January 1993, Ting (TAMU unpublished report to HL&P, 1993) investigated the stability of a model sized replica of the proposed artificial reef that was to be deployed in the Gulf of Mexico. These tests on the model reef were conducted in a two dimensional wave tank, and subjected to storm conditions with recurrence intervals of 10, 50,100, and 200 years. Both regular and irregular waves were used in the study. No significant damage or movement of the blocks used in constructing this model reef, occurred in any of the storm stability tests.

In July 1993, with authority from Texas Parks and Wildlife Department and the COE, Houston Power and Light Company and JTM Industries constructed an 18 foot high pyramid shaped artificial reef, within a state designated reef site. Three hundred and twenty-five CCBP blocks, with dimensions 3 feet by 3 feet by 3 feet, weighing one ton (1800-3600 kg) each, were placed approximately 40 miles offshore, in 100 feet (35 m) of water, adjacent to an established shipwreck, known as the *V.A. Fogg*.

Texas A&M University at Galveston (TAMUG) scientists monitored this reef site for four sampling periods over a three consecutive year period; and a final report is pending publication (Landry et al. unpublished data). Reef fish recruitment to the fly ash blocks was monitored using sable fish traps, hook and line, divers' visual censuses, video tape transects, and creel survey data from anglers fishing on the reef site. Preliminary evaluation of this data shows that the most abundant fish consistently observed by divers on the reef, and captured in sable fish traps was tomtate, *Haemulon aurolineatum.* Red snapper *Lutjanus campechanus* were also abundant on the reef according to diver censuses, hook and line capture, and in fish traps over four sampling periods. Tomtate, which were not captured by hook and line, and may appear to be "under-represented" in the total abundance comparisons, whereas red snapper were easily captured by hook and line as well as by fish traps. Preliminary evaluations of all data showed that juvenile tomtate, adult tomtate, red snapper, gray triggerfish *(Balistes capriscus),* and blue runner *(Caranx crysos)* were the most abundant fish observed or captured over the four sampling periods. Cumulative sable fish trap data showed that catch per unit of effort numbers of fish was highest in September 1995 (3 fish/hr), and biomass (15.63 kg) was lower than in any other years. Cumulative hook and line, catch per unit effort data showed that greatest numbers of fish were captured in September 1995 (6 fish/hr) and September 1996 (6 fish/hr) with only moderate biomass (74.11 kg and 84.45 kg respectively). Higher catch per unit of efforts and lower biomass in trap and hook and line data suggest that mostly smaller sized fish and possibly juvenile fish were recruited to the reef in September. These results were also confirmed by diver censuses and video transects data.

TAMUG's diver censuses and video transects on the CCPB blocks also documented the presence of Spanish hogfish, blue angelfish, french angelfish, various blennies, various reef butterfly fish, cardinal fish, squirrelfish, warsaw grouper, black grouper, gag, scamp, rock hind, graysby, cardinal fish, bigeye, greater amberjack, sharks, and others. The number of these types of reef fish species appeared to increase over time as the reef matured and encrusting organisms colonized the CCBP blocks. A whale shark *Rhincodon typus* was also observed swimming through the reef site in October 1993 during TAMUG's initial monitoring period.

As part of this TAMUG monitoring study, smaller sized "fouling blocks" made of the same material as the CCBP blocks, were placed on the pyramid reef, and later retrieved in April 1994 and July 1994 by divers to document invertebrate recruitment over time. These blocks were preserved in formalin; and later transferred to alcohol for evaluation of benthic recruitment. Todd (unpublished report1996) evaluated these blocks using a point quadrate technique to determine species composition and abundance of the benthic organisms on the reef after one year's growth period. He found the "fouling blocks" dominated by bryozoans, polychaetes, tunicates, and hydroids. The methods used to preserve these blocks did not allow for the preservation of anemones or sponges, which were observed by divers on the larger CCPB reef blocks. However, using what species could be identified, Todd (unpublished report 1996) indicated that the diversity and types of encrusting species on the smaller fouling blocks had not yet reached a climax benthic community stage during its first year of growth.

No toxicity analysis of the benthic organisms encrusted on the CCPB blocks was made during the four year monitoring period. However, TAMUG divers (Landry unpublished data) documented the following encrusting and benthic organisms on the larger reef blocks over the four year study: sponges, soft corals, finger and cup corals, Atlantic spiny oysters, conch, murex, cowrie, anemones, oyster drills, polychaete worms such as Christmas tree worms and bristle worms, hydroids, bryozoans, brittle stars, sea urchins, hermit crabs, reef crabs, and sea squirts or tunicates populated the reef. Special note should be made that divers also observed Carribean spiny lobster, *Panulirus argus* in crawl spaces between blocks during all four monitoring efforts from 1994-1996. These divers' observations are important for future evaluation of the CCPB blocks as effective artificial reef substrate.

