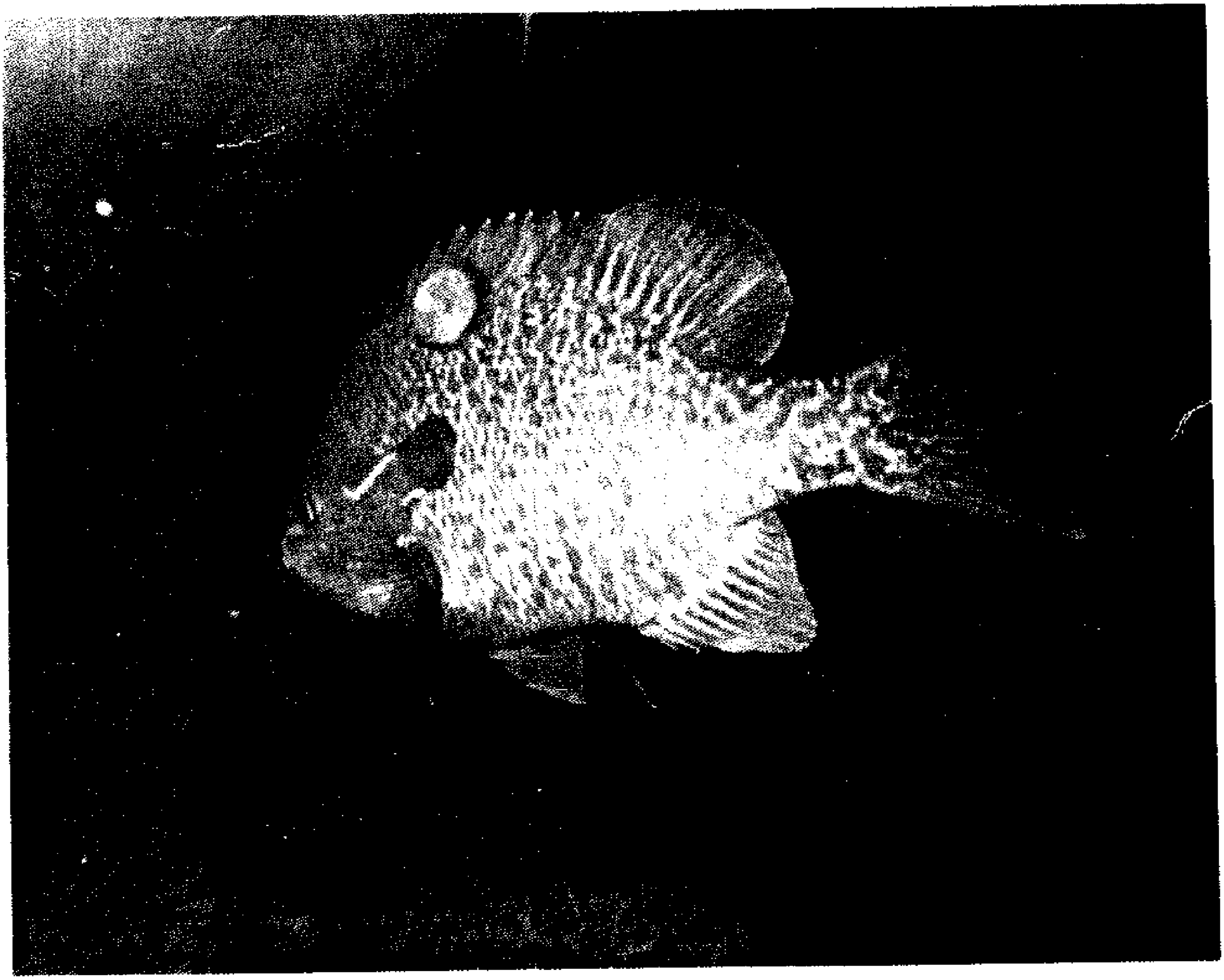
HOW TO BUILD A FRESHWATER ARTIFICIAL REEF

Second Edition



Sea Grant
Extension Division
Virginia Polytechnic Institute and State University
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HOW TO BUILD A FRESHWATER ARTIFICIAL REEF

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by
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FOREWORD

Construction of artificial reefs in marine waters is a popular method of improving saltwater sport fishing. Steimle and Stone (1973) have compiled a voluminous bibliography on the subject, and Parker et al. (1974) of the National Marine Fisheries Service have published a guide, *How to Build a Marine Artificial Reef,* as an aid in planning and constructing artificial reefs in marine environments.

Fishing in lakes, reservoirs, and ponds also may be improved by proper use of artificial reefs. However, the freshwater reef builder is confronted with problems somewhat different from those encountered by ocean reef builders. The purpose of this publication is to offer updated guidelines for planning and constructing artificial reefs in freshwater.

