GUIDELINES FOR MARINE ARTIFICIAL REEF MATERIALS

Compiled by the

Artificial Reef Subcommittee

of the

Technical Coordinating Committee
Gulf States Marine Fisheries Commission

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January 1997

This project was conducted in cooperation with the U.S. Fish and Wildlife Service, and funded by Federal Aid in Sport Fish Restoration Administrative Funds, FWS Grant Agreement No. GS-96.

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ACKNOWLEDGMENTS

The Gulf States Marine Fisheries Commission would like to thank the authors of the various sections of this document for their thorough treatment of the subject matter and their diligence in getting the job done. We wish to express our gratitude to the U.S. Fish and Wildlife Service for their support of this project, and their patience in allowing us a time extension to finish this important document. Finally, we would like to thank Nancy Marcellus for her talents and dedication applied to the development and completion of this document.

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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 use in the 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 the ubiquitous Mr. Webster. So, why be concerned about the definition of the word "habitat" in a paper which 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 reality, artificial reefs constitute habitat for fish and other aquatic organisms. Consequently, regardless of the underlying reason for the development of particular artificial reefs (ie. enhance fishing success, publicity, disposal of solid waste, etc.), the end result is the creation of habitat for a variety of fish species and other organisms that utilize the new habitat for a variety of reasons, including shelter, feeding, thigmotaxis, and perhaps others with which we are unfamiliar.

The occurrence of certain species of fish in a given area is largely attributable to the existence of factors on which the species depends 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. 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. Those factors will also dictate to great extent what species of fish will be attracted to and flourish on an artificial reef.

Generally, the largest number of artificial reefs have been developed in areas that are largely devoid of irregular bottom topography. A large portion of the continental shelf of the northern Gulf of Mexico is gently sloping with a seemingly barren 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 which inhabit low salinity, relatively shallow estuarine areas include spotted seatrout, red drum, flounder, Atlantic croaker, among others. These species utilize a variety of habitat components including mud flats, submerged and emergent grass beds, and oyster reefs, to name a few. The addition of artificial habitat will, in all likelihood, attract these species of fish at various times, but will not likely 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. An index of similarity comparing the species composition of the flat, featureless bottom with the artificial reef resulted in a value of 0.32, which indicates little similarity (Lukens 1980).

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) provide an excellent summary of the history of artificial reef development in the United States. This summary will cover some of the high points in that article. The first documented artificial reef in the United States was off South Carolina in the 1830s using log huts. From that time to the present, over 80% of artificial reefs in United States waters have been created using materials of opportunity. Materials of opportunity 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 1970's, and continues to the present. While materials of opportunity are still relied upon in the majority of artificial reef construction projects, several 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. Whether using designed materials or materials of opportunity, it is likely that artificial reef development will continue at a pace that early activists would not have predicted, a situation which 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.

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. If there are environmental risks associated with using a specific material, that risk should be known and steps to minimize that risk should be taken if such a material is to be used. If the risks outweigh the other criteria, or minimizing the risks becomes too expensive, alternative materials should be considered.

1.4.3 Durability and Stability

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 that environment. Durability is specifically related to how long a material will last in the marine environment in a form that will maintain its function and compatibility. Stability 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 durable and stable, then alternative materials should be considered.

1.4.4 Availability

Of critical importance to the ability of artificial reef programs to develop artificial reefs is the availability of materials. Cost is a significant factor related to availability. 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.

Each of the four criteria 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 must be selected because they meet the primary goal of creating habitat for marine fish and invertebrate organisms.

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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 *Natural Materials*

2.1.1 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 indicates that grunts, damselfish, and parrot fish 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 (ie. 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

- C 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.

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

- C 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.

- C 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.

- C 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, Texas Parks and Wildlife, personal communication).

- C 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).

Recommendations

- C Because reef building with electrodeposition is still experimental, and the possibility that the process of electrodeposition could produce harmful byproducts, it is not recommended for artificial reef construction, except in experimental applications.

- C 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.

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

2.1.2 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 are used in many parts of the world as reef material for fish attraction devices (FADs), particularly in local traditional fisheries (Grove et al 1991). On the Gulf Coast of Mississippi and Louisiana, willow and wax myrtle branches have been tied in bundles and set on lines to attract peeler crabs for harvest (Jaworski 1979). Other references to wood, other than wooden vessels, for artificial reef development in the United States are rare. In Mississippi, and probably most other coastal states, there is anecdotal information about placing Christmas trees or brush in nearshore waters to serve as fish attraction devices.

Benefits

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

C 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.

C 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 were examining wooden vessels.

Drawbacks

C Many of the same problems in using wooden vessels would be inherent in using natural wood resources as reef material.

C Wood has a short life span in marine environments, as it is broken down rapidly by boring and microbial organisms. As the reef structurally deteriorates, pieces of it are subject to breaking off and floating away from the reef site.

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

C Processed wood, used for many construction purposes, is often treated to minimize rot. Such processed wood can introduce toxic compounds into the environment.

Recommendations

- C 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.

- C To keep a wooden reef on site it would need to be heavily ballasted which could incur the cost of ballast material (i.e. concrete) and labor needed to prepare the material for deployment.

- C Chemically treated, processed lumber should not be used as artificial reef material, because of the potential introduction of toxic compounds into the environment.

2.1.3 Shell

Overview

Shells have historically been used by each state in the Gulf of Mexico region to replenish or create 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 1950's and in Mississippi from the late 1970's. Most references generally discuss how shell functions as cultch for oyster spat attachment, rather than how it performs as artificial reef material. Two studies which 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, that 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 effect the species that would colonize and utilize the potential reef site. One of the considerations when using shell for nearshore artificial reefs should be a knowledge of species it would possibly attract or benefit.

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, Texas Parks and Wildlife Department, 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 Corps of Engineers as part of an enhancement project at the Mouth of Colorado River (Bob

Bass, U.S. Army Corps of Engineers, Galveston District, personal communication). The Corps of Engineers 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).

Two other studies (Bradley 1963 and Bradley 1965) evaluating oyster shell as artificial reef material were done 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.

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.

- Little liability is associated with shell reefs because they are not a hazard to navigation or to a traditional trawl fishery.

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.

C 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.

C Local pressure to transplant shell material for developing public oyster reefs by commercial fishermen would make stockpiling shell material for artificial reef application difficult.

C Shell is a small, light-weight 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. It is doubtful that shell would be of any value in offshore areas because the deeper water and currents would tend to scatter the shell over a wide area, offering little relief or continuous hard bottom habitat.

Recommendations

C Shell may not be effective for offshore reef development because of the small amount of relief and complexity it would provide and the high probability of it being widely scattered by offshore currents.

C 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 because the shell may be buried. 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.

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

C 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.

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

C 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.

C 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).

2.1.4 Quarry Rock

Overview

Until recently, quarry 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). Other studies of artificial reefs constructed of quarry rock in California compared fish densities between artificial rock reefs versus natural rock reefs and kelp forests (Jessee et al. 1985 and DeMartini et al. 1989). These studies found that significantly higher densities of fish were found on the rock artificial reefs.

Programs in southern Florida are beginning to use quarried limestone for artificial reef development. Estuarine reef development has occurred off Palm Beach County, using two to six foot limestone rock. This project used 270 tons of the material in conjunction with concrete modular units. Also off Palm Beach County, a project used over 2,500 tons of limestone in 75 to 80 feet of water to construct corridors between existing shipwrecks. Off Boca Raton, limestone rock was used to develop a snorkeling reef. The project, developed as a mitigation effort 50 feet from shore in nine feet of water and using two to four foot diameter limestone pieces, was evaluated nine months after deployment and revealed 23 species of fish associated with the material. Several projects have also been conducted using limestone boulders of various sizes off Dade County (Jon Dodrill, Florida Department of Environmental Protection, personal communication). Florida has also used limestone embedded in concrete modules off Dade County to increase surface area for benthic fouling organisms (Virginia Vail, Florida Department of Environmental Protection, personal communication). While quantitative analyses were not conducted, evaluations by the Florida Department of Environmental Protection of dredged limestone placed in 33 feet of water nearly 70 years ago indicate that vertebrate and invertebrate fauna resembled the fauna found around natural hard bottom sites in similar depths in that general area.

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 1995, Mississippi deployed 4,500 cubic yards of one to two inch limestone rock in various quantities at 11 different inshore, estuarine sites for low profile reef development. They have not yet been evaluated.

