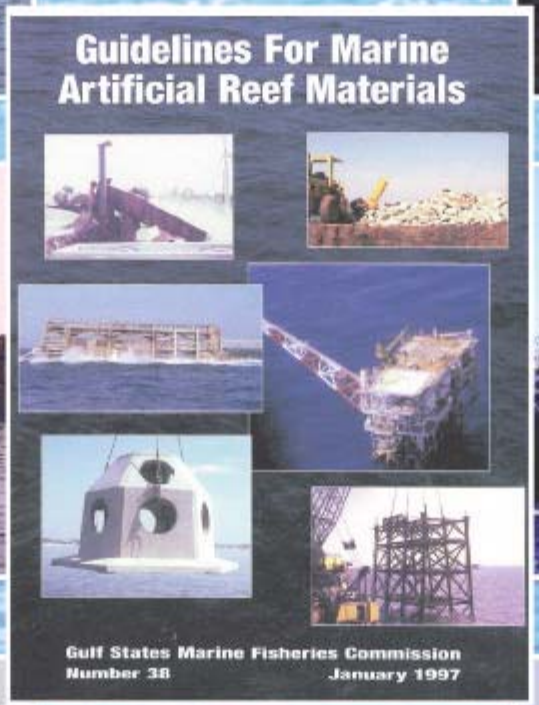
GUIDELINES FOR MARINE ARTIFICIAL REEF MATERIALS

SECOND EDITION



A JOINT PUBLICATION OF THE GULF AND ATLANTIC STATES MARINE FISHERIES COMMISSIONS

NUMBER 121 **JANUARY 2004**

GUIDELINES FOR MARINE ARTIFICIAL REEF MATERIALS

Second Edition

Compiled by the

Artificial Reef Subcommittees

of the

Atlantic and Gulf States Marine Fisheries Commissions

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January 2004

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 Nos. GS96 Amendment 7, A-4-1 and A-5-1. Support was also provided through the Atlantic Coastal Fisheries Cooperative Management Act NA17FG2205 and NA03NMF4740078.

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ACKNOWLEDGMENTS

The Atlantic and Gulf States Marine Fisheries Commissions would like to thank the various authors of sections contained in this document for their diligence and dedication to getting the job done. All recognize the importance of this document and gave of themselves freely toward its completion. Nancy Marcellus, Gulf States Marine Fisheries Commission, is also deserving of thanks for her talent and hard work toward completion of this document, and we gratefully acknowledge her efforts.

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PREFACE

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

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

It is anticipated that the adoption of this document, and its distribution, will provide artificial reef programs and prospective artificial reef developers with information that will increase the potential for successful efforts at habitat creation and enhancement. It is not intended to be either anti-artificial reef development or a promotional publication. Rather it is a factual reference for those who are tasked with the responsibility for managing, developing, or regulating artificial reef programs and must consider conservation, fisheries management, environmental protection, recreational, and economic objectives. Materials for artificial reef development will continue to be selected on a case-by-case and program-by-program basis within the permit conditions established by the appropriate state and federal regulatory agencies; however, the ultimate goal of this document is to encourage movement away from the use of questionable materials that have a history of problems, toward the use of materials with a proven track record of success. This is the first revision of a document that was originally published in 1997, and it is expected that this document will continue to be updated and revised periodically. The readers of this document are encouraged to provide additional information regarding positive and negative experiences with specific artificial reef materials and any recommendations for use of specific materials to either the Gulf States Marine Fisheries Commission, P.O. Box 726, Ocean Springs, Mississippi 39566-0726, (228) 875-5912 or the Atlantic States Marine Fisheries Commission, 1444 Eye Street, NW, 6th Floor, Washington, DC 20005, (202) 289-6400.

GUIDELINES FOR MARINE ARTIFICIAL REEF MATERIALS

1.0 INTRODUCTION

1.1 *Purpose*

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

1.2 *Background*

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

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

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

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

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

1.3 *History*

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

research, and experimentation with various materials, including designed structures (Bohnsack 1987).