Texas Parks and Wildlife Artificial Reef Program Divers (Peter and Embesi unpublished data) also conducted independent fish surveys at this reef site using diver's visual census and video transects between 1993 and 2001. They surveyed the reef fish surrounding the CCPB blocks after the blocks were first deployed in July 1993; later in July 1995; and recently in June 2001. TPWD diver observations identified the most abundant fish on the CCPB reef as juvenile and adult tomtates, red snapper, blue runner, gray triggerfish, Atlantic spadefish, vermilion snapper, blue headed wrasse, seaweed blenny, and greater amberjack. TPWD diver observations confirmed that both adult and juvenile tomtate were the most abundant fish observed on the CCPB reef. Other reef fish identified, but not as abundant included: bigeye, reef butterfly fish, squirrelfish, cocoa damselfish, gray triggerfish, french angel fish, cubbyu, hawkfish, rock hind, sheepshead, spanish hogfish, spotfin butterfly fish, townsend angel fish, blue angel fish, soapfish, cardinal fish, yellowtail damsel fish, sergeant majors, barracuda, lookdown, and many unidentified grouper species. TPWD diver's observations of benthic and encrusting organism indicate that the CCPB blocks are providing stable substrate for encrusting organisms such as cup corals, hydroids, sponges, tunicates, and bryozoans.

However, not all studies have shown the consistent results of New York, Delaware 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 and Delaware 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.

Although not directly applicable to the use of CCBs as artificial reef substrate, a health risk assessment (Denison 1992) to use stabilized CCB ash as a substitute aggregate in Minnesota road bed construction materials was recently completed by the Environmental Defense Fund. Denison wrote that the risk to the environment and human health was directly increased because of the high concentration of heavy metals in the “ash substitute aggregate” compared to the “natural aggregate”, and the soils from the unpaved roadway. He found that lead concentrations in the substitute aggregate material was present in levels 160 times greater than natural material; mercury levels were 280 times greater; and cadmium levels were 22 times greater. Denison concluded that these higher concentrations of heavy metals in the stabilized ash material had a greater potential to leach out of the roadway through erosion and runoff than the natural aggregate substrate.

This particular evaluation of one ash material used for roadbed material from one specific coal incinerator plant in Minnesota, indicates that the source of coal ash material used is very important in determining the environmental risks of the leachate. Not all ashes should be considered for use as roadbed or artificial reef substrate. The source of the coal and treatment process is an important factor in determining the potential toxicity of the leachate of the ash material.

2.10.3 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. These studies may be an important component in determining the future use of this specific ash when EPA makes it final regulatory decision concerning this substance.

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.

- Ash byproducts are not readily available as of this writing, because there is a high demand for use of the material in the construction industry (Jan Culbertson, personal communication).

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PERSONAL COMMUNICATIONS

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2.11 *Vehicles*

Overview

The composition of automobiles has changed considerably over the past thirty (30) 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 macro-invertebrates 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). Alabama continues to permit truck and school bus bodies for use by private artificial reef builders within the general permit areas. The fact that these are generally heavier than a standard automobile seems to improve the stability and durability of these materials.

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).

On August 10 and 11, 1992, as part of a Florida Department of Environmental Protection sponsored automobile monitoring study, 45 automobiles, partially crushed with one door and engines and transmissions removed, were deployed at three separate sites in 75 feet of water off Pensacola, Florida. Each site had five individual patch reefs of five, four, three, two, and one vehicle, respectively. Each patch reef was in association with a control structure, comprised of 40 concrete blocks stacked on one another. Within six to eight weeks, 34 species of fish were documented on the automobile body reefs. The most abundant were bank sea bass, cigar minnows, tomtate, red snapper, pigfish, and vermilion snapper. Evaluations took place August through October 1992, and June through August 1993. During the 1992 monitoring period, the test reefs were exposed to 50 mile per hour winds and 9 to 12 foot seas, associated with Hurricane Andrew. Minor movement and change of orientation of some vehicles, in relation to the control structures and each other, was noted on some replicates. Distances moved by vehicles were generally less than 10 meters, and some scouring around vehicles occurred (Bortone 1993).

A material inspection was made of a group of five automobile bodies from the above referenced project on August 22, 1995. After three years in the marine environment, the vehicles were still recognizable as automobile bodies. They had settled into the sand, providing only two to three feet of vertical relief. Even though Hurricane Erin, with 90 mile per hour winds, had passed over the site in early August 1995, the automobile bodies had not noticeably moved. Twenty-two species of fish were observed associated with the site, including juvenile vermilion and red snapper and a variety of tropical fish species and other small fish (Horn 1995). Video footage of this site shows that wiring and other miscellaneous small parts appeared loose in association with at least one of the automobile bodies (Jon Dodrill, personal communication).

On October 4, 1995, Hurricane Opal, the strongest storm system to hit the Pensacola, Florida area since the test vehicles were deployed, produced sustained winds of 115-125 miles per hour and seas exceeding 20 feet. Results were similar to that reported by Alabama in that in addition to a large number of private reefs lost through movement, break-up, or burial, there was movement and some breaking up of those test project vehicles which could not be located (Steve Bortone, personal communication).

An artificial reef of 20 old car bodies was placed in 50 feet of water at Paradise Cove near Malibu, Los Angeles County, California, on May 26, 1958 (Carlisle et al. 1964). In 1960, car bodies were placed in three additional locations in Santa Monica Bay, Los Angeles County. Fourteen each were placed at experimental replication reefs at Malibu and Hermosa Beach (Carlisle et al. 1964). It is unknown how many years these automobile bodies persisted, but none can be found as of this writing, and it is safe to assume that they were gone many years ago (Dennis Bedford, personal communication).