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 material, so it would be unlikely to move off the reef site except in the most extreme conditions.

- Rock is durable, and a reef built from it would last a long time.

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

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.

Recommendations

- When deploying quarry rock, the use of a front-end loader instead of a crane, or the use of a bottom-opening hopper barge may reduce the cost of deployment (Foster and Fowler 1992).

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2.2 *Concrete*

Overview

Concrete, either in fabricated units specifically designed for artificial reefs 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. A scan of the national database for artificial reefs, developed through the Artificial Reef Development Center at the Sport Fishing Institute, indicates that, as of 1993, 35% of the 717 known permitted artificial reefs used concrete materials of opportunity. The data for Florida indicate that 285 (62.2%) of the 458 state or federally funded deployments have been concrete materials. Four (4) percent, nation-wide, used concrete in prefabricated units.

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. Type I Portland cement is not suitable for marine applications, because it will deteriorate quickly under attack from sulfates, carbon dioxide, and Magnesium ions. Sea water contains 150 to 1500 parts per million (ppm) of sulfates, so concrete must be sulfate resistant. Type II Portland cement can be expected to provide a life expectancy in the marine environment of 20 to 35 years. Higher grades of concrete, using perhaps Type V Portland cement, are recommended for longer life expectancies. Marine applications of concrete under load bearing conditions, such as bridge spans, require at least Type II Portland cement. Scrap concrete from other sources, such as building foundations or parking lots, may not possess necessary strength due to the use of Type I Portland cement. These materials may not last as long as expected in marine applications such as artificial reefs.

Lime (calcium hydroxide) in "green" or uncured cement may have surface pH levels of 10 to 11, which is significantly more basic that sea water, 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.

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 at least 30 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 cementitous material. Fly ash batches used by FDOT are checked through independent quality assurance tests based on industry standards for sulphate 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, Texas Parks and Wildlife Department, 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 (Jan Culbertson, personal communication). 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 Texas Parks and Wildlife Department 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, Texas Parks and Wildlife Department, personal communication).

Texas Parks and Wildlife Department, with cooperation from the U.S. Coast Guard, is in the process of constructing a reef offshore of Sabine Pass made of 100 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).

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.

- Most concrete materials that have been used are in the form of rubble or pieces, and must be piled high in order to provide an artificial reef with a high bottom profile. This can be challenging depending upon the sea state, water depth, and current velocity.

- While concrete materials are known to last a long time in the marine environment (concrete pipes planted in 1962 are still evident off Perdido Pass, Alabama), it is thought that the cement binding material will eventually leach out, leaving only the remaining aggregate, reinforcement rods, and wire.

Recommendations

- 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.

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2.3 *Automobiles*

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 macroinvertebrates to a greater degree than those manufactured subsequently. The sheer weight of attachment and encrusting organisms on plastics and fiberglass tends to break the organisms loose from the ultra-smooth surface. This does not occur with ferrous metals, except in situations where corrosion is advanced.

A search of the available literature indicates the earliest use of automobiles as artificial reefs to be in the late 1960s; 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 jewfish, 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, Jeff Tinsman, personal communications).

Reports from anglers offshore Alabama indicated that following Hurricanes Frederick and Elena in 1979 and 1986, respectively, there was little movement of automobile bodies deployed as artificial reefs in Alabama’s large general permit areas. Hurricane Opal, which skirted the Alabama Gulf

Coast in October 1995, had a devastating impact on the automobile bodies in that area, with many artificial reef builders reporting the loss of over 80% of their sites. Months later, approximately 50% of the lost automobile bodies were found approximately 900 feet northwest of their original location. Some of the automobile bodies were discovered in their original locations, but were buried under three to four feet of sand. It is interesting to note that, prior to 1992, automobile bodies deployed as artificial reefs offshore Alabama were not required to have the engines removed. The engines certainly provided additional weight, which could have been a factor in reducing movement of the material during earlier storms (Walter Tatum, personal communication).

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

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, totmate, 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).

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 Environmental Protection Agency (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, Environmental Protection Agency, 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 and 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).

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.

C 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.

C 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.

C 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.

C There may be a residue of heavy metals in the sand after the metal corrodes away.

Recommendations

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

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

C Oil must be removed from the engine block.

C The engine should be steam-cleaned or removed.

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

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

C Electrical components capable of emitting polychlorobiphenyls (PCBs) must be removed.

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

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

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

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

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2.4 *Vehicle Tires*

Overview

Analysis of a national artificial reef database, originally developed through the Sport Fishing Institute's Artificial Reef Development Center, reveals that, nation-wide, vehicle tires are found on 21% of all existing, permitted artificial reef sites, ranking second behind concrete. In the Gulf of Mexico, tires are found on 14% of all permitted sites. Vehicle tires have been used in the United States as artificial reef material since the late 1950s or early 1960s (Mathews 1983). Early use of tires was haphazard, deploying tires in unballasted bundles. Because tires are either neutrally or slightly negatively buoyant in salt water, stories abounded in the 1970s regarding tires washing up on beaches and being caught in shrimp trawls, a phenomenon that has recurred as recently as 1995, when Hurricane Opal caused several hundred tires to be washed onto the beach in the Florida panhandle (Jon Dodrill, personal communication).

Recognizing that tires are basically unstable in salt water, artificial reef researchers and developers began to experiment with ways to make tires more stable. Tire 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). This approach also created problems, because the material used to bale the tires together eventually corroded or rotted, thus resulting in loose, unballasted tires on the sea bottom (Kasprzak et al. unpublished). Mathews (1983) states that even when bundled together, tires are still unstable in salt water and can easily be moved about by tide and current action.

The next approach to attempt to use tires effectively as artificial reef material in salt water was to ballast the tires with concrete. Units consisting of from one tire (Fast and Pagan 1974) to 20 or more tires (Myatt et al. 1989) have been developed using concrete core cylinders or poured concrete as ballast (Parker et al. 1974, Myatt et al. 1989, and Stone et al. 1974). Early efforts simply applied concrete with no consideration to the amount necessary to properly ballast the material. As efforts continued, engineering principles were applied, and a formula for the proper amount of concrete was derived (Figley 1991). The use of properly ballasted tire units has been successful, resulting in artificial reefs that attract and hold fish and invertebrate populations without being unstable in salt water.

In 1966, vehicle tires were first used in Texas by a private company as artificial reef material 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 in ten feet of water depth. In 1968, divers found that barnacles and other encrusting organisms covered this reef and there was no evidence of settling into the substrate. In 1971, a sportfishing association constructed a second tire reef in West Galveston Bay. The reef was composed of 500 units, consisting of four tires joined by steel rods and weighted with concrete in West Galveston Bay. This reef covered 344,438 square feet in just under seven feet of water and was marked with pilings. However, by 1975 both of these reef sites had settled into the mud and were no longer functioning as viable artificial reefs (Benefield and Mercer, 1982).

In 1976 the Texas Parks and Wildlife Department and the Texas Coastal and Marine Council entered into a cooperative program to construct six separate tire reefs to provide fishing areas with reef location markers 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 to contain the tires in the event the plastic strapping broke and to also prevent movement in individual bundles by tidal and wave action.

The largest of the six tire reefs consisting of 6,000 tires punched, bailed and assembled into two 500 module units covering approximately one acre, 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 sunk into the mud (Crowe and McEachron 1986). These reefs were constructed in water with less than ten feet in depth and were subject to forces from currents and wave action not experienced by tire reefs built in deeper water by other state reef programs.

Reports are inconclusive regarding the leaching of toxicants from tires into water. Studies in the past (Kellough 1991 and Anonymous 1992a) resulted in mortality of rainbow trout from tire leachate. While these studies were conducted in fresh water, the results are cause for some concern. Mike Meier (personal communication to Bill Muir), Virginia Artificial Reef Coordinator and Chairman of the Atlantic States Marine Fisheries Commission's Artificial Reef Advisory Committee (ASMFC/ARAC), expressed concern on behalf of the ASMFC/ARAC that tires may expose the marine environment to toxicants in leachate. In a letter to Bill Muir, U.S. Environmental Protection Agency (EPA), he requested that the EPA initiate a comprehensive study to determine if tires leach toxic substances. That study was planned, but was canceled due to a lack of funding.