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

1.4 *National Artificial Reef Plan*

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

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

1.4.1 <u>Function</u>

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

1.4.2 Compatibility

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

1.4.3 Durability

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

1.4.4 Stability

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

1.5 *Gulf and Atlantic States Marine Fisheries Commissions*

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

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2.0 DISCUSSION OF MATERIALS

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

2.1 *Concrete*

Overview

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

Webster's Dictionary defines concrete as "a hard, strong building material made by mixing a cementing material (commonly Portland cement) and a mineral aggregate with sufficient water to cause the material to set and bind." Portland cement is largely made from lime, a component of limestone. Limestone is comprised primarily of calcium carbonate, which is the substance of which coral reefs are made. Portland cement falls into five classes, as designated by the American Society of Testing Materials in the Designation Standard Specifications for Portland cement. Marine applications of concrete under load bearing conditions, conditions of repeated wetting and drying and conditions of periodic freezing and thawing, such as bridge spans, require at least Type II Portland cement. Cement types II-V are resistant to the sulfates and other chemicals in sea water which can attack and break down concrete made with Type I concrete. Concrete materials of opportunity used for reef building (such as culvert, bridge decking or demolition debris) are often made of Type I concrete. These materials perform very well and have a much longer lifespan as reef materials than might be predicted, for several reasons. There are significant factors other than cement type, which influence durability. First, concrete reef materials are not load bearing and are not subjected to structural stresses. Second, concrete reef materials are not repeatedly being wetted and dried. During the drying process in Type I concrete, sulfates from seawater react with tricalcium aluminate in the concrete to form needle-like ettringite crystals. It is the formation of these crystals, within the structure of the concrete, during drying that gradually breaks down the structural integrity of the concrete matrix. This is not a problem with reef materials, because they are constantly submerged and there is no repeated wetting and drying. A third factor influencing the longevity of Type I concrete in seawater is the ratio of water-to-cement used in the manufacture of the product. If this ratio is low enough, the performance of concrete Types I, II and V in seawater become much more similar. The reason for this is that the permeability of the resulting concrete is much lower and less seawater enters the structure of the concrete. Most culvert, and other imperfect manufactured concrete materials, is made with Type I concrete, but a very low water-to-cement ratio is used. This produces high early strength of the concrete, an asset in the manufacturing process, and produces an impermeable concrete which will resist chemical attack in use. These characteristics make it resistant to the effects of seawater exposure as well.

Lime (calcium hydroxide) in "green" or uncured cement may have surface pH levels of 10 to 11, which is significantly more basic than seawater, which has a pH of 8.3. This can make the surface of uncured concrete toxic to invertebrate organisms for 3 to 12 months. Pozzalanic materials can help to neutralize the surface pH by combining with the free lime. Such materials include coal combustion fly ash, diatomaceous earth, clays, shales, pumicites, micro-silica, among others. A pozzalanic material reacts with the free lime, lowering the pH and also providing for better bonding between aggregates, thus making the concrete stronger. The majority of concrete used in reef applications is not used in the "green" or uncured form. Most imperfect culvert, bridge or road decking or demolition debris has aged and cured for many months or years prior to deployment as reefs. An estuarine reef made from concrete culvert in Delaware Bay exhibited the rapid development of an epifaunal community, dominated by the polychaete worm, *Sabellaria vulgaris*. Biomass and species diversity equaled that of the adjacent infaunal community less than two months after deployment.

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

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

coastal area, and the "scuttled" concrete material was placed offshore for artificial reefs. Culvert constitutes the most frequently used concrete material for artificial reefs offshore Florida (Jon Dodrill, personal communication).

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

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

The coal source of fly ash in concrete products available for reef projects is often unknown. Florida alone has several coal-burning plant operations providing a source of fly ash to the construction industry. The hazards of heavy metal leachates from fly ash vary with the coal source and treatment process. There are thousands of tons of scrap concrete placed in the ocean annually off Florida alone, indicating that this is an issue which should be addressed in the future.

The Texas Game and Fish Commission used six foot long concrete pipes cabled together in three separate units for a reef site established 11 miles offshore of Galveston in 1962 (Jan Culbertson, personal communication). The first unit consisted of five sections of 36 inch diameter pipe and five sections of 60 inch diameter pipe placed on natural bottom within a 100 foot by 100 foot area. A second unit consisted of ten sections of 48 inch diameter pipe placed on a one foot thick steel mill slag mat adjacent to the first unit. The third unit consisted of 10 sections of 60 inch diameter pipe on a one foot thick steel mill slag mat adjacent to the second unit. In 1963, the Texas Parks and Wildlife Department (TPWD) increased the size of the "Galveston Pipe Reef" by adding a fourth unit of 300 sections of four foot long, 30 inch diameter pipe cabled together on natural bottom. The two clusters of concrete pipes placed on the metal slag mats were visible with a four foot profile during the side scan sonar survey conducted by a Naval Reserve Mine Sweeping Unit for the TPWD

in 1993 (TPWD Unpublished Data). However, the first and fourth units were covered by mud and no longer visible during the survey. Numerous anglers have been observed fishing at this reef site periodically since it was constructed (Bob Bass, personal communication).

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

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

Since 1989, Mississippi has deployed concrete rubble in 107 locations within fifteen permitted reef areas. These deployment sites include near shore waters 0.25 miles from the mainland in approximately eight feet of water to sites approximately 30 miles offshore in eighty feet of water. This rubble was obtained from several demolition projects, including military barracks, concrete culverts of various sizes, a cooling tower, and an airport runway. Concrete rubble sizes varied from six inches to ten feet. The larger pieces were placed in offshore areas. Side-scan sonar was utilized to evaluate stability of most of the concrete rubble deployments. In most instances, concrete rubble has proven to be very reliable reef material, with no movement and very little subsidence. However, in 1996, four barge loads of rubble deployed in a near-shore area, which was mined for sand for beach re-nourishment to a depth of fifteen feet, subsided very quickly. Three barge loads of concrete rubble deployed offshore, 3.5 miles south of East Ship Island, could not be detected during a side- scan sonar survey. The bottom on this particular reef site (FH-5) consists of silty clay, and its assumed that this material also subsided.

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

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

Concrete has been the major reef building material for Delaware's eight estuarine reef sites. Since 1995, over 50 patch reefs have been established on these sites. Culvert and other manufacturer's second quality material is donated to the program. Only new, clean material is used. Each patch reef is created by pushing approximately 1,000 tons of concrete off an anchored deck barge. The resulting pile of concrete is from 5 to 15 feet in vertical relief. Piling the material inhibits scouring and subsidence. Concrete placed on sand generally settles slightly during the first year and remains stable thereafter. Culvert in piles has excellent complexity and high surface area. Monitoring of Delaware's concrete patch reefs has shown a 50 to 100 fold increase in invertebrate biomass, compared with the natural bottom. Concrete reefs in Delaware support tautog and provide juvenile habitat for seabass. High profile reefs attract baitfish and species such as weakfish, bluefish, and striped bass.