MARPOL (International Convention for the Prevention of Pollution from Ships) Annex V, part of an international treaty which addresses ocean dumping, provides that plastics cannot be disposed of in the marine environment. Automobile bodies that are dumped into the ocean for the purpose of disposal would be in violation of MARPOL Annex V, because of the associated plastics. Regarding permitted deployment of automobile bodies in the ocean as artificial reefs, the interpretation of the EPA is that plastics cannot be free or unattached so that they can become a hazard to animals or conflict with the multiple uses of public waters and water bottoms (Bob Howard, personal communication). As mentioned above, plastics represent a significant portion of the materials in an automobile. Currently, the use of automobile bodies as artificial reef material is allowed by the EPA, MARPOL Annex V notwithstanding, because there are no data to show conclusively that plastics associated with automobile bodies deployed as artificial reefs become free and unattached, thus creating an illegal material. The EPA has expressed an interest in further investigation into the use of automobile bodies as artificial reefs as it relates to MARPOL Annex V (Bob Howard, personal communication).

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. Over 12,000 automobile dismantlers and 200 automobile shredders are actively engaged in vehicle recycling efforts, nationwide (American Automobile Manufacturer's Association 1994).

In Mississippi, approximately 50 car bodies were deployed in the 1960s in water 35 feet deep three miles south of Ship Island. Efforts have been undertaken to locate the car bodies using side-scan sonar; however, in the area indicated by knowledgeable individuals to contain the car bodies, some hard returns were seen, but not recognizable as a car body.

Benefits

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

Drawbacks

- 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.

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2.12 *Vehicle Tires*

Overview

Tires are manufactured primarily from artificial rubbers, but some natural rubbers are present in tire recipes. A typical tire rubber compound consists of 100 parts rubber, 50 parts fillers, extenders, and reinforcers, 3.5 parts curing and accelerating agents, and 8.0 parts antioxidants and pigments (Sitting 1975). 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).

The use of waste vehicle tires as artificial reefs began in the United States in the late 1950s or early 1960s (Mathews 1983). 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 regrooved (Chapter 62-701.200, Florida Administrative Code, Florida Department of Environmental Protection).

Historically, the utilization of scrap tires as artificial reef material was undertaken to accomplish two objectives. The first objective was to develop fishing reefs by utilizing an abundant material source composed of individual units that could be easily handled and assembled and that was readily available at no cost (Stone and Buchanan 1970**).** The second objective was to provide a possible solution to the growing solid waste disposal problem (Stone et al. 1974). By the early 1970s, the U.S. was generating 200 million scrap tires a year (Minter 1974). In 2000, the U.S. generated 273 million tires (Rubber Manufactures Association 2002). 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). 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.

Since 1990, there has been a dramatic shift in scrap tire management as new markets for scrap tires have been developed. Before 1990, less than 10% of tires were reused or recycled. By 2001, more than 70% of scrap tires were being reused or recycled. In addition, technological advances have significantly increased the average tread life on a passenger tire (about 24,000 miles in 1973 to 43,000 in 2000), requiring less frequent tire changes per automobile (Rubber Manufacturers Association, Scrap Tire Management Council 2000). Today, most illegal tire stockpiles have been abated and regulations on tire stockpiling, transport, and disposal have been established across the nation. Nationwide, the number of stockpiled scrap tires has been reduced by 85% (from a peak of 2 billion in 1988 to 300 million in 2000). In Florida, approximately 6 million illegal waste tire sites were documented in 1990, and by 2002 only 100,000 tires remain in illegal piles (Jessie Carpenter, personal communication). 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). Representative un-ballasted tire projects and their results are summarized below:

Gulf of Mexico

Texas

In 1966, un-ballasted vehicle tires were first deployed as artificial reef material off Texas by a private company in a coastal bay. The "Dry Hole Reef" in Trinity Bay consisted of 250 tires interconnected with cable ties, tread to tread, forming a single layer five tires wide by 25 tires long, covering 21,527 square feet of bottom area in ten feet of water. In 1968, divers found that barnacles and other encrusting organisms covered this reef, and there was no evidence of subsidence. By 1975, this reef had subsided into the mud and was no longer functioning as a viable artificial reef (Benefield and Mercer 1982).

In 1976 the TPWD and the Texas Coastal and Marine Council entered into a cooperative program to construct six separate tire reefs for local anglers. Goodyear Tire and Rubber Company provided an air compressor, tire punch, and tire compactor for baling tires into units for reef material. Each reef consisted of tires donated by local dealers, which were punched and baled at several deployment locations. The initial process consisted of punching four holes through the tire tread and removing a round divot of rubber about one inch in diameter. These holes were spaced evenly apart to allow air to escape from the tires when placed in water. Twelve punched tires were placed on the compactor and pressed to form a bundle of about 3.5 feet long and weighing about 243 to 353 pounds, depending on sizes of tires used. Four commercial grade plastic strapping bands were attached to each bundle to hold the tires in a compact module after the baling machine compactor was released. Six tire modules of twelve tires were interconnected using tarred steel cable joined together by four galvanized steel cable clips. Steel cables were used to contain the tires in the event the plastic strapping broke and to also prevent movement of individual bundles by tidal and wave action.