A briefing statement from the Tire Management Council (Anonymous 1992b) states that several studies have proven conclusively that leachate from automobile tires is well below EPA Drinking Water Standards and poses no environmental threat. The statement does not stipulate if tests were conducted in salt water. A study conducted by Stone et al. (1974) found no adverse effects to marine fish used in leachate tests when exposed to automobile tires. This test was conducted using a flow-through system, and may be flawed as a result, since a flow-through study would, by definition, wash away any substances leached from the tires.

Conversations with individuals who have used tires as artificial reefs, or information from project reports, yield mixed comments. Dodrill (personal communication), citing a report, indicated that approximately 2,400 tires were placed off Palm Beach County, Florida. They were placed in 70 to 80 feet of water and became periodically covered and uncovered with sand. These tires have exhibited no associated biological productivity. In a 1994 environmental impact report to Dodrill (personal communication), Tony Harroun, City of Jacksonville, Florida, indicates that the stability of tires in the marine environment is not predictable, and that costs associated with their use as artificial reefs is prohibitive. Ken Banks (personal communication to Jon Dodrill) reported that hundreds of tires were bundled together using nylon strapping and sunk off Ft. Lauderdale, Florida several years ago. Those tire bundles separated, scattering tires over a large area. Local residents consider the tires an eyesore and want them removed. Foster and Fowler (1992) reported that North Carolina has experienced large numbers of tires washing up onto beaches in the southern part of the state after deployment of tens of thousands of tires, unballasted, and strung together by cables. North Carolina no longer permits the use of tires as artificial reefs. Mike Meier (personal communication to Jon Dodrill) indicated that crabbers pulling dredges over tire reefs may have seriously damaged the structures. Tires deployed as artificial reefs off Virginia have moved south and have washed up on beaches in North Carolina.

In contrast to the negative reports above, Foster and Fowler (1992) report from several Atlantic coast states, including New Jersey and Maryland, that the use of tires, properly ballasted, has yielded positive results. They remain relatively stable in the marine environment, encourage fouling, or epiphytic, communities, and attract fish species. While some tire use continues, even some of the agencies listed above have discontinued the use of tires, citing difficulty in handling, high costs, and a concern over the perception of at-sea disposal of solid waste. It should be noted that, in some areas, pressure has been placed on artificial reef programs to use tires to construct artificial reefs primarily for the purpose of solving a land-based solid waste disposal problem. As of 1985, the use of automobile tires as artificial reef material was restricted or banned in California and Washington (Stone 1985).

Tire chip aggregate/concrete products for artificial reefs have recently been proposed as an alternative to whole tires imbedded in concrete. In Florida alone, 19 million waste tires are generated annually. Of these waste tires, three and one half million are used a cement kiln fuel, six million are used as boiler fuel in power plants, two million are made into crum rubber for highway use, and three million are retreaded or resold as used tires. Additional non-industrial uses include providing daily cover for landfills, developing safer playground surfaces, and improving drainage on athletic fields. Some cut-up tires continue to be placed into landfills (Bill Parker, personal communication).

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, though the time period is considered insufficient to draw valid conclusions concerning the suitability of the tire chip/concrete aggregate as an artificial reef construction material (Spieler 1995). The second project used Sarasota County waste tire grant funds to incorporate four to six inch pieces of steel-belted radial tires in a concrete mix to produce Reef Ball (patented product) 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, thus potentially affecting the stability of such artificial reef units. 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 artificial reef application. For example, the wave tank models indicated that the unit weight of a tire chip/concrete tetrahedrons 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 and Selby 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 no known; however, once that time has passed, the embedded tire chips would be released into the surrounding environment.

Benefits

- Vehicle tires are readily available in large quantities. Minter (1974) stated that as of 1974, the United States was producing about 200 million used tires annually. That number has undoubtedly increased.

- Vehicle tires can usually be acquired free or very inexpensively. McIntosh (1974) described a cooperative project between the governmental sector and Goodyear Tire and Rubber Company to develop an artificial reef in Florida. Such collaborative efforts can be cost effective in not only acquiring tires, but also in getting tire unit construction and transportation donated (Minter 1974). Many tire businesses are looking for ways to utilize used tires that have accumulated and may be willing to pay for or otherwise provide transport of the tires to a staging area.

- Tires will last indefinitely in the marine environment (Parker et al. 1974, Tolley 1981, Mathews 1983).

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

Drawbacks

- Many individuals are concerned that there may be leaching of petrochemical or heavy metal toxicants from tires into the marine environment. The leachate issue has not been satisfactorily resolved.

- Tires are inherently unstable in salt water. As a consequence, they must be ballasted in order to assure that tire units do not move in response to tidal or current movement.

- Ballasted tire units are bulky, heavy, difficult to handle, and difficult to transport without heavy equipment.

- There is disagreement regarding whether or not fouling, or epiphytic, communities attach to tires. States on the Atlantic coast have documented such fouling growth; however, tires that have been deployed offshore Mississippi for over 18 years still exhibit no fouling growth.

- 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.

Recommendations

- Tires should be clean and free of petroleum or other environmentally incompatible substances.

- Only used tires should be used as artificial reef materials, as new tires are known to leach petrochemical and heavy metal toxicants.

- Tires should be ballasted according to 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. 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 can be chipped and incorporated into concrete as an aggregate.

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2.5 *Aircraft*

Overview

Military aircraft operating out of southeastern coastal naval, 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 north west Florida in the 1940s to 1950s are still used as artificial reefs (Steve Bortone, University of West Florida, and Mike Hendrix, private citizen angler, personal communications).

References to 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. It is possible that some of these Pensacola wrecks located in close proximity to each other were intentionally disposed of by the armed forces. 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, dive shop owner, 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-84's 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, Florida Department of Environmental Protection, and Larry Beggs, SCUBA instructor, personal communications).

Documented aircraft wrecks off other Gulf Coast and Atlantic Coast states in less than 175 feet of water are apparently uncommon. Some unsalvaged 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 Heines, personal communication). 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.

Beginning in the mid 1970s, damaged planes or those aircraft whose designs had reached a point of obsolescence after 25 to 40 years became more readily available to organizations interested in the intentional placement of such aircraft as artificial reefs. Florida and North Carolina represent the two major states where surplus aircraft have been intentionally deployed as artificial reefs during the last decade. In Florida, known locations of aircraft, purposefully placed for use as artificial reefs, include one DC-4 off Broward County (1985, 71 foot depth), two Navy F-4 Phantom fuselages off 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-4 fuselage off Wakulla County (1988, 23 foot depth, Pybas, 1991), one F-101, one F-102, one Sikorsky helicopter, and one T-33 trainer, all off Bay County (mid-late 1970s, 60 to 70 foot depth, Danny Grizzard, Panama City Marine Institute, personal communication), a Boeing 727 jet placed off Dade County (1993, 82 foot depth). The most recent southeastern aircraft artificial reef deployments were summer 1995 placements of approximately 30 Navy A-6 Intruder aircraft fuselages in 100 feet of water off St. Johns County in northeast and six Air Force F-106 drone jets with wings still attached and nose cones removed in 90 to 100 feet of water off Bay County (Charles Gonzales, Bay County Planning Division, personal communication). Regarding the A-6 Intruder aircraft, review of video footage taken one month post-deployment indicated that the majority of the aircraft components 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 and unable to escape. Efforts have subsequently been made by divers to make escape holes in the canopies. Fish species documented in the video include barracuda, amberjack, and round scad. Grouper and snapper species were not seen at that time.

North Carolina has placed six aircraft for use as artificial reefs at depths ranging from 50 to 65 feet. These include two C-130 cargo fuselages, two intact F-4 Phantoms (minus the engines), and two A-4 fuselages (Steve Murphy, personal communication). Other aircraft placements include the 1992 placement of steel aircraft tail assembly sections in 90 feet of water at Alabama's Morisette Reef (Walter Tatum, personal communication).

Video footage, in the possession of the Florida Department of Environmental Protection, taken around 1992 and donated by Mike Hendrix (personal communication), showed three 40 to 50 year old aircraft wrecks at depths exceeding 90 ft 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). 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. The wing tips and prop had ripped off, and some of the aircraft skin was missing but the internal frame of the plane was intact over 50 years later. Visible in the video were vermilion snapper, triggerfish, spadefish, amberjack, blue angelfish and butterflyfish.

A torpedo bomber crashed and sank onto a soft mud bottom in the late 1940's. The propeller, doors, hatches, and canopy were missing, but the fuselage and wings were clearly discernable, and the aircraft still identifiable as to type. Warsaw grouper, red snapper, 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. The surface fabric was gone but the metal framework and the fuel tanks remained. Several large stingrays, small grouper, snapper, many triggerfish, and some bank sea bass were visible around the wreck.