The California Department of Fish and Game first placed prefabricated concrete box structures as reefs between 1958 and 1960. Surveys during the first two years following deployment found a strong trend for fish to gather around these box reefs (Carlisle, et al. 1964). Over many years concrete has been demonstrated to be a durable material, as well as a good quality substrate. Concrete rubble has been used repeatedly to build reefs off southern California for the last 40 years. Concrete slabs for demolition projects and pier pilings and decking have been utilized since 1986 to build the largest single artificial reef off the California coastline. The Bolsa Chica Artificial Reef off Orange County currently consists of 160,000 tons of concrete rubble, with an actual foot print of approximately 30 acres, in a permitted area of 200 acres. The Bolsa Chica reef supports much of the commercial passenger fishing boat industry activity operating out of Los Angeles and Long Beach Harbors during several months of the year (Dennis Bedford, personal communication). During 1992, the first self-sustaining artificial kelp reef was built by the California Department of Fish and Game off Mission Beach, Dan Diego County, utilizing 9,200 tons of concrete slab rubble from the demolition of a local roadway. Covering approximately 11 acres, this reef supported a kelp bed community for the last 10 years. It was subsequently surveyed as a potential model for a larger mitigation reef planned by Southern California Edison Company (Ecosystems Management Associates, Inc. 1999). During the fall of 1999, Southern California Edison Company built an experimental 22 acre artificial reef off San Clemente, Orange County, designed to support a kelp community. Half of the 48 reef modules are built with concrete rubble.

Benefits

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

- Concrete materials are extremely compatible with the marine environment.

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

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

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

Drawbacks

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

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

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

Considerations

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

- To enhance durability, use concrete materials which have Type II or greater Portland cement as the binding agent. Type II concrete should be used in designed structures and concrete ballasted tire units produced for reef applications.

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

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2.2 *Steel Hulled Vessels*

Overview

In the United States, scrap materials of opportunity, deployed without assembly or much modification, still account for a large portion of reef construction materials. Vessels have served as components of most state artificial reef programs. Where available, and where depth conditions allow for deployment, vessels remain an important reef material to many reef managers, particularly on the Atlantic coast (Grove et al. 1991). The earliest record of intentionally sinking vessels for artificial reef fishing is 1935 when four vessels were sunk by the Cape May Wildwood Party Boat Association (Stone 1974). Dozens of steel-hulled ships sunk in coastal continental shelf waters along the Atlantic and Gulf Coasts during WWII still provide commercial and recreational fishing opportunities and diving enjoyment more than 60 years later.

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

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

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

In 1984, P.L. 92-402 was amended by P.L. 98-623 to include noncombatant reserve fleet ships other than the Liberty class for artificial reef construction. Initially most of the nearly 650 WWII era merchant vessels still available in the early 1970s were Victory class ships. However, relatively few of the Victory class merchant vessels were ever secured for use as artificial reefs. Like the Liberty ships before them, most of the Victory class component of the inactive reserve fleet was subsequently scrapped. Deployment of P.L. 92-402 ships virtually ceased from 1978 to 1987. Only

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

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

Current Procurement and Preparation Issues Related to Large Military Vessels

Hazardous Waste Removal Issues

Today P.L. 92-402, formally known as 16 United States Code (U.S.C.) ▪ 1220 (a)-(d). ▪ 1220(a), specifies the terms and conditions under which a coastal state has the authority to accept title to a vessel from the United State Government, generally with the vessel in an "as is, where is" condition. This phrase has historically had significant monetary and environmental implications that until the

spring of 2003 resulted in limited progress towards reefing MARAD vessels as reflected by the slow progress made by MARAD vessel sponsors during the 1990s. A brief history of the hazardous waste issues related to military ships is provided below. The following section is not intended to serve as a detailed guideline for the identification, removal, and handling of hazardous waste materials on vessels but is intended to highlight some of the environmental preparation considerations when dealing with vessels.

Polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are mixtures of synthetic organic chemicals with the same basic chemical structure and similar physical properties ranging from oily liquids to waxy solids. Due to their nonflammability, chemical stability, high boiling point and electrical insulating properties PCBs were used in hundreds of industrial and commercial applications including electrical, heat transfer, and hydraulic equipment; as plasticizers in paints, plastics, and rubber products; in pigments, dyes, carbonless copy paper and many other applications. More than 1.5 billion pounds of PCBs were manufactured in the United States prior to cessation of production in 1977. (EPA, website: *http://www.epa.gov/opptintr/pcb/*).

Concerns over the toxicity, bioaccumulation, and persistence in the environment of PCBs led Congress in 1976 to enact §6(e) of the Toxic Substances Control Act (TSCA) that included among other things, prohibitions on the manufacture, processing, and distribution in commerce of PCBs. TSCA legislated management of PCBs in the United States from initial manufacture to disposal. (EPA, website: *http://www.epa.gov/opptintr/pcb/*).