The largest of the six tire reefs consisted of 6,000 tires and was assembled into two 500 module units covering approximately one acre. This reef was placed in Sabine Lake on April 18, 1977. The other five reefs constructed included: 1,200 tires (100 modules) near Sylvan Beach fishing pier in Galveston Bay; an undetermined number of tires over one quarter acre at Coon Island near Tres Palacious Bay; 70 to 80 tires in the shape of a wagon wheel, cabled together over less than a quarter acre at Wadefish Reef near Palacious in Matagorda Bay; 1,700 tires (140 bales) over one-quarter acre near Rockport jetty in Aransas Bay; and 1,200 tires (25-30 bales) near Cole Park fishing pier in seven to eight feet of water in Corpus Christi Bay. Although three of the tire reefs could only be reached by boat, the tire reefs in Aransas, Galveston, and Corpus Christi Bay systems were built adjacent to fishing piers and local anglers had access by land or by boat. Surveys of these tire reefs in 1980 showed that, except for the Sabine Lake tire reef, the other five tire reefs had subsided into the mud (Crowe and McEachron 1986). These reefs were constructed in water that was less than ten feet in depth and were subject to currents and wave action not experienced by tire reefs built in deeper water by other state reef programs.

Louisiana

Louisiana reviewed available information on the use of tires as artificial reef material and concluded that tires are not suitable reef material. This conclusion resulted in the banning of tire use for artificial reefs in Louisiana (Kasprzak et al. unpublished).

Florida Gulf Coast

Between 1982 and 1985, approximately 183,770 un-ballasted, compressed, and bundled automobile tires were deployed on public reefs off Panama City at a depth of 70 feet (FWC artificial reef data base). According to dive charter captains Danny Grizzard and Craig Gold (personal communication), who frequently dove the tire reef sites during the 1980s, areas covered by tires were initially so great that recreational divers would get lost among vast fields of tires. The results of a recent revisit to three different reef sites found no more than 50 tires. Most of those observed were pinned under other material later placed on top of the tires or had been dropped inside a previously deployed barge that restricted tire movement (Mille and Horn 2001).

To gather information on the historical types of materials placed on private reefs in the Gulf of Mexico offshore of the Florida Panhandle, an anonymous survey of fishing and dive charter operators was conducted by the Florida Department of Environmental Protection in 1994. The results from 65 respondents revealed that over 7,000 private reefs were placed during the 30 year period from about 1964-1994. Citing low cost, availability, and ease of deployment, 55% of the respondents listed tires among the top three material types they had deployed over this time period (Maher 1994).

Loose tires also have been found on the beaches of Florida's Panhandle. With winds of 126 mph, Hurricane Opal (October 4, 1995) was one of the strongest hurricanes to make landfall along the Panhandle during the 1990s. Review of post-storm damage aerial video transect assessments of Panhandle beaches found approximately 11 tires per linear beach mile, accounting for more than 1,000 tires on the beaches between Panama City and the Alabama-Florida border (Horn and Mille 2001a). Derelict automobile tires and other debris have also been found offshore of Pensacola during trawling operations. In September 2000, a commercial calico scallop trawler reported trawling up scores of automobile tires and other debris south of Pensacola and the Florida-Alabama line located outside the limits of artificial reef permit areas (Bill Burkhart, personal communication). The captain expressed concern about potential damage to fishing gear and stated that while his scallop gear could lift about 10,000 pounds, a shrimp trawl net would have been lost by the unexpected volume and size of some of the derelict material he had collected.

The other known concentrations of tire reefs along Florida's Gulf coast were deployed offshore of Wakulla County, Pinellas County, and southwest Florida. From the late 1960s through the late 1970s the Pinellas County Solid waste program, with support from local fishing clubs, deployed 1-1.25 million un-ballasted tires as artificial reefs. Although some tires reportedly remain at their original locations (Heyward Mathews, personal communication), the majority have dispersed. In 1985, heavy weather brought ashore dozens of tires onto the public recreation beaches of Caladesi and Honeymoon Island state parks (Ron Weiss, personal communication). Maintenance dredging events in Pinellas County have also encountered significant numbers of tires over the years, causing delays by shutting down dredge operations when tires became lodged in the dredge intake pipes. In August 2000, more than 2,000 tires were removed from Blind and John's Passes, causing the dredge contractor to charge the U.S. Army Corps of Engineers over $800,000 in down time ($250 per tire) to deal with tire removal (Rick McMillan, personal communication). Tires have also been found during previous dredge events at Blind and John's Passes and dredge contract specifications now include special conditions on dealing with derelict tires.

In the 1970s and early 1980s bundled tires were also deployed off the Gulf coast of Sarasota, Florida. In 1994 after a storm event, the artificial reef coordinator had to pick up approximately two tons of tires (130-200 tires) from the beach as a private citizen. The reef coordinator recalled seeing tires on Sarasota County beaches as far back as the early 1980s. In recent years the reef coordinator has seen only one tire during diving operations on the county’s former tire artificial reef sites (Mike Solum, personal communication).