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 with tail hook and landing gear extended, in 110 feet of water. On the wreck were large grouper under the wings, red snapper immediately above the wreck, a loggerhead turtle, and a barracuda. Circling higher in the water column above the wreck were scores of large amberjack whose collective weight was estimated by the video narrator at 50,000 pounds (Mike Hendrix, personal communication).

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, have survived as fishing and diving sites at least 10 years (Danny Grizzard, personal communication). A P-47 single-seat Thunderbolt fighter that ditched in 65 feet. of water in 1943-1944, 25 miles off Franklin County, Florida, 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, Florida Department of Transportation, personal communication).

No data are available on the status of two F-4 Phantom fighter jet fuselages sunk in 80 feet of water in 1988 off Dade County, Florida. Two F-4 aircraft, sunk in April 1992 offshore of North Carolina in 53 feet, 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. The A-4 North Carolina aircraft, on the other hand, were substantially damaged when a load of concrete material was deployed on top of them (Kurtis Gregg, personal communication). The North Carolina artificial reef coordinator stated that given the choice between aircraft and a similar size steel-hulled vessel, he would choose the latter for durability and stability. He would not actively seek out aircraft or pay to prepare and deploy them as an artificial reefs. North Carolina’s plane project took place because the aircraft were obtained free of charge (Steve Murphey, personal communication).

Three Florida aircraft artificial reef deployments and an aircraft ditching in shallow water off southeast Florida are worth discussing in the context of some of the previously mentioned drawbacks. 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. The aircraft were fuselages only and 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, Collier County Department of Natural Resources Management, personal communication).

Before one of the above aircraft broke up, a sea turtle entered an open door of one of the aircraft, became disoriented, was too large to escape through the windows, and drowned inside the fuselage. Efforts to cut larger holes in the fuselage to prevent future incidents further weakened the structural integrity of the aircraft and probably accelerated its break up (Kevin Dugan, personal communication).

As part of a federally funded artificial reef project, 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. The aircraft was anchored by separate cables run from six concrete blocks weighing several hundred pounds each, which were evenly distributed along the fuselage, three to a side. The cables ran through one window and back out an adjacent window to the blocks where the cable was secured to itself with a clamp. The fuselage was in an area of shifting currents. Divers could sit in the fuselage and feel it rock. Within a year the cable had cut through the fuselage, resulting in the breakup of the aircraft. No parts of the aircraft can be located (William Horn, personal communication).

The largest intact 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 which consisted of seven special anchors secured to the wings and fuselage and costing about $750 each. Within 18 months a 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, Dade County Environmental Resources Management, 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. The only other large aircraft fuselages (two C-130 cargo planes) were in the water off North Carolina 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).

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).

Military cargo plane fuselages and conventional passenger aircraft, even securely anchored, do not hold up in shallow water in the face of normal 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.

Reef coordinators currently working with aircraft are doing so on a pilot project basis. Aircraft are not preferred over steel vessels of similar size but of greater weight, or even other materials. They have been utilized primarily because they were free, deliverable to a staging area or deployment site at little or no cost, or were to be used in a materials comparison study.

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.

- Aircraft or parts of aircraft in deeper water (90 to 150 feet) attract mangrove, red, vermilion snapper, grouper, flounder, triggerfish, amberjack, and other preferred species. Little known aircraft wreck sites in northwest Florida were prized fishing locations for recreational anglers for decades. Some fishermen claim that aircraft aluminum selectively attracts red snapper though no studies could be found to document this. Similar unsubstantiated claims regarding selectivity of king mackerel to aluminum aircraft wrecks off North Carolina have also been reported (Kurtis Gregg, personal communication).

- In clear, subtropical waters, fouling communities appear to readily develop within two years. However, same-site comparisons of aluminum fouling with other materials was unavailable.

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

Drawbacks

- C Aircraft can be unstable and short lived in shallow water (less than 50 feet), or high current situations at greater depths. Separate pieces (tail sections) may be unstable in deeper water. The aluminum skin will corrode over time, though the frame will last for decades if not subjected to severe structural stress. The corrosion rate may depend on the types of alloys (eg. titanium) incorporated with the aluminum.

- C Aircraft may require substantial ballasting (concrete poured into wings and fuselage). Use of an external anchoring system would involve additional expense and necessitate periodic checking and maintenance.

- C Aircraft are designed to fly and are lighter than heavy gauge steel vessels with similar hull surface areas. Leaving the wings on in their entirety could create a potential for lift to occur if strong currents move over and under the wings. However, the current speed may be insufficient to lift heavy aircraft, or the surface area of the wings, once in contact with the substrate, may provide some suction. With wings entirely removed, the structural integrity of the aircraft may be partially compromised, along with a reduction in habitat complexity.

- C 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.

- C Aircraft aluminum has salvage or recycling value that may compete against their use as artificial reefs.

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

- C There is some concern about other heavy metal alloys that may be present in aircraft aluminum or paint of aircraft (Kevin Dugan, personal communication).

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

Recommendations

- C A decision to use aircraft as artificial reef material should be based on ready availability 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.

C Small, heavily built, combat fighter aircraft are likely to be more stable and durable in the marine environment than larger military cargo or commercial passenger aircraft. 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 30 to 50 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, which are not recommended for use.

C Aircraft were not specifically engineered to remain stationary in a high energy ocean storm situation. The deeper the depth the plane is placed, the better it seems to fare over a period of decades. Additional ballasting of the fuselage and wings, if no anchoring system is planned, is recommended to improve the surface area/mass ratio.

C 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.

C When using aircraft, all fuel and hydraulic lines should be removed. Through holes drilled in the wings, degreaser should be used to flush out residual fuel and hydraulic fluid.

C Luminous dials should be removed, as they contain toxic materials.

C Fuel manifolds should be cleaned, and the aircraft should be completely steam-cleaned prior to deployment.

C Areas where fish or other marine organisms can be trapped should be opened to water flow by cutting escape holes.

C 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 which would cause cable abrasion against or cut into the aircraft structure itself should be avoided, along with expensive maintenance-intensive systems or those which would promote vandalism or theft.

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2.6 *Railroad 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 2 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, Okaloosa County Artificial Reef Coordinator, 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) 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, Lee County Artificial Reef Coordinator, personal communication).

The Lee County, Florida hopper cars were inspected after approximately 2.5 years following deployment. The group of 16 cars that were stacked 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 jewfish, gag, and large schools (100+) of grey 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 were the two single hopper cars which were located about 60 feet from each other at the same location as those rail cars discussed above. Fish species diversity was similar to the larger 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 know 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).

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, Brown Marine Service, personal communication).

Steel boxcars, 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). Box cars offshore of Alabama supported red snapper and vermilion snapper (Walter Tatum, personal communication). Box cars deployed off Sarasota County, Florida supported mangrove snapper, lane snapper, jewfish, white and tomtate grunts, juvenile amberjack, and queen angelfish (Jon Dodrill and Tom Maher, personal communication).

The structural failure of the majority of the boxcars in North Carolina occurred within two years post deployment and has been confirmed by side scan sonar surveys of the sites. (Steve Murphy, personal communication). 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. 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).

The collapse of 48 wood and steel box cars off Lee County, Florida began within months after 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). Deterioration of the wood apparently played a role in the rapid demise of boxcars in both projects. The wood components of a wood and steel tram car deployed in Moreton Bay, Queensland, Australia, in 1986, badly deteriorated (no time frame given), with only the steel portions of the structure remaining intact (Branden et al., 1994).

The experience with boxcar use in New Jersey followed a similar trend. Following the experiences of others where boxcar sides collapsed, the state program never deployed complete boxcars, opting to cut the horizontal side walls and end panels off, and deploying 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 (Bill Figley, personal communication).

After six years, some steel boxcars off Sarasota and Okaloosa Counties, 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, Sarasota County Artificial Reef Coordinator, personal communication). Although the status of every boxcar was not available for Bay, Gulf, and Okaloosa Counties, Florida, anecdotal information received from charter diving operations in those areas indicates that at least some of the box cars have fully or partially collapsed (Nancy Birchett, diving charter operator, and Danny Grizzard, personal communication).

Boxcars in water deeper than 100 feet may 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). Remote video from the NMFS showed boxcars off Alabama still intact six months after an August 1989 deployment in 100 feet of water. These sites have not been evaluated since that time (Walter Tatum, personal communication).