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

the U.S. Navy discovered PCBs aboard their surplus vessels in levels high enough to cause concern."

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

In 1995, The EPA's Office of Pollution Prevention, Pesticides and Toxics prepared a technical policy document entitled "Sampling Ships for PCBs Regulated For Disposal," (Interim Final Policy, November 30, 1995) that provided an interim method for determining whether PCBs had to be removed from ships. That document was intended for evaluating vessels destined for scrapping to recover metal. The waste and water programs within EPA believed this policy was not appropriate to use as a guide to PCB removal work on vessels to be sunk in shallow water marine environments as artificial reefs. To help address the PCB concern, the South Carolina Marine Artificial Reef Program initiated a study to examine the levels of PCBs found in organisms collected from ex-military ships which had been sunk as artificial reefs. After confirming the presence of PCB-laden materials, fishes and invertebrates were collected from the ship reefs as well as from natural hard-bottom control sites. Analyses revealed no significant differences in PCB concentrations between any of the sites. In addition, the levels that were detected were well below concentrations deemed hazardous by the FDA (Martore et al. 1997). In the late 1990s, the Navy also commenced laboratory PCB leach rate studies, and deepwater PCB studies on military ships sunk in 6000 feet or greater, as well as risk analysis on environmental and human health effects of PCBs . Findings and recommendations from the Navy studies will be available by the summer of 2003 and are expected to verify the results of South Carolina's preliminary testing (Frank Stone, personal communication).

In 2001, the EPA Office of Pollution Prevention, Pesticides, and Toxics program operating under the TSCA developed additional guidelines that helped address the situation of the *Spiegel Grove* project that had been languishing for several years awaiting resolution of the PCB issue. Without allowances for some low level of PCBs to remain on military ships proposed to be sunk as artificial reefs, no vessel could be cost-effectively prepared for sinking. In response to this dilemma, the EPA Office of Pollution, Prevention, Pesticides and Toxics program considered use of a

military ship to create an artificial reef a "disposal." That is, the original use for which the vessel was intended has terminated. Because vessels contain PCBs that are not an "authorized use", the only current recourse for EPA short of initiating enforcement discretion was to consider the activity of preparing a ship for sinking as a "disposal" whereby minimum acceptable residual PCB levels can be left on board [at levels less than 50 parts per million (ppm)]. EPA cannot without some type of enforcement discretion allow a "continued use"of materials containing substances like PCBs that are not authorized to be left in place in an ongoing use scenario. However, to complicate the situation, the EPA waste and water programs viewed the ship cleaning and sinking activity as a "continued use". (Stuart Perry, personal communication). Under the disposal scenario the concentration limits of PCBs in materials are limited to less than 50 ppm (40 CFR 761.60, 761.50, 761.30). Under the "continued use" scenario the PCB limits are 2ppm.

Asbestos

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

The approach to asbestos inspections on ships in the 1980s and 90s was varied. A U.S. Coast Guard marine safety officer in Florida required removal of asbestos from a ship in 1994, while another in South Carolina did not. The EPA Region 4 inspection criteria for vessels under P.L. 92-402 was to leave the asbestos in place until more information was available on the impact, if any, of asbestos in the marine environment. Elizebeth Stanley, the EPA Director of the Office of Compliance, in a June 9, 1997 letter to Winston Smith, Director of Air, Pesticides and Toxics Management Division, EPA Region IV, stated that sinking of a ship was most reasonably classified as a demolition of a facility under the asbestos National Emission Standard for Hazardous Air Pollutants (NESHAP). The facility or ship is considered to undergo demolition when some event occurs to make a load supporting structural member no longer capable of supporting the load of the facility, or with respect to a vessel some modification to the ship occurs in preparation for sinking the vessel or causing the vessel to sink. Elizebeth Stanley said, "The owner/operator would need to remove the regulated asbestos containing material (RACM) from the ship that may have a high probability of becoming regulated during or after the demolition. Certain asbestos-containing materials may be left in place during the demolition. Nonfriable asbestos-containing material, such as asbestos-containing gaskets, may generally be left in place during the demolition. Additionally, friable material on a facility component that is encased in concrete or other similarly hard material may also be left in place. For example, asbestos in the bulkheads would be allowed to remain in place as long as the asbestos in the bulkheads are not wrecked and the asbestos is not exposed during the demolition. We believe that it is unlikely that this material would be released into the environment. Pipe lagging that is wrapped in cloth or tin would not be an example of encased material. Any encased asbestos that

will be exposed by any of the demolition activities would need to be removed prior to the demolition. Category II asbestos-containing material may or may not be left in place.. A case-by-case determination would need to be made for these materials….Where there is a question, EPA or local delegated agency should use sound judgement concerning the fate of the material in question." The current requirements in Florida for state and federally funded reef projects is that an EPA or Florida Department of Environmental Protection (DEP) air quality specialists or a designated certified consultant with asbestos experience must conduct an asbestos assessment of a vessel prior to sinking. Federal regulations which deal with asbestos are 40 CFR Part 61.145 Subpart M and the OSHA regulations in 29 CFR Part 1915.