Off Collier County, southwest Florida, the 30 foot deep Marco Island Five Mile Reef was first permitted in the early 1970s to a private land development corporation called the Deltona Corporation. As mitigation for the destruction of marine habitat during the construction of Marco Island, the Corporation constructed two tire reefs using over 75,000 used automobile tires deployed in bundles under the guidance of the Marco Applied Marine Ecology Station. Reportedly biologists from this station documented more than 80 species of fish at the first reef constructed, along with “trophy size” recreational catches (Goodyear Tire and Rubber Company 1974). At least some of this tire reef development may have involved the use of concrete ballasted tires. Goodyear Tire and Rubber Company, in its 1974 reef building manual, stated: “The builders of the Marco Island Reef believe that weighting the bundles with concrete is preferable”. However, twenty-five years later, most of these tires were reported to be scattered, buried, or washed up on the beach (Kevin Dugan 1997).

A tire reef promoted by the Jaycees was deployed off Fort Myers, Florida, during the early 1970s. One single tire was observed at the site during the early 1990s. It is assumed that the tires had not stayed together and that most of the tires are buried, as the sand at the site is rather deep and no tires are known to have washed up on the beaches of Ft. Myers (Chris Koepfer, personal communication). The status of similar tire reefs built during the same time by a local yacht club off Naples, Florida, is unknown.

Mississippi

In Mississippi, hundreds of un-ballasted automobile tires were cabled together, using steel cable, and placed in the hulls of Liberty ships being deployed as artificial reefs in 1978. In the late 1980s, dive surveys to the Liberty ships containing the tires revealed that the tires were being scattered throughout the ship's hull (Lukens and Cirino 1989). Subsequent dive trips in the late 1990s revealed that no tires could be located. Tires were not observed on the entire permitted site in 2001, during a side-scan sonar survey conducted by the Mississippi Department of Marine Resources.

Atlantic Ocean

New Jersey

Observations in New Jersey demonstrated that un-ballasted split tires, originally placed 5.5 miles offshore, traveled approximately 1.5 to 6.0 miles per year, and were found washing up on beaches 15 to 60 miles from the reef site after 10 years (Bill Figley, personal communication). In 1984 during informal stability studies of tire units, a bound 60-tire un-ballasted tire unit used in Virginia and several Florida counties was tested and found to be unstable (Myatt et al.1989).

Virginia

Virginia's primary tire reef, the Tower Reef off Virginia Beach, was constructed in the 1970s using 400,000 un-ballasted tires. The tires began to be recovered on beaches off of Corolla, North Carolina in 1994, following storm events. The recovered tires traveled 60 nautical miles from their original site of deployment. As a result, Virginia artificial reef staff have periodically driven trucks to North Carolina to recover more than 4,000 tires from the beach. To accommodate the additional cost, a solid waste recycling grant, providing up to $25,000 per year, was initiated to facilitate the reef tire recovery from beaches and accompanying shore side disposal operations (Mike Meier, personal communication).

North Carolina

In North Carolina, approximately 650,000 un-ballasted tires were bundled together with steel chain, stainless steel cable, nylon rope, and polypropylene rope and placed as artificial reefs between 1975 and 1983. In 1989 Hurricane Hugo made landfall and tires were found in large numbers on the beach for the first time. Since 1989, approximately 100,000 tires have been removed from beaches in North Carolina at the cost of more than 1 million dollars. Tires continue to wash ashore in large numbers off North Carolina, and as recently as 1998, 28,000 tires were collected after Hurricane Bonnie (Gregg 2001).

Florida East Coast

Several tire reefs were deployed offshore off Jacksonville during the mid-1970s. Jacksonville volunteer dive team personnel report that most, if not all tire reefs off Jacksonville can no longer be located (Alex Waters, personal communication).

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 (B.F.Goodrich Tire Co. 1974). Later, barges stacked with thousands of tires were utilized (Pamela Fletcher, personal communication). In 1979, the Osborne Tire Reef was described "as probably the largest scrap tire reef in the world" (Tolley 1981). The tires were bundled in groups of 8 and bound with plastic strapping that was designed not to rust or corrode. Unlike tire reefs in the Gulf of Mexico which were deployed over relatively open sandy areas, the tires offshore of Ft. Lauderdale were deployed at depths of 65-70 feet between two coral reef tracts (the second and third reef) running parallel to the beach. Assessments of this area document adverse impacts to adjacent natural reefs caused by damage to the reef community as tires pile up along the reef edge (Horn 1997; and Horn and Mille 2001b).

A 1974 report details the 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 stacked on the barge 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.

In 1978, an underwater photogrammetric survey of the Osborne Tire Reef was conducted to provide a base map intended for future monitoring of tire distribution and transport (Raymond 1981). Unfortunately, the 1978 survey is the last known published report, and there is no known evidence of subsequent monitoring.

Due to the historical lack of follow-up monitoring information, by the late 1990s current state and local staff knew very little about the tire reef. It was only by coincidence, during a search for the 1970 Erojack modules, that county and state staff were made aware of the extent of this tire reef (Horn 1997). These recent observations brought new attention to the adverse effects of the migrating tires, and helped initiate efforts by Dr. Robin Sherman and others to execute a pilot tire removal project in 2001 (Sherman 2001).