Lukens Consulting (1995) reported on the vertical heights of the corners of four steel boxcars deployed offshore Mississippi in 1986. The first measurements 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.

Partially collapsed boxcars continue to provide reduced habitat, the effectiveness of which may depend upon how the walls of the boxcars 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 remains standing on each of two boxcars after six years. Sixteen species of fish were still observed on those boxcar 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. Off Sarasota County, Florida, another pair of 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 (jewfish) or resulted in fish as small as 10 inch lane snapper 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).

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 continue 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).

Benefits

C 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 holds will also provide for better water circulation in the boxcar's interior.

C Boxcars, to date, have been donated, so only cleanup, preparation, and sea transportation costs were incurred. The railroad companies realized tax writeoffs. The costs to deploy 16 boxcars off Okaloosa County, Florida in 1988 amounted to $22,000, or $1,375 per car (Jack Spey, personal communication).

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

C Boxcar vertical profile that exceeded 10 feet appeared, at least initially, to be attractive to both pelagic and demersal fish species.

Drawbacks

C Most of the vertical relief on steel walled boxcars appears to be lost within four years. This is due to 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. The collapsed walls of a boxcar, depending on how they fall on each other, may continue to supply low profile ledge habitat in excess of seven years post deployment.

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

C Boxcars as materials of opportunity 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.

C Life expectancy of boxcars as functional reef material beyond 10 years, the length of time they have been in the water off North Carolina, is unknown.

C 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.

Recommendations

- C 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.

- C 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.

- C Stacking of railroad cars may provide greater reef longevity (Steve Murphy, Steve Boutelle, and Tom Maher, personal communications).

- C Observations offshore Florida indicate that hopper rail cars are more durable than standard box cars, after 2.5 years in the marine environment.

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2.7 *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 50 years later.

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. A 1972 appropriations bill provided for the transfer of obsolete Liberty ships from the MARAD to coastal states for use as artificial reefs and resulted in the passage of Public Law (P.L.) 92-402, the Liberty Ship Act. 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). In 1984, P.L. 92-402 was amended by P.L. 98-623 to include reserve fleet ships other than the Liberty class for artificial reef construction, since most of the nearly 650 WWII era merchant vessels still available in the early 1970's were Victory class ships. However, relatively few of the Victory class merchant vessels were ever secured for use as artificial reefs and most of the Victory ship fleet has apparently been scrapped. Deployment of P.L. 92-402 ships virtually ceased from 1978 to 1987. Only six (15%) of 42 P.L. 92-402 vessels sunk as reefs outside of Florida were deployed from 1988 through 1992 (Gregg and Murphy 1994). In Florida under the amended P.L. 92-402, 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 seven years of no availability of ships from MARAD under the Liberty ship program, a fall 1996 sinking of a donated 510 foot ex-navy Landing Ship Dock (LSD) off Key Largo, Florida is scheduled. This will be the largest vessel intentionally sunk in the U.S. as an artificial reef. Although MARAD vessels dominate the vessels over 300 feet in length, vessels of this size, intentionally placed as artificial reefs, constitute only 9% of vessels used as artificial reefs on the Atlantic and Gulf Coasts (Gregg and Murphy 1994).

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 Murphy (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 a comprehensive “Rigs-to-Reefs” program has no vessels in its artificial reef program (Gregg and Murphey 1994). Although Texas has a comprehensive "Rigs-to-Reefs" program, there are 12 Liberty Ship reef sites. Two of those sites require lighted buoys and active maintenance programs costing in excess of $100,000 per year. In August 1995, Texas sank a tug boat at the Port Isabel/South Padre Island Reef. Although there is no current plan to place Texas A&M University's now-obsolete 600-plus feet research vessel "Clipper", the Texas Parks and Wildlife Department (TPWD) has pledged $100,000 towards the clean-up and offshore transportation fees for this vessel.

Since 1986, in Florida alone, out of 283 federal or state artificial reef grant projects, 28 projects ($495,125) have involved vessel procurement, cleaning and sinking, and 20 projects ($482,200) have dealt with barges. This accounts for 17.3% of the total federal/state expenditures of $5,613,932 on artificial reef projects in Florida during 1986 through 1995. Excluded from this list were vessels funded wholly by non-state, local government funds or private contributions. (Jon Dodrill, personal communication). 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 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). The annual value of a wreck to the diving community in Broward County, Florida was estimated at $144,000 (Ken Banks, personal communication). 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 jettys (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).

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 jettys (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 feet long or greater, operating out of the nearest inlet. The ships were seen as one of numerous possible fishing sites (Ditton et al. 1979).

Vessels have cleaning and preparation requirements which need to be evaluated in a cost-benefit analysis of their use as artificial reefs. 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, private recreational angler, 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). In April 1995, the cost to move a refloated 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).

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). 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, Reef Ball Development Group, 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).

Some vessels, not designed to withstand heavy sea conditions, and further weakened through age and deterioration, may not withstand normal sea/current conditions, if deployed as artificial reefs, 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 twelve years prior to salvage was sunk off Palm Beach County, Florida in 100 feet of water in May 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). 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).

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; stern 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; stern section separated from hull.
Deep Freeze	freighter	210	135	35 feet of stern section separated from hull.
Doc De Milly	freighter	287	150	No damage.
Miracle Express	freighter	100	60	Pushed on top of *Biscayne*; hull broken into pieces.
Narwhal	freighter	137	115	90% of structure collapsed, many areas reduced to steel plates on sand.
Orion	tug	118	95	Pilot house ripped from hull.
Police Barge	barge	75	55	Moved 75 yards into concrete reef material; hull has opened up.
Proteus	freighter	220	72	Stern ripped off, remainder of wreck moved 100 yards and is broken up.

Vessel Name	Type	Length (ft)	Water Depth (ft)	Damage/Movement
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**.

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.

Three examples illustrate the necessity for great care to be exercised on the part of contractors to insure 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, Lee County Division of Natural Resources Management, personal communication). Off Texas, a Liberty ship under tow, which sank miles from its permitted site in 40 feet of water, has required the maintenance over the past 20 years of an expensive lighted buoy, costing thousands of dollars a year (Jan Culbertson, 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, a vessel 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 100 feet of water (Bill Horn, personal communication).

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 a vessel as an artificial reef. Other methods are less showy, and slower paced. Ships as large as 460 feet have sunk in 45 minutes without the use of explosives. Opening sea cocks and the use of cutting torches and portable pumps to cut holes in the hulls and flood compartments are alternatives to explosives, which have produced fish kills in the past (Jim Bohnsak, National Marine Fisheries Service, personal communication), and have required extra safety measures to be taken for protection of both observers and personnel involved in the sinking.

In 1994, the Atlantic States Marine Fisheries Commission's (ASMFC) Artificial Reef Advisory Committee (ARAC) drafted a statement addressing the issue of surplus military ships and PCB contamination. In the statement the committee stated that "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."

In 3,000 tests, the Navy found PCBs in paints, gaskets, vibration dampeners, wire and cable insulation jackets, and oils used in capacitors and transformers. The Navy stopped using surplus vessels for target practice and ceased making their vessels available as artificial reefs. Since military specifications requiring the use of PCBs could apply to any number of government vessel types, especially prior to the late 1970s, concerns have arisen that clean-up costs of other available government vessels from the MARAD would be prohibitively expensive, or that regulatory agencies would no longer allow deployment of any government surplus vessels due to presence of PCBs, asbestos, cosmolene, or other contaminants.

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 is that "states should continue to operate their programs in an environmentally responsible manner, using surplus ships until the requested EPA standards are adopted." The initial stance of the EPA has been that deployment of vessels containing PCBs violates the Clean Water Act (Gregg and Murphey 1994).

The EPA expects to issue a formal written response on the PCB issue regarding artificial reef application of vessels, pending the final outcome of testing by the Navy. The agency has developed

PCB removal guidelines for those vessels that are to be scrapped and the steel recycled. The EPA's Office of Pollution Prevention and Toxics has prepared a technical policy document entitled "Sampling Ships for PCBs Regulated For Disposal,' (Interim Final Policy, November 30, 1995) that provides an interim method for determining whether PCBs have been removed from ships. That document is intended for evaluating vessels destined for scrapping to recover metal, and EPA Region 4 believes it may not be appropriate to use it to guide PCB removal work on vessels as artificial reefs. The decision on this issue is pending.