Lead

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

Fuel and Oil Products

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

Hazardous waste cleaning standards which seemed appropriate in the early days of MARAD ship sinking may no longer be appropriate based upon current experience. For example EPA in the early 1970s developed ship cleaning criteria for liberty ships secured under P.L 92-402. One of these criteria were: "The presence of cosmoline on the walls of fuel tanks can be adequately mitigated by filling the tanks with water, and bolting and welding the tank hatches closed. Any tanks that will be ruptured by the explosive charges used to sink the vessel must be free of cosmoline (Source: EPA Region 4, Atlanta Georgia)." The Liberty ship *Joseph L. Meek*, sunk off Escambia County, Florida in 1976, was found 20 years later to be leaking bunker "C" fuel oil from a small corrosion induced

leak in a tank that was thought to have been pumped clean, inspected and sealed. This incident cost the Florida Department of Environmental Protection's Emergency Response section $100,000 to address. (Jon Dodrill, personal communication) Liberty ships sunk off Mississippi were associated with oil slicks for several years post deployment and in fact the slicks were used as a means by boaters without navigation equipment to locate some of these reefs (Ron Lukens, personal communication). It requires only a few gallons of residual fuel or other petroleum source to create a noticeable oil slick. This was clearly demonstrated by a leaking five gallon fuel container accidentally left on board the *Spiegel Grove* when it sank prematurely off the Florida Keys in 2002. This resulted in a persistent oil sheen on the surface and a Coast Guard mandated lab testing of the petroleum sheen composition with a follow-up multi-day search requiring scores of dives until the can could be located and recovered (David Score, personal communication).These instances combined with negative publicity received in the case of both Florida scenarios, emphasize the need to thoroughly clean ships of all petroleum products prior to deployment as an artificial reef. The U.S. Coast Guard has the responsibility to inspect all vessels proposed for deployment as artificial reefs to ensure they are free of petroleum products and floatables prior to vessel deployment.

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

Specific direction for PCB and other hazardous waste and pollutant material removal will be incorporated into a document entitled "National Guidance: Best Management Practices (BMPs) for Preparing Vessels Intended to Create Artificial Reefs." This document, authored by a multi-agency federal working group is anticipated to be available in the summer of 2003 (Elizabeth Freese, personal communication).

MARAD Navy Vessel Cleaning and Preparation Cost Issues

The implications of sampling for and subsequently dealing with hazardous materials in large complex military vessels, is that hazardous waste removal is more involved and associated vessel preparation costs are considerably greater than what they were in the 1970s. The original liberty ships of the 1970s were scrapped to the second deck, salvage efforts more than recovered the cost of the labor, and holes were cut in the sides and they were sunk as little more than very large bathtubs. Under the original MARAD liberty ship program, the vessels were accepted by the states in an "as is/where is" condition, at no cost to the federal government. Weighing 3,400 tons, the original Liberty ships were 441 feet long, 57 feet wide, and 80 feet from the top of stack to the mold line. States recouped cleaning and towing fees by having the salvors pay them to remove the entire superstructure down to specified levels, along with all other items of salvage value. Although the states realized $30,000 to $40,000 in salvage value from each vessel, there were complaints that the Liberty ships were stripped down to the point that they were glorified bathtubs, without much complexity (Virginia Vail, personal communication).

Fifteen years after the last Liberty ship was deployed, the cost to secure, clean, tow, and sink the 460 foot military transport *Muliphen* off St. Lucie County, Florida, in a largely structurally intact

condition, was $118,000 (Stan Blum, personal communication). Salvors involved complained to the Department of Defense about not being able to benefit from the more complete stripping of the vessel (Virginia Vail, personal communication).

Today's large military and civilian vessels have cleaning and preparation requirements which need to be evaluated in a cost-benefit analysis of their use as artificial reefs. Scrap steel values are low as of 2002. Additionally there is increased demand on the part of the diving industry to leave vessels externally intact in physical appearance to the extent possible. Estimates to cover all costs associated with hiring consultants, securing, permits, yard space, cleaning, hazardous waste removal and disposal, towing, sinking, for a military vessel over 500 feet long in 2002 range from 1-2.2 million dollars per vessel. For example the *Spiegel Grove* as only one component of its cleaning process had 102 diesel, aviation fuel, lubricant, ballast, and sewage tanks which had to be individually cleaned, inspected and temporarily resealed. During the four months of cleaning, more than a dozen inspections by the U.S. Coast Guard Marine Safety Officer were required (Jason Walker, personal communication). The EPA mandated that all wiring from the *Spiegel Grove* be removed due to concerns about PCBs in the insulation. The wiring alone removed from the ship exceeded 100,000 pounds, though the removal, temporary storage and shipment to a hazardous waste disposal site accounted for only about 4% of the overall vessel cleanup and preparation cost and precluded having to conduct an extensive amount of PCB sampling in a cable and wiring system thousands of yards long (Tim Mullane, personal communication). Even though an agency may receive a ship from the U.S. Maritime Administration for free, the subsequent individual ship cost estimates as projected in 2002 substantially exceed the annual operating budget of a typical state artificial reef program. Without major private, and local government financing and fund raising efforts as occurred with the *Spiegel Grove*, and *Hoyt Vandenberg*, or a federal plan to subsidize artificial reef deployments of federal ships, the expense involved in start-to-finish environmentally friendly cleanup and deployment of large military vessels remained prohibitively expensive for most state reef programs.