Observations on December 12, 2001, (after approximately 25 years) showed that the majority of the tire reef consisted of loose whole tires and split tires laying flat on the bottom, one to several layers thick. Although a few sets of bundled tires (4 to 6 tires together) were seen, the number of bundled units remaining intact after 25 years appeared to be negligible (Horn and Mille 2001b). Many of the remnant tires were “half tires”, that is tires that were split longitudinally into two sides. These individual split units were lighter and less stable than the whole tires. The tires themselves were very much intact and showed almost no signs of deterioration. Invertebrate growth was minimal on these tires and in most cases the original brand name lettering and white walls on the tires were clearly visible. The minimal benthic growth on all sides of each loose tire suggested that the lack of growth on the tires 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 2001b).

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 2001b).

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). This is 450 feet larger in both directions than the estimated size of this reef in 1974 (D.E. Britt & Associates 1974). The footprint has 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 has been confined to natural reef lines, with resultant impacts to the border of these reefs by tires moving against or over them (Horn and Mille 2001b).

Directed efforts to cleanup 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 (Robin Sherman, personal communication)

Recognizing chronic impacts to adjacent reefs, and the need for dedicated tire removal projects, tire removal projects in Broward County, Florida, have been accepted as mitigation for other permitted projects in coastal waters. In 1998, removal of tires migrating from former artificial reefs was used as mitigation associated with placement of a dredge pipeline over algae dominated nearshore hardbottom habitat (Florida Department of Environmental Protection 1997). Tire removal may be proposed as partial mitigation for the planned 2002-03 beach nourishment projects in Broward County (Stephen Higgins, personal communication).

Pacific Ocean

California

During the mid 1970s several tire reefs were built off the coast of southern California. The largest of these was built by a private fishing club, the Los Angeles Rod and Reel Club. It utilized 25,000 tires, bound together with nylon parachute cord, on a 35 acres site off Huntington Beach, Orange County. During the winter storms associated with 1977 “El Nino” event several thousand tires washed up on local beaches.

In the same time frame, another much smaller tire reef was constructed off Hermosa Beach in Santa Monica Bay, Los Angeles County, by Department of Fish and Game biologists. It utilized larger aircraft tires, bound together by nylon line through holes drilled into the tires and anchored in place by large gage anchor chain. The reef was built at a depth of 60 feet. It remains in place today. This reef is of particular interest because it was placed at a site which included other materials, including quarry rock, concrete structures, concrete rubble, car bodies, and street cars. Some of these were originally placed as far back as 1958. During the mid 1990s all of the remaining materials at this site were examined for their usefulness as reef substrate. Compared to quarry rock and concrete, the tires had a relatively impoverished cover of attached invertebrates and algae. After 20 years the tire tread was still clearly visible (Dennis Bedford, personal communication).

Based on their inherent instability and apparent lack of suitability as a high quality substrate for the attachment of invertebrates and algae, the Department Reef Program recommended against the further use of tires for reef construction off California.

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.

Nationwide, un-ballasted tires appearing on beaches after storm events are the coastal debris legacy of early artificial reef development and tire use in the marine industry. In addition to storm related cleanup efforts, every year in September, the Ocean Conservancy coordinates a one-day nationwide cleanup on the third Saturday of September. During the five most recent annual coastal cleanup days (1996-2000), each year an average of 9,000 tires nationwide have been collected during the one-day event from beaches and coastal waterways (Ocean Conservancy, 1996-2000 Coastal Cleanup data).

Individually Unmodified and Un-ballasted Tires Incorporated into Designed Concrete Reef Modules

One designed module presently 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 in a 20-year return interval hurricane event (Paul Lin and Associates 2000).

Tires Ballasted in Concrete

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, plastic) has been shown to be significantly less than the long life expectancy of the tires themselves. Data on the predicted life span 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 life spans in seawater of greater than sixty years, there remain concerns that ultimately concrete ballasting material may deteriorate prior to the tires themselves. The predicted longevity of tires relative to concrete should be further researched. Examples of tires ballasted in concrete are described below by state.

New Jersey

In New Jersey, a one year study (September 1986 to July 1987) by marine fisheries personnel was conducted to evaluate ten different concrete ballasted tire designs (5-6 replicates each) for acceptable tire reef stability and durability at depths of 59 - 79 feet. Although no hurricanes were recorded during this period, 13 winter storm events produced wave heights of 3-3.7 feet, with one January storm generating 15 foot seas at 30 foot depths. Ballasted replicates of five types moved during this period while all replicates of five others remained in place (Myatt et al. 1989).

Bundled and individually ballasted tires do not provide a guarantee that such tires will remain in place. Key factors separating the ballasted units that didn’t move from those that did were the following characteristics: greater submerged density (266-499 kg/m3); submerged ballast to car tire ratio of 12-41 kg (26-90 lbs.) of concrete ballast per tire, and the presence in 4 of 5 units of 15-30 centimeter thick concrete slabs in which tire units were anchored (Myatt et al. 1989). Figley (1991), in a New Jersey tire manual, provided additional ballasted tire stability information such as stacking split, compressed, and bundled tires into three-cylinder units filled with concrete, using at least 31 pounds of ballast per cubic foot of unit volume.

The shape of ballasted tire units also affected stability. Single-stack units constructed of 12 compressed truck tires, which were barrel shaped, were rolled by storms away from their deployment sites, even though the entire central cylinder was ballasted with concrete. To prevent rolling, two or three stacks of ballasted tires must be joined together. In New Jersey, the rubber beads from truck tires (cut and opened like giant rubber staples) were used to join adjacent tire stacks together at both the top and bottom. Two- and three- stack ballasted tire units have remained stable at depths of 50 feet for 10 years.