PCBs do not represent the only hazardous material that may be of environmental concern on ships. Floatables, plastics, various petroleum products, lead, radioactive materials (eg. luminous dials), antifouling paints such as tributyl tin, and asbestos have all been identified as items of potential concern either by reef managers, the U.S. Coast Guard, of the EPA. The Region 4 Office of the EPA stated that the presence of cosmolene 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 would be ruptured by explosive charges used to sink the vessel must be free of cosmolene (Steve Murphey, personal communication). The Liberty ship *Joseph L. Meek*, sunk off Escambia County, Florida in 1976, was found to be leaking fuel oil from tanks that were thought to have been pumped clean. This incident will be costly to address and emphasizes the need to clean ships of all petroleum products prior to deployment as an artificial reef (Jon Dodrill, personal communication). Regarding other contaminants, such as asbestos, in vessels, no formal policy statement has been issued by the EPA. 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 in the impact, if any of asbestos in the marine environment.

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 overexploited 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 more than a decade ago (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, Harbor Branch Oceanographic Institute, 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 1980's (Jon Dodrill, personal communication). An 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 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 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. Seasonal aggregations of now-protected adult jewfish, believed to be engaged in spawning activity, have been reported from ship wrecks off southwest Florida (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

- C Vessels make interesting diving locations and provide a social and economic benefit to the local community through the dive charter and, secondarily, the recreational/charter fishing industry.

- C Vessels have life spans as artificial reefs that may exceed 50 years, depending on vessel type, physical condition, location of deployment, and storm severity.

- C 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 which are attractive to schooling forage fishes, which in turn attract species of commercial and recreational importance.

- C Vessels have a heritage of popularity with divers, fishermen and reef managers. Some opponents of artificial reefs believe that shipwrecks are the only legitimate form of artificial material that should be placed offshore, since they are the only type of man-made structures that typically went to the bottom with or without man's intervention during the millennia of man's use of the seas.

- C Depending on location, vessels may seasonally hold a large biomass of commercially and recreationally important fish species.

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

- C 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.

Drawbacks

- C 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.

- C Some opponents of the use of ships consider them merely DADs (Diver Attraction Devices). They view ships as reef sites where divers either preempt fishermen or create user conflicts more pronounced than on other natural or artificial reef sites. If ships are purchased with saltwater fishing license revenues or Federal Aid in Sportfish Restoration funds, it is felt that the return to the diving community is out of proportion to that community's user-funded contribution.

- Accidents associated with shipwreck diving account for almost 25% of all reported diving accidents in the U.S.

- Vessels are costly 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.

- Due to high vertical profile of vessels, some Coast Guard District requirements for buoy systems, particularly lighted buoy systems, on vessels are very expensive to maintain.

- 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.

- On older government vessels, treatment of contaminants such as asbestos, cosmolene, and polychlorinated biphenyls (PCBs), which are considered hazardous wastes under other scenarios, have not been aggressively addressed by the EPA in any well-publicized, formal policy statement.

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

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

- Although no known lawsuits have been directed against permit holders who accepted liability for scuttled vessels on which SCUBA divers were injured or killed, in theory the permit holder remains liable for the materials, including their condition and maintenance.

Recommendations

- The one-and-one-half to two year delay in securing MARAD vessels under normal circumstances, and the lack of a formal policy statement by the EPA or specific guidance on the subject of PCBs, beyond the fact that their presence in vessels is a violation of the Clean Water Act, make uncertain the prospect of securing Victory class ships or military vessels in a timely manner. Until the issue of PCBs in military vessels is dealt with decisively by the EPA, and time factors are also a consideration in vessel procurement, it is recommended that reef managers, interested in pursuing vessels as artificial reefs, work through marine salvage companies or other donor groups other than the MARAD.

- 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 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 spearfishing 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).

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

- All fuel must be removed from tanks on ships. 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 (Jon Dodrill, personal communication).

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2.8 *Fiberglass, Ferro-cement, and Wooden Vessels*

Overview

2.8.1 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 (up to $200 in Florida). 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, Florida Department of Environmental Protection, 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. Recently, South Carolina was approached with an offer of 370 boat molds for use in their artificial reef program (Robert Martore, South Carolina Wildlife and Marine Resources Department, 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 Army Corps District (Jacksonville, Florida Regulatory Office) no longer permits fiberglass boat or boat mold use under their newly revised 1995 COE SAJ-50 general artificial reef permit. However, private use of fiberglass boats as a delivery system for other miscellaneous reef materials continues at night, particularly in northwest Florida. Fiberglass boats, as an artificial reef material and a delivery system for other materials, have been 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 Florida, 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, Gulf States Marine Fisheries Commission, 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, Sarasota County Natural Resources Department, 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, Florida Department of Environmental Protection, 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, St. Lucie County Department of Leisure Service, personal communication). New Jersey’s experience with five loads of fiberglass boats and boat molds is that they break up and disappear without 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 (Bill Koran, Captain Black's Dive Shop, personal communication).

While 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 (Joe Evans, Florida Marine Research Institute, 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, Manatee County Parks and Recreation Department, personal communication).

Benefits

- Discarded fiberglass boats are readily available, cheap, and have a tradition of use with charter fishermen and fishing clubs.

Drawbacks

- The Florida Marine Patrol has occasionally encountered situations when fiberglass vessels were sunk for private use as an artificial reefs but did not remain in place because floatation was not removed and/or the vessel was insufficiently ballasted. The vessels were found floating just below the surface or washed up on the beach. This created a situation where it was not known whether the vessel was derelict and intentionally sunk or there was an accident and individuals may have been missing. Time was wasted in futile search and rescue efforts.

- Use of derelict, fiberglass, recreational vessels has been closely 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.

2.8.2 Ferro-cement Vessels

Little information is available on the use of ferro-cement vessels as artificial reefs. Lee County, Florida reported sinking a 60 feet ferro-cement boat which remained intact only about four months. The sides collapsed and the vessel was eventually covered over (Bob Wasno, Lee County Department of Public Works, Division of Natural Resources Management, personal communication). A 50 foot ferro-cement sailboat, sunk on hardbottom 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).

2.8.3 Dry Docks

Dry docks have been utilized as artificial reefs off Alabama, New York, Virginia, northeast and southeast Florida. Dry docks have been readily accepted as a material of opportunity in New York's artificial reef program. The structures are considered stable with a 20 year estimated lifespan. The New York structures were constructed of southern yellow pine, had already been in the water 30 to 50 years prior to deployment and may have been initially treated with a preservative (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 suggested that wing walls be removed prior to sinking, or they may become detached and can resurface or appear onshore (Mike Meier, 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 wooden dry dock, which was 615 feet long, 127 feet wide, and 57 feet tall, and 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).

2.8.4 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 1000 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 for up to 30 years (Jon Dodrill, personal communication).

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, National Marine Fisheries Service, 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 essentially falls to pieces within five years 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 (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.

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.

- C 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.

- C 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.

- C Wooden vessels are not generally recommended for use as artificial reefs. They can be difficult to clean, and, if portions of the vessel's wooden structure are soaked with petroleum products, or the wood contains preservatives, it may be impossible to thoroughly clean.

- C Wooden components present potential flotation problems. When combined with structural weakness brought on by marine boring organisms and storm events, parts of wooden vessels may break up and become surface navigation hazards or unwanted beach debris.
- C 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.

- C Fiberglass boats seem to be the preferred material of opportunity 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 Army Corps of Engineers districts no longer permit their use under the general reef construction permit.

- C 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.

Recommendations

- C Reluctantly accepting the material because it is free should not be a determining factor in accepting fiberglass boat hulls or any other material of opportunity.

- C 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.