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

By 2001, the Navy and MARAD recognized the impediments of making "as is, where is" vessel transfers to state artificial reef programs contingent upon no cost to the federal government. After Congress made the decision not to lift the moratorium on transfer of vessels overseas for scrapping purposes, in March 2003 MARAD announced to the coastal state artificial reef programs and the interstate marine fisheries commissions that it had been able to secure legislative authority in 2002 to provide limited federal funding in the form of grants to states to assist them with the cleaning, preparation, towing, and sinking of requested MARAD vessels for artificial reefs. 16 USC 1220c-

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

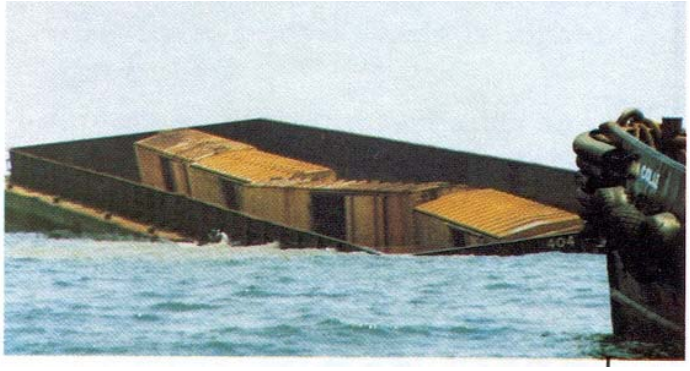
In April 2003, the Naval Sea Services Command in cooperation with MARAD announced that an 820 feet long, 34,881 ton Korean War/Viet Nam era ex-Navy aircraft carrier, *U.S.S. Oriskany (CVA 34)* would be available as an artificial reef pilot project through a turn key operation where MARAD received and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

Use of non-MARAD Vessels as Artificial Reefs

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

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

Vessel sinkings during the last decade have emphasized smaller vessels obtained outside the MARAD program. Common sources have included vessels available through marine salvage and construction companies, private donations, vessels confiscated by the U.S. Coast Guard, or other types of government surplus property transfers. Gregg and Murphey (1994) reported that 77% of all vessels deployed in the Gulf and Atlantic were 150 feet in length or less, with barges (33%) and landing craft (28%) dominating the list. One hundred of 136 landing craft reportedly used as reefs were sunk at one site off Virginia and comprise most of the 130 vessels, including six Liberty ships, which that state has deployed (Mike Meier, personal communication). Gregg and Murphey (1994) summarized data on 666 vessels used as artificial reefs, 414 (87%) of which were steel vessels. They stated that vessel use has been largely restricted to Atlantic States (58%) and the state of Florida (34%) with only 8% of the vessels deployed as reefs off Gulf states (excluding Florida). Louisiana, a state with the most comprehensive "Rigs-to-Reefs" program with 112 decommissioned oil and gas structures as of 2003 had no vessels in its artificial reef program (Gregg and Murphey 1994) until a single vessel was sunk in 2001 (Rick Kasprzak, personal communication). Although Texas also has a comprehensive "Rigs-to-Reefs" program, there are 12 Liberty ships sunk as reefs



at five separate reef sites. Subsequent Texas reef deployments have utilized smaller vessels. In August 1995, Texas sank a tug boat at the Port Isabel/South Padre Island Reef followed by a 100 foot Navy surplus dive work barge at this same 70 foot deep site. Both vessels have provided habitat to numerous reef fish species including Goliath grouper (TPWD unpublished data).

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

The steadily increasing popularity of sport diving over the past 25 years, combined with the increase in dive charter operations to meet demand, has been a major driving force in some local communities behind the procurement of vessels to sink as artificial reefs. Murray and Betz (1991), in a survey of 721 divers, commercial fishermen, sport fishermen, and environmentalists in Texas, North Carolina, and Florida, reported that 54.2% of all diving trips were to artificial reefs (with emphasis on vessels) versus only 15.5% of all recreational fishing trips. Additionally, 66.7% of all respondents identified as divers stated a preference for ships and barges over other artificial reef sites. The southeast Florida Counties of Miami-Dade, Broward, Palm Beach and Monroe have the highest concentration of vessels sunk as artificial reefs on the U.S. east coast or Gulf of Mexico. Off these counties, 9.81 million diving and fishing days were spent on or around artificial reefs in 2001, with vessels comprising an important component of the sites visited (Hazen and Sawyer Associates, 2001). Bank loans of several hundred thousand dollars incurred by the Key Largo Chamber of Commerce as a result of providing financial assistance to the *Spiegel Grove* project in the Florida Keys are on track to be repaid within two years through the sales of souvenir medallions to thousands of divers who are diving the wreck (Spencer Slate, personal communication).

The value of vessels as dive sites to some individual charter dive boat operators is substantial. In Beaufort, North Carolina, a single, multiple-boat dive charter operation reported an annual gross of $250,000 from trips targeting ship wrecks (Kurtis Gregg, personal communication). In April 1995, the cost to move a re-floated 150 foot dredge barge, cleaned and towed from South Carolina to southeast Florida and sunk as an artificial reef, was $100,000 (Ken Banks, personal communication). However, the annual value of a single ship sunk as a reef to the diving community in Broward County, Florida in 1995 was estimated at $144,000 (Ken Banks, personal communication). In Broward County alone the economic contribution in sales from a107 reef artificial reefs system that

included 18 barges and 52 boats and ships, was an estimated $961 million in 2001 (Hazen and Sawyer Associates 2001). Data from post card respondents in a 1990 diving survey relating to South Carolina dive sites indicated that of 2,406 dives reported, 1,294 were on naturally occurring ship wrecks (54%), and 921 (38%) were on artificial reefs, which included some intentionally placed ship wrecks. Only 8% of the reported dives were on live bottom areas or rock jetties (Rhodes et al. 1992).