Due to the potential of tire rubber to outlive the concrete ballast and binder in seawater, New Jersey prohibited the use of tires and other lightweight components of reef structures in 2000. This was done in spite of the excellent qualities of tire units in providing substrate for fouling communities and habitat for fish.

New York

Buchanan and Stone (1970) reported that the New York State Conservation Department in the 1960s set three auto tires side by side in a concrete base to form ballasted tire reef modules. Subsequent information regarding this effort is not available.

Delaware

Delaware's artificial reef program is the newest active state reef program among the Gulf and Atlantic coastal states. The program began deploying artificial reefs in the mid 1990s. Approximately a third of the reef material deployed by volume are concrete ballasted compressed truck tires. These units are primarily used because they are prepared and deployed free of charge by the reef program's major contractor, who in turn receives tipping fees to dispose of the tires. The tire disposal is not a state mandate. No automobile tires are utilized and no deployments take place in estuaries. Multiple truck tires are compressed and banded together, and concrete is poured into the center of the cylinder. A typical truck tire weighs 87-100 pounds in air. To minimize stability problems, the units are deployed in no less than 60 feet of water and are regularly monitored. As of 2001, no movement problems have been reported during the first six years of the project (Jeff Tinsman, personal communication).

Texas

In 1971, a sportfishing association constructed a tire reef in West Galveston Bay, Texas. The reef, deployed in West Galveston Bay, was composed of 500 units consisting of four tires joined by steel rods. An attempt was made to ballast the tires with coffee cans filled with concrete; however, the weight associated with the ballasting was insufficient to provide enough ballasting to prevent movement of the tires according to present-day engineering principles. This reef covered 344,438 square feet in just under seven feet of water and was marked with pilings. By 1975, both of these reef sites had subsided into the mud and were no longer functioning as viable artificial reefs (Benefield and Mercer 1982).

Florida

Historically, private and organizational tire reef building endeavors in Florida were very popular from a community participation standpoint. The belief was that both the environment and fishing were being enhanced cheaply and efficiently. However, lack of subsequent long term monitoring, minimal accurate record keeping, the loss of individuals with historic memory, and the later purging of local government or reef committee files, has resulted in a loss of the means to accurately locate and assess the remnants, if any, of these very early ballasted tire reef projects in Florida. Those that have been located and assessed are described below.

Efforts to ballast scrap tires in Florida with concrete occurred as early as 1960. Stone and Buchanan (1970) reported on a ballasted three tire unit. The auto tires were held side by side with a piece of reinforcing rod run through the tire sidewalls, and then an unspecified weight of concrete was poured inside of each tire. This design was used by the Jacksonville Offshore Sportfishing Club to construct an artificial reef off the mouth of the St. Johns River (Northeast Florida) in 1960 and by the City of St. Petersburg to build several reefs in the Gulf of Mexico off Pinellas County in 1962 (west-central Florida). The 2002 status of these ballasted tire reefs is unknown.

Another early record is of a public ballasted tire reef in Florida constructed in 1964 off Wakulla County in 25 feet of water. Two-thousand five hundred car tires were deployed at one site. Each tire was filled at one end with cement and bound in lots of three with steel rods, similar to the techniques used off Jacksonville and St. Petersburg. Florida State University was initially involved in this project and university personnel subsequently followed up with a post-deployment monitoring effort. The results of an assessment conducted 17 years later found that the reef was intact and all tires were upright, although cross sectional diameter measurements of the steel rod showed 25% reduction of the exposed rod compared to pre-construction dimensions (Stanton and Suarez 1980). Results of side-scan sonar work and a visual assessment conducted 36 years after the tire reef was deployed found that the numbers of single tires laying flat on the bottom in one or two layers had been greatly reduced. However, several three-tire units were observed still intact (Maher and Horn 2000).

In the 1960s, prior to formal state artificial reef programs, fishing clubs and private individuals were encouraged to incorporate concrete ballasted tires into artificial reefs. Fishing clubs and private individuals could then cheaply build and easily roll, lift, push, or throw the tires overboard from private vessels. A photograph in Stone and Buchanan (1970) shows individuals throwing overboard single tires each ballasted with 15 pounds of concrete placed in a #10 tin can. The concrete filled cans were jammed inside the tire on the opposite side of the tire from the vent holes.

Another ballasted tire unit described used eight tires strung on two pieces of 3/8 inch diameter reinforcing rod protruding vertically from a single tire into which concrete had been poured to serve as a base. The tires were secured by bending over the excess length of the reinforcing rods at the top. The unit weighed 240 pounds in air and could easily be rolled and pushed overboard where it would stand upright at a height of about four feet (Stone and Buchanan 1970).