- C 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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2.9 *Oil and Gas Platforms*

Overview

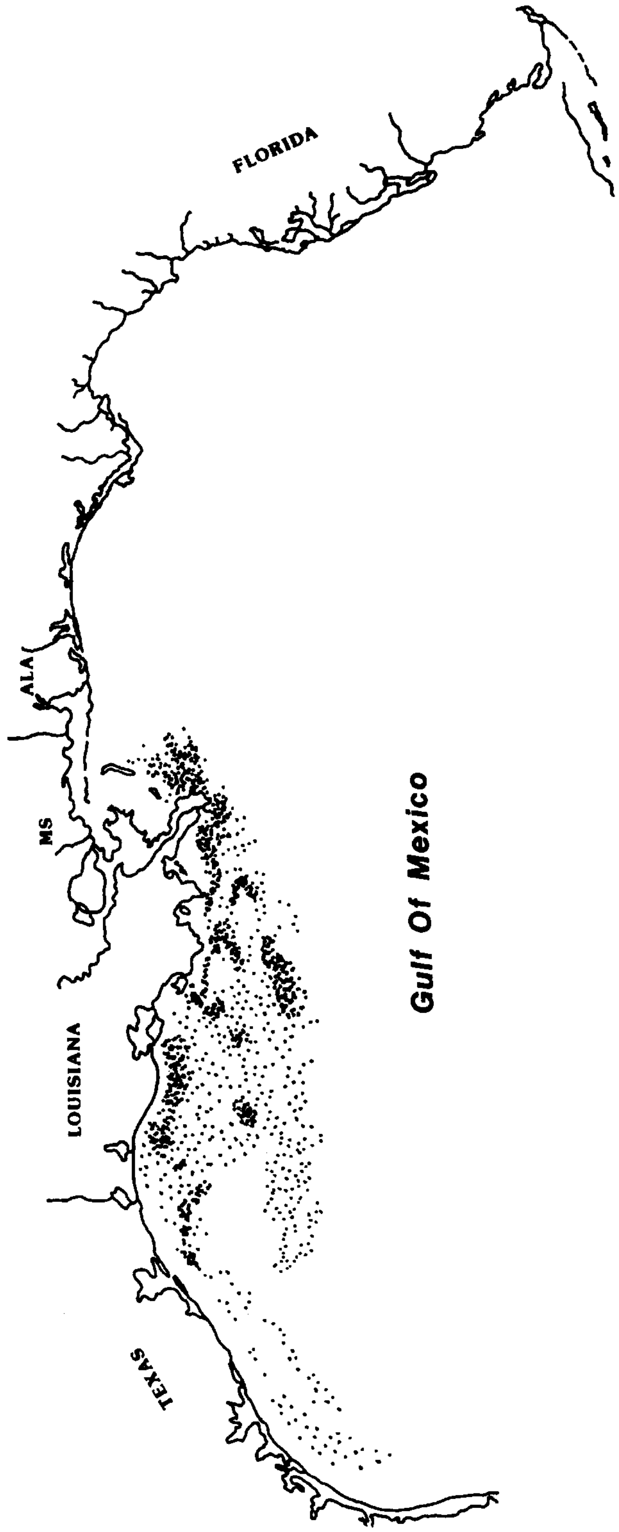
Offshore oil and gas platforms first began functioning as artificial reefs in 1947 when Kerr-McGee completed the world's first commercially successful oil well out of sight of land. It is recognized that oil and gas reserves are often associated with salt domes on land, so it made sense to geologist 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. As technology improved, offshore oil and gas development quickly expanded into waters over 1,000 feet.

There are approximately 3,700 petroleum platforms in the Northern Gulf of Mexico (Figure 1). In addition to supplying oil and gas, these platforms provide an important source of hard bottom or reef habitat (Reggio and Kasprzak 1991). The Gulf of Mexico Fisheries 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, which is typically dominated by clay, silt and/or sand with little to no relief. The addition of these 3,700 petroleum platforms and the hard bottom substrate they provide has undoubtedly had some effects on fish populations, although their effects are not well understood (Stanley 1994).

Since their installation, the platforms have become an important fishing destination for both the recreational and commercial fishermen and have long been recognized as *de facto* artificial reefs by fishermen. It has been estimated that nearly 20 to 50% more fish occur in these areas than over the nearby soft bottoms of the Gulf of Mexico (Dressen 1989). 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). Avanti (1991), using data from the National Marine Fisheries Service's 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

Figure 1



from around oil and gas platforms. Although these resources are important, there is little documented information on the effects of oil and gas platforms on fish populations. This is primarily due to the difficulty in sampling these locations with traditional fishing gears, 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 & 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 between 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 estimated approximately 12,000 fish, ranging in size from one half inch to 3.5 feet, as a monthly average number associated with a platform. 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.

Galloway 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 (Galloway and Lewbel 1982).

As of December 1993 there were approximately 2,596 platforms classified by Galloway 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 an unspecified number in Texas state waters (beach to nine miles). Offshore and bluewater communities accounted for 699 and 406 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 1993 over 1,150 structures have been removed from the Gulf of Mexico, as required by federal law. At present, there are 885 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. 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 this new 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 (Kasprzak and Reggio 1991).

In 1989 Texas passed similar legislation that directed Texas Parks and Wildlife Department to promote, develop, maintain, monitor and enhance the artificial reef potential in state and federal waters adjacent to Texas. This legislation also directed Texas Parks and Wildlife Department to "actively pursue acquiring offshore platforms for use as artificial reefs in the Gulf of Mexico, in deference to other structures" (Stephen 1990). To date, more than 101 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.

Once an oil or gas structure is properly plugged and abandoned, there are three removal options available when donating a structure. 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 costs and time savings; however, there are safety concerns regarding the need for divers to place the explosive charges inside the jacket legs at considerable water depth. Another disadvantage to the use of explosives is the potential mortality of sea turtles, marine mammals, and fish that might be associated with structures.

The second removal option involves divers cutting the jacket legs below the mudline using abrasive or mechanical cutters. Once the legs are severed, the entire structure can then be placed on the bottom in a horizontal position. 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 would be no adverse impacts to associated living marine resources. This method is 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 observed were transported along with the structures and stayed with the structures when placed on the bottom.

The third removal option involves the partial removal of the upper portion of the jacket and placing it on the bottom next to the standing bottom portion of the jacket. This method is particularly beneficial with deep water structures that are donated to the program. 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 species. Also, the upper portion that is removed provides relatively low profile habitat to compliment the standing section. This method has been used twice offshore Texas, under waivers granted by 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).

Benefits

- 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 in 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 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 3,700 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 1994, of the over 800 platforms removed from Louisiana and Texas waters, only 90 platforms, or approximately 11%, became artificial reefs (Kasprzak 1994).

Drawbacks

- C There are, however, 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.

- C Another disadvantage is the expense in removing these structures. Derrick barge rates currently run between 50 thousand to 100 thousand dollars a day depending on the lifting capabilities of the barge. The size of the structure to be removed determines the size of barge required.

- C 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, the MMS and the 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.

Recommendations

- C 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.

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

- C 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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2.10 *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). 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 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 or "exempt" from Subtitle C regulations, fall under Subtitle D and are subject to regulation by States as solid wastes.

While RCRA is the principle Federal law affecting the regulation of ash byproducts, there is a larger statutory framework of Federal laws that are 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.

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 v. 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 & 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 gypsium."

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. The FBC materials generally have a high sulfur content and high amounts of residual alkalinity, which would make them less suitable artificial reef material. Until more information is known about this specific ash generated from a relatively new combustion process, EPA has delayed making a decision on its regulatory status.

Some features of the ashes, which have been ruled "exempt," make them excellent material to construct artificial reefs. 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.

In 1980, Congress enacted Solid Waste Disposal Act Amendments to RCRA. Under these amendments, certain ash byproducts, including CCBs were temporarily excluded from Subtitle C regulation. This regulatory "exception" provided CCB's be regulated under subtitle D and subject to regulation under State laws as a solid waste. After extensive review of these materials, EPA issued its final regulatory decision on fly ash, bottom ash, boiler slag, and flue gas desulfurization emission control ash from coal combustion (EPA 1993). They stated that effective September 2, 1993, these materials will not be regulated as hazardous wastes under Subtitle C, and officially placed them under Subtitle D as solid wastes, and under the jurisdiction of individual States.

EPA narrowly interpreted this final exception to only apply to CCBs and FGDs from coal fired electric utilities and independent power producers. CCB's generated from other industrial activity and coal ash generated FBCs were not included in this ruling. However, these other sources of ash will continue to be exempt from hazardous waste regulations, until more information is available and EPA can make a final regulatory decision in April 1998.

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 effect 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 done 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 meter 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 10-20mm from the outside surface of the block. This dark region was enriched with Mg, but without distinct crystals present. He 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. He 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, where 28 stacks of 100 block sections were placed 9 miles offshore of Cedar Key, in 25-ft of water. This demonstration project included: laboratory testing of the leachate using standard EP Toxicity testing and modified seawater EP Toxicity testing; bioassay testing of the leachate; benthic and fish tissues analysis for metals; and biological evaluation of the habitat by core analysis, photo-transacts, scrapings, traps, and trawls.