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

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

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

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

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

Storm Impacts on Steel-hulled Vessels

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

High vertical profile and the trend towards placing vessels at depths accessible to divers makes steel-hulled vessels vulnerable to major storm systems, especially hurricanes of category 4 and 5 intensities. Table 1 provides a summary of known damage to artificial reefs using steel-hulled vessels as a result of Hurricane Andrew, a category 5 storm which hit the Dade County, Florida area on August 22, 1992. Most vessels, which were in 65 to 125 feet of water and in the direct path of the hurricane, experienced structural damage. Maximum movement of 700 yards was noted for a concrete-loaded steel barge and up to 100 yards for a steel freighter. Scouring of fouling organisms from hulls, removal of wheel houses and stern sections, and hull subsidence into scour depressions were common hurricane effects, when the eye of the hurricane passed nearby. To the north of Dade County in Broward County, Florida, 80 miles from the hurricane's eye, at least one vessel was moved offsite, four were laid over on their sides, and wrecks in water as deep as 180 feet experienced hull damage. The hulls of the steel freighters *Mercedes* (250 feet in length in 97 feet of water) and the *Noula Express* (220 feet in length in 90 feet of water) were both broken in three places. A light gauge metal yacht in 65 feet of water was reduced to rubble. There was evidence that shipwreck reefs were literally bounced up and down against the bottom (Ken Banks, personal communication). Hurricane Hugo (1989), like Hurricane Andrew, which had sustained winds exceeding 150 miles per hour, bounced a 450 foot long troop ship, sunk off South Carolina 700 feet laterally across the bottom. The vessel, which originally was in 130 feet of water, sat in a scour depression at 140 feet after the hurricane passed (Bell and Hall 1994 and Mel Bell, personal

communication). Off North Carolina, Hurricane Hugo also heavily damaged a large barge serving as an artificial reef (Steve Murphey, personal communication).

Table 1. Damage Sustained by Dade County, Florida Steel Hulled Vessels Used as Artificial Reefs During Hurricane Andrew (August 22, 1992).*

Vessel Name	Type	Length (ft)	Water Depth (ft)	Damage/Movement
Almirante	freighter	210	125	Ship turned upside down; 17 years of coral growth scoured off.
Andro	freighter	165	105	Stack damaged, cargo area collapsed; 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.
Rio Miami	tug	105	63	Settled 20 feet into sand depression.
Shamrock	Navy LCI	120	46	Coral scoured from hull; position and condition unchanged.
Sheri Lyn	freighter	235	95	50 feet of stern broken off and moved into 105 feet of water.
South Seas	yacht	175	65	Stern broke off; vessel moved 50 feet.
Steanne D'Auray	trawler	110	68	Intact, unchanged.
Star Trek	freighter	200	210	Some steel plates torn off, largely intact, same position.
Tarpoon	grain carrier	175	71	Moved inshore 75 yards, pushed up against natural reefs, hull broke into three pieces.
Ultrafreeze	freighter	195	118	Starboard side of hull ripped open, vessel bent amidships at 90 degree angle, pilothouse torn from hull.

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

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

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

Some vessels, not operationally designed to withstand heavy sea conditions, and further weakened through age and deterioration, if deployed as artificial reefs, may not withstand normal sea/current conditions, let alone a major storm event. As an example, a triple deck 340 foot, 60 year old car ferry whose lower deck sat under water for 12 years prior to salvage was sunk in a .75-1.5 knot current environment off Palm Beach County, Florida in 110 feet of water May 23, 1993 at a cost of $55,000. Following the arrival of the first winter weather seven months later, the lowest deck had collapsed, and the upper two decks had been wrenched sideways, resulting in the creation of jagged sheets of metal and other hanging debris, and forming a potential diving hazard Salvage procedures, use of explosives, and impact of the vessel with hard bottom upon sinking, may also have contributed to the ship's initial deterioration (Jim Vaughn, personal communication). Continued monitoring of the vessel showed that the superstructure was eventually completely sheared off and lies on the seabed west of the vessel. Nine years after sinking, the superstructure and the ship proper are experiencing structural collapse. The starboard side of the hull continues to deteriorate and is splitting away from the remainder of the hull (Palm Beach County Reef Research Team, 2002). In contrast, the sturdy 110 foot North Atlantic trawler, *Steanne D'Auray*, sunk in March 1986 as a reef off Dade County, Florida in 68 feet of water, withstood Hurricane Andrew intact (Table 1 and Jon Dodrill, personal communication).