COVER

A sunfish (*Lepomis* spp.) on an artificial tire reef in Smith Mountain Lake, Virginia. The fish bears a plastic disc tag in the dorsal musculature. (Photo by Eric D. Prince.)

HOW TO BUILD A FRESHWATER ARTIFICIAL REEF[1]

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INTRODUCTION

Over 40 million freshwater sport fishermen caught an estimated 800 million pounds (363 million kilograms) of fish in the United States in 1970 (U.S. Fish and Wildlife Service, 1970). With the ever-increasing demands on stocks of freshwater fishes and the continuing disruption and pollution of inland waters, new management practices must be initiated to conserve and develop inland fishery resources.

Structures[6] are important to many warmwater sport fishes (Hubbs and Eschmeyer, 1938). Man-made structures in aquatic environments are called fish concentrators, fish attractors, fish hides, fish havens, fish shelters, fish cribs, or artificial reefs. All these terms refer essentially to the same type of structures; throughout this booklet, man-made structures are designed as artificial reefs. This term is more descriptive than others since reefs not only concentrate some species of fishes but may also serve as spawning habitat, shelter, and a surface for attachment of fish food organisms (Prince et al., 1975).

Hubbs (1930) was among the first to recognize the potential of artificially placed structures as a freshwater fishery management technique. Research recommended by him and conducted by Rodeheffer (1939, 1940, 1945) showed that man-made structures placed in selected Michigan lakes concentrated large numbers of fishes.

The use of artificial reefs as a freshwater fishery management technique stems from evidence which suggests that structures may be a limiting factor for fishes in some lakes and reservoirs (Prince et al., 1975; Prince, 1976; Brouha, 1974). In response to a recent questionnaire we sent to state and federal fish conservation agencies, 28 of 45 officials reported that their agencies used artificial reefs in freshwater fishery management (Prince et al., 1975). Structures are lacking in many freshwater environments (particularly reservoirs) for several reasons: (1) standing timber is clearcut in potential shallow areas before impoundment (this practice has been a policy of the Federal Power Commission to avoid navigational hazards); (2) standing timber that was not initially clearcut has decayed; (3) silt may have covered much of the firm substrate in shallow areas, resulting in unstable mud (muck) bottoms; and (4) fluctuating water levels prevent growth of aquatic vegetation. The rationale for using artificial reefs as a fishery management technique includes at least six facets:

(1) In structure-deficient non-flowing waters, artificial reefs effectively concentrate warmwater sport fishes — primarily bass, sunfish, and catfish (Prince, 1976; Brouha, 1974; Wilbur and Crumpton, 1974).

(2) Firm reef substrate serves as a surface of attachment for plants and animals, thus increasing biological productivity (Maughan et al., 1976; Prince et al., in press). Attached aquatic organisms are then eaten by reef fishes.

(3) Many warmwater sport fishes (bass, sunfish, and catfish) often spawn on or near artificial reefs. Young fish occupy the reefs through the growing season. Eggs and young of reef fishes also are seasonally important in the diets of reef sport fishes.

(4) At temperate latitudes, sport fishes use reef areas only seasonally. Warmwater sport fishes move to reef areas as temperatures exceed 50°F (10°C) in the spring. The numbers of species and individuals increase through the spring, remain at high levels through the summer and early fall, and decline when

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[1] References to data from Smith Mountain Lake, Virginia, are taken from an artificial reef study conducted by the authors, Dingell-Johnson Project VA-F-31.

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[5] The Unit is jointly supported by the U.S. Fish and Wildlife Service, the Virginia Commission of Game and Inland Fisheries, and the Virginia Polytechnic Institute and State University.

[6] Structures are defined as any visual irregularities of substrate or relief, either artificial or natural, living or non-living, which are concave or convex on the lake bottom or floating on the surface, that could potentially provide habitat for warmwater sport fishes. Examples of structures include artificial reefs, standing timber, weed beds, caves, piers, rocky outcrops, floating docks, and wind-felled trees.

water temperatures decrease in late fall.

(5) Depending on the species present in individual watersheds, geographical location, and season, small sport fishes are often most abundant on reefs in shallow water (less than or equal to 5 feet or 1.5 m), and larger ones are often found on reefs in deeper water (15-20 feet or 4-6 m) (Prince, 1976; Rodeheffer, 1939; Chapman, 1975). However, reefs in temperate latitudes at depths of 20 feet (6 m) or less are generally devoid of fishes in winter (Prince, 1976).

(6) Fishing quality for warmwater sport fishes is better on artificial reefs than on nonreef areas.

Although the need for more structures has long been recognized, handling and maintenance costs of the classical construction material (brush) have restricted its use. Early researchers who attempted to identify the proper design and placement, and the costs, of installing brush in structure-deficient lakes found that the twigs and branches were soon lost, and that periodic replacement was required as the density and quality of the structures decreased.