In December 1978, and January 1979, Manatee County (southwest Florida) deployed 15 or more concrete slabs (4' X 4' X 2') with 3-4 split tires in them in 20 feet of water in the Gulf of Mexico. Each form held one cubic yard of "end of day" waste concrete and weighed about 1,500 pounds. An inspection one year later (January 20, 1980) by Cindy Lott of Sarasota reported: "Fouling was relatively light on the tires with some parts completely bare and much of the surface covered with silt." In 1992, these concrete tire slabs were encountered during a search for a suitable artificial reef site for a mitigation artificial reef for the Anna Maria Island Beach Nourishment Project. The slabs were observed to have the same or greater density of scleractinian corals on the rubber tires embedded in the cement as the cement slabs themselves (Rick Spadoni, personal communication). As of 2002, the current status of these tire reef units is unknown. The current county artificial reef program has been unable to confirm the continued existence of these units (Bob Fluke, personal communication).

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 (FFWCC 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 2001b). 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 was 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).

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 2001b, 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 2001b). 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).

In northwest Florida, a five foot diameter tractor tire was observed at a depth of 68 feet. The tire was covered by encrusting organisms including non-hermatypic corals, anemones, barnacles, and hydroids (Turpin 2002). Since the tire was not located in a permitted artificial reef site it is expected to have moved offsite from its original deployment location. The large size of the tire likely has minimized movement, allowing enough time for invertebrate colonization.

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

Studies in the past resulted in mortality of rainbow trout from tire leachate (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.

While early studies were lacking data and inconclusive, studies conducted over the last ten years provide more information on 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.

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 have been 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 crum 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. Today, more than 70% of scrap tires are being used or recycled (Scrap Tire Management Council 2001). Illegal stockpiles of waste tires have also been significantly reduced during the last ten years.

During the 1960s and 1970s, tire manufactures 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.

During the 1990s state legislation was enacted across the nation to achieve the above successes. As of 1999, with the passage of new legislation in Alabama, all Gulf coast states now assess a fee on the purchase of new tires to manage scrap tire programs, require permits for storage, collection and transportation of scrap tires, and require manifest during scrap tire transportation (Rubber Manufacturers Association 2002).

To date, the only tires that cannot be cost effectively recycled are massive earth moving vehicle tires resistant to cutting due to their thickness. As of 2002, a single Florida tire recycling facility possesses the cutting equipment to cut an earth moving tire into seven sections. However, transport of large earth moving tires to this Bonita Springs location has not occurred with any regularity.

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 2002, the only states currently allowing deployment of tires as reefs are Delaware (truck tires ballasted with concrete) and Alabama (auto tires incorporated into modular frame concrete units).

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 being durable.

- 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 tires are carefully managed by all Gulf coast states. Tire collection sites must be permitted, and vehicles transporting tires must be registered with appropriate cargo manifests.

- Tire recycling alternatives are available. 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 and regulatory agencies as environmentally acceptable.

- Minor 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 (more research is needed from the marine environment on this subject).

- 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 stable in order for fouling or epiphytic communities to attach to tires, 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.

- Tire unit design should be ballasted and placed at appropriate depths according to recognized engineering principles. The handbook developed by the state of New Jersey provides basic guidelines for ballasting and construction.

- 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. Experimentation is underway to use the inner tire bead as a connector (Figley 1991). This may preclude the need to ballast every tire. However, under any circumstances, sufficient weight must be used to account for all tires used in a unit.

- Tires should not be deployed if they are not properly ballasted. Tires deployed without being ballasted have been documented to move offsite (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 and Selby 1996).

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2.13 *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

2.14 *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, such as with coal combustion fly ash, 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 plastics, fiberglass reinforced plastic (FRP), polyvinyl chloride (PVC) pipe, miscellaneous metals (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.

Approximately 15 ocean-land shipping containers fell off a ship during a storm about 15 miles offshore of Cape May, New Jersey. Since the containers held drums filled with arsenic, there was an intensive hunt and retrieval effort. Some of the containers were never found and most of the ones that were found had broken apart and released their cargo of drums. This experience, while not an artificial reef deployment, led the State of New Jersey to determine that cargo containers of that kind are not considered durable or stable enough to be acceptable as reef material.

In the autumn of 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 US 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.

Georgia deployed approximately 400 Chicken Transport Units (CTUs) at two estuarine artificial reefs in the early 1990s. They were placed on the intertidal sites in clumps of four.

The reefs were sited according to the inshore program's siting criteria, and the cages are fully colonized and covered with oysters. At one of the reefs that was not sited by program personnel, the cages have subsided in to a great degree; however, the exposed portions still support good oyster growth. All cages that were deployed in the 1990s remain intact.

In northwest Florida, miscellaneous materials, including CTUs 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. CTUs and other miscellaneous materials go through a county inspection program. Any fiberglass flooring has to be removed from the CTUs 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 CTUs have been deployed to northwest Florida Large Area Artificial Reef Sites (LAARS) by private recreational fishermen and charterboat 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 CTUs. 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 CTUs. From December 2002 through April 2003, of 38 private reef deployment inspections, 35 (92%) were conducted mostly or entirely on CTUs and included a total of about 504 CTUs. 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 CTUs 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 CTUs 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 CTUs over a multi-year period by fishermen suggests they are performing effectively as fishing reefs. Formal documentation of CTU performance off Florida has been limited to word-of-mouth and to video clips showing CTU utilization by such recreationally targeted species as red snapper (Jon Dodrill, personal communication).

CTU 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 CTUs 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 CTUs was reported out to depths of 90 feet (David Walter and Robert Turpin, personal communications).

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3.0 CONCLUSION

It is expected that this will be a living document, now in its second 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.