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

The majority of vessels used in artificial reef programs have been sunk at their designated sites with no major problems. For the benefit of increasing awareness among reef managers and planners, the following representative examples are provided that highlight potential problems to be aware of. These examples illustrate the necessity for great care to be exercised on the part of contractors or other involved parties to ensure the condition of vessels under tow, and to operate when the sea state allows for safe arrival on site. Off Franklin County, Florida, a steel shrimp trawler, *One More Time*, was under tow in very choppy sea conditions. Waves knocked out the wooden boards sealing previously cut holes in the hull and the vessel sank more than six miles from the permitted site (Bill Horn, personal communication). Off southwest Florida, a contractor, towing two barges in weather too rough for the operation, cut both vessels loose miles from the permitted site when they began taking on water. One of the barges has yet to be located (Steve Boutelle, personal communication). Off Texas, in late October 1976, the twelfth and final Liberty ship of the Texas reef program became one of the first artificial reef lighted buoy maintenance undertakings. The *S.S. George Vancouver* under tow, to the Freeport permit site was caught in heavy seas. The tug could not get the Liberty ship back to port. The tug and ship moved into shallower water to the southeast but a 3,000 pound anchor broke loose from the *George Vancouver* and accidentally deployed. In gale force winds the ship dragged the anchor along the coast until the vessel sank miles from its permitted site in 60 feet of water nine miles south of Freeport Texas. Rather than attempt to move the vessel, the Army Corps of Engineers issued a new permit for the site. Because there was only 33 feet of clearance, the Coast Guard required the placement of a light and sound buoy (Arnold et al. 1998). This buoy had to be continuously maintained at a cost of thousands of dollars per year until 1998 when it was replaced by an unlighted buoy following authorization by NOAA in cooperation with the USCG (Jan Culbertson, personal communication). On March 25, 2000, a small leaking barge, uninspected by the Coast Guard, was under tow offshore for placement at an Okaloosa County (NW Florida) reef site by a private citizen. The vessel sank at the edge of the channel in Destin Pass even before it reached open water. The U.S. Coast Guard and the Army Corps of Engineers deemed the County liable. Salvage and shore side disposal of the barge cost the County reef program $47,500, nearly their entire annual artificial reef budget (Cindy Halsey, personal communication).

Once the vessel arrives on site, care must be taken to insure that it is properly anchored and sinks on the site in its intended orientation. Off Palm Beach County, the 340 foot long car ferry, *Princess Anne*, sunk as an artificial reef on the edge of the Gulf Stream in marginal sea conditions, drifted a quarter mile before it came to rest on live bottom outside the permitted area in 110 feet of water (Bill Horn, personal communication). Off Jacksonville Florida, a 327 foot long Landing Ship

(LST), the *Casablanca*, sunk as an artificial reef, dropped beneath the surface as anticipated but due to entrapment of air did not stabilize on the bottom. The vessel moved and was reported lost for a time. It was finally relocated nearly 10 miles down current from the original sinking location (Ed Kalakauskis, personal communication). While it may be possible to control the position of small unanchored vessels in low current environments when a tug is present while they sink, larger vessels sunk in stronger current situations must be anchored by an anchor system appropriate to maintain the vessel position as it sinks.

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

The perceived advantages of explosive use are public entertainment, program publicity, expediency in sinking, and training opportunities for agencies tasked with explosives use or disposal. Additionally, by leaving the hull as intact as possible while enroute to the deployment site, there is less danger of the vessel sinking prematurely. Another perceived benefit is that vessels sunk with properly placed explosives can sink rapidly, thus shortening the time spent on station during a ship sinking. One hundred foot and 165 foot vessels can be sunk in less than one minute and four minutes, respectively, with as little as 40 pounds of dynamite (Ben Mostkoff, personal communication). Unfortunately, excessive amounts (200 to 400 pounds or more) of explosives have been used in the past. At least one vessel was blown to pieces. Photos of dynamited ships off Florida, dating from the late 1970s and 1980s, show, at the time of detonation, airborne debris, plumes of airborne pollutants, and in at least one instance, superstructure damage from the blast (Berg and Berg 1991). Off North Carolina, during the deployment of a barge, an accidentally delayed charge went off as the barge's bow lifted clear of the water. Metal plates were blown half a mile, landing within 600 feet of an observation boat (Kurtis Gregg, personal communication).

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

Situations where explosives use is warranted would be in the sinking of a large (greater than 1500 tons or 300 foot long) military non-cargo auxiliary or combatant vessel. These vessels are built to resist sinking, and have scores of water tight compartments on multiple decks. To sink them requires the controlled movement into the vessel of hundreds of tons of water and a means for trapped air

to escape rapidly. In such situations in the interest of safety of personnel involved in flooding the ship and to help insure the vessel sinks in its proper orientation, demolition experts working in conjunction with marine engineers utilizing vessel stability information, should develop a demolitions/sinking plan that determines the type, poundage and proper placement of charges. Aerial surveys should be flown over the ship beginning 45 minutes before detonation to ensure there are no visible marine turtles or marine mammals noted within ½ mile of the vessel. A security perimeter should be maintained by the Coast Guard or local law enforcement agencies no closer than a five hundred yard radius from the vessel. The perimeter should be maintained until the vessel to be sunk is on the bottom and has been checked by diving demolition professionals to ensure that all charges have detonated.

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

The value of vessels as fishing habitat, from a management perspective seems to be a double-edge sword, especially regarding recreationally important, demersal fish populations which may remain on wrecks for a period of time. Recognizing that improved catch and positive economic impact depend on people being able to reach and use sunken ships and other artificial reefs, it is also apparent that accessibility can generate so much pressure that the value of the vessel as a fishing reef is seriously compromised. Ditton et al. (1979) stated that Texas Liberty ships "appear to constitute a significant and