The bioassay tests indicated no significant leaching was detected from the fly-ash elutriate. However, one of the three species of diatoms used in the bioassay test, had an Lethal Concentration (LC 50) of 38.22 percent of the block elutriate, which is a moderate level of toxicity for this sensitive organism.

Although biofouling and recruitment of fish at the reef site was rapid on both fly ash and concrete control blocks, 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 in fishes 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; 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 desulferization treatment process before starting the expense of testing the leachate from the substrate and bioassay tests.

Houston Lighting and Power 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 CCBP 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 1993 (with authority from Texas Parks and Wildlife Department and the Corps of Engineers), HL&P Company and JTM Industries with Texas A&M University constructed an 18-ft high offshore artificial reef within a state reef . Three hundred and twenty five CCBP blocks weighing one ton each were placed in 100-ft of water adjacent to an established ship-wreck, known as the V.A. Fogg. Texas A&M University has been monitoring this reef site for two years and a final report is pending publication. Several smaller CCBP blocks were placed on the reef and later retrieved by divers to document invertebrate recruitment over time. Fish surveys were conducted using traps, hook and line, divers's visual census in addition to creel survey data collected from anglers.

However, not all studies have shown the consistent results of New York, Delaware and Texas. Studies done on CCBs in Mississippi (Homziak et. al. 1995, in press) 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 (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 florescence), 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

EPA's ruling on Section 3001(b)(3)(c) of the Resource Conservation and Recovery Act (RCRA) on four large volume wastes from the combustion of coal by electric utility power plants on August 9, 1993 did not include CCB's generated from other industrial activities such as oil combustion byproducts. However, these other sources of ash will continue to be exempt from hazardous waste regulations, until more information is available and EPA can make a final regulatory decision in April 1998.

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 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 1970's 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 has allowed oil combustion byproducts and coal fluidized bed (boiler) combustion byproducts to remain temporarily exempt under Subtitle C of RCRA until further studies of these low volume waste materials can be reviewed. 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.

Recommendations

- Potential reef material constructed of ash from coal combustion processes (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.

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2.11 *Designed Materials*

Overview

While materials of opportunity are still relied upon in the majority of artificial reef construction projects in the United States, carefully engineered, manufactured reef structures have been utilized in Japan and other Asian nations to carry out numerous large-scale fisheries enhancement projects since the 1960's (Grove et al. 1991). The use of designed reef materials in the U.S., while often limited to experimental-scale projects in the past, has expanded in recent years, with increased levels of funding for many artificial reef programs, and the disappearance of some previously relied-upon sources of reef structure. Since the early 1980's, eight states along the Atlantic Seaboard alone have utilized some type of designed artificial reef structures in varying scales to carry out reef development projects (Mike Meier, personal communication).

Although they generally have a higher initial cost than most materials of opportunity, designed artificial reef structures offer certain advantages in reef construction which may eventually lead to more wide-spread use. Utilization of designed reef materials will vary among artificial reef programs, based on the specific needs, financial and local resources, and reef development objectives of individual programs.

Typically, designed artificial reef structures in the United States have been relatively small (35 to 70 cubic feet in volume), and made from readily available durable materials such as concrete or steel. Cubes, cylinders, prisms, and domes are the most commonly employed shapes. Examples of these designs are found in McGurrin and Wilson (1991). A few artificial reef programs have found the need and funding to utilize much larger, more complex, designed structures in reef construction projects (Ben Mostkoff and Jeff Tinsman, personal communications), but due to relatively high deployment costs these types of reef units may have limited application for large-scale use.

While the performance of individual reef unit designs 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), each artificial reef program must evaluate for itself the need, feasibility and overall cost-benefits of relying upon designed materials.

Benefits

- Designed structures can be specifically engineered to meet requirements of a particular reef site or performance objectives for a reef.

- Construction from long-lived, durable, environmentally-safe components such as concrete, steel, or heavy-duty plastics can result in a long, safe, and somewhat predictable service life of reef units.

- Problems and expenses often encountered in cleaning, preparing, transporting, and handling some materials of opportunity are minimized or non-existent.

- Artificial reef program managers can more easily plan reef construction efforts around actual needs and fiscal resources rather than relying on the often unpredictable availability of materials of opportunity.

- The potentially longer service life of designed reef materials as compared to many materials of opportunity can result in a much greater cost-benefit ratio over time.

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 materials of opportunity.

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

- Most affordable designed reef structures lack some of the appeal and potential public interest that can be generated in the sinking of certain materials of opportunity (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.

- 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.

Recommendations

- 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, with aggressive field testing, whenever possible, to broaden the menu of available, suitable designs for artificial reef programs.

- Artificial reef programs currently utilizing designed materials should continue to share their experiences (successes and failures) with other reef programs nation-wide.

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PERSONAL COMMUNICATIONS

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Tinsman, Jeff. Delaware Artificial Reef Coordinator. Delaware Department of Fish and Wildlife. Dover, DE.

2.12 *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.

2.13 *Military Hardware*

Overview

In 1993, the U.S. military, in addressing options to dispose of obsolete main battle tanks (MBTs) stockpiled at various military bases in the U.S., realized that immersion in sea water was an acceptable method of demilitarization. A major U.S. Army surplus property depot, located in

Anniston, Alabama at the Anniston Defense Depot, held a large number of these MBTs. 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 using the equipment for artificial reefs rather than for scrap. They contacted the Alabama Department of Conservation and Natural Resources, Marine Resources Division, regarding the possibility of placing the material in the artificial reef general permit areas offshore Alabama. Alabama was very supportive of the concept and provided the DLA with supporting documents from the Office of the Governor and members of the U.S. Congress. From this initial support, REEF-EX, a military program to cooperate with state resource management agencies in the transfer of obsolete military hardware for artificial reef development, was organized. That program has provided obsolete MBTs, armored personnel carriers, and other military battle hardware for a number of state artificial reef programs from New Jersey to Louisiana.

As might be expected, main battle tanks are extremely heavy and are proven to be stable on the ocean bottom. For example, in 1994, a number of MBTs were sunk in the general permit areas offshore Alabama. During October 1995, Hurricane Opal hit the Florida panhandle, just to the east of Alabama. A large 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 they 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 REEF-EX artificial reef sites to satisfy previously booked fishing trips.

Armored Reconnaissance Assault Vehicles, also know as Sheridan tanks, have also been made available for use as artificial reefs. Two major concerns raised over these units 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 Environmental Protection Agency (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 2, provides a breakdown of the distribution of military hardware made available to the Atlantic and Gulf States through REEF-EX.

Table 2. This table represents the type and distribution of military hardware used by the states as artificial reef material, acquired through the REEF-EX program.

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

[1]MBT = Main Battle Tank
[2]APC = Armored Personnel Carrier. Some of the APCs are also missile launchers.

Benefits

- C Selected military surplus equipment is typically of high quality, built to engage adversaries, and expected to outlast most artificial reef material now being used.

- C 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.

- C Diver observations on the MBTs deployed offshore Alabama 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.

- C Video tape samples, collected using a trap-video technique employed by the Southeast Area Monitoring and Assessment Program, revealed that the most prominent species associated with the Alabama tanks was red snapper. Additional species, which have taken advantage of the nooks and crannies provided by the military hardware, have been reported by divers.

- C A total of 34 fish species has been observed around the Alabama tanks. Such diversity, revealed by these preliminary observations, indicates that the MBTs deployed offshore Alabama provide suitable habitat for a variety of marine organisms, including those that are targeted by fishermen.

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

Drawbacks

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

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

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

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

Recommendations

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

- C 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.

- C 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.

PERSONAL COMMUNICATIONS

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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 predeployment preparation, such as with coal combustion fly ash or automobile tires, 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.

3.0 CONCLUSION

The purpose of this document is to provide a comprehensive discussion regarding a variety of materials that have been used in the development of artificial reefs. 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 most frequently and in the most volume by artificial reef developers 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 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 series of recommendations to consider if the materials are selected for use as artificial reef material.

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. Materials for artificial reef development will continue to be selected on a case-by-case and program-by-program basis; however, the ultimate goal of this document is to encourage movement away from the use of questionable materials that have short-term application toward the use of long-lived materials that have a proven track record of success. It is expected that this document will 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 the Gulf States Marine Fisheries Commission office, P.O. Box 726, Ocean Springs, Mississippi 39566-0726, (601) 875-5912.