More durable reef construction materials include broken concrete blocks, drain tiles, automobile bodies, plastic seaweed, and scrap automobile tires. Of these, scrap tires are among the most common materials used in both marine and freshwater environments (Edmond, 1967; Parker et al., 1974; Stone et al., 1974; Prince et al., 1975; Wilbur, 1975). Stone et al. (1974) and Nozaka et al. (1973) found that no harmful substances leach out of tires in saltwater or freshwater, and it has also been suggested that old tires filter dissolved mercury wastes from water (Bushnell, 1976). In addition to the use of durable construction materials such as scrap tires, reef construction costs can be reduced by making the project a community endeavor and soliciting support from business or municipal, state or federal agencies (Prince and Brouha, 1974). Economic aspects of the Smith Mountain Lake, Virginia, artificial reef project can be used as an example to illustrate this point (Maughan et al., 1976). Artificial reefs covering a bottom area in Smith Mountain Lake of about 10,389 yd^2 (or 9,500 m^2) cost an estimated total of $5,000, with over 50 percent of construction costs (about $2,800) donated by various segments of the community.

The freshwater reef builder is confronted with problems somewhat different from those encountered in marine waters, since many inland waters have multiple uses (e.g., hydroelectric power, municipal water supply, and such recreation as water skiing, boating, and fishing). Our purpose in this second edition is to describe reef construction problems, consolidate and update available information on freshwater artificial reefs, and offer guidelines for reef construction under the various conditions encountered in freshwater.

REEF BUILDING GUIDELINES

Reef-building methods vary depending on habitat type (i.e., lakes, ponds, and reservoirs). Artificial reefs involve different problems in rivers than in nonflowing waters. The present guidelines are for nonflowing waters. Since each body of water has unique characteristics and poses different problems, the reef builder must be flexible in adapting these instructions to each particular situation.

Biological and Physical Need for Reefs

1. *Need for Reefs.* Reefs should be installed only after physical and biological surveys of the waters for which reefs have been proposed have been conducted by trained personnel. These surveys should determine whether the scarcity of structures and bottom reliefs is limiting fish production and whether artificial reefs would be effective. Although a complete evaluation of structures as a limiting factor can be difficult, if not prohibitively expensive, the general availability of structures in a body of water can usually be determined.

2. *Biological Factors.* Providing additional spawning sites, shelter, and food may increase fish survival. However, in warmwater fisheries, differential survival rates, in conjunction with high reproductive potentials, often result in unbalanced populations. Such imbalances cause increased numbers of stunted fish. Artificial reefs must be planned to avoid increasing potential or existing imbalances in fish populations. Swingle (1968) found that the use of brush structures increased the body condition (plumpness) of certain sunfishes but did not increase the number of stunted fish. Prince (1976) found that tire reefs yielded similar results. Problems associated with imbalances in fish populations vary from one water to another; accordingly, decisions should be made on an individual basis. In other words, artificial reefs are not a panacea for every freshwater fishery management problem, and one should use caution in installing artificial reefs in order to prevent aggravation of already existing problems.

3. *Shape of Individual Reef Units.* Reef structures should be bulky, possess many cavities, and have several entrances. Units that rise as close to the surface as legally permissible provide more shelter and surface area than do low-profile structures. In general, the higher the profile of the structure (or the further it extends up through the water column), the more efficient the reef is in concentrating fishes, because the surface area available is greater. Low-profile structures, however, may be better for shallow water and may increase spawning habitat for many

warmwater fishes. Reef units that are near the surface may pose potential navigational hazards and may need to be marked with buoys or modified. These problems are discussed further in a later section on legal considerations.

4. *Number and Size of Reefs.* The reef should be large enough to attract a substantial number of fish, but as Wilbur et al. (1973) asked, "How big is big enough?" In general, the number of fish associated with reef units is directly proportional to the number of tires composing the reef (Chapman, 1975). Also, reefs should be large enough to support anticipated fishing pressure, since marine studies have shown that intensive fishing on reefs can diminish fish populations (C.C. Buchanan, National Marine Fisheries Service, personal communication). Wilbur et al. (1973) recommended that total reef acreage should not exceed 0.25 percent of the surface acreage of a lake, or 0.25 acres (0.1 ha) of reefs per 100 acres (40 ha) of lake. They also suggested a maximum of three reef locations for waters 100 acres or less (40 ha) in area, and three to ten locations for lakes 100 to 1000 acres (40 to 405 ha). Lakes larger than 1000 acres (405 ha) should not exceed one location per 500 acres (202 ha). With these guidelines in mind, we advocate building a reef in stages until the size is satisfactory to support the realized fishing pressure.

5. *Arrangement and Ballast of Reef Units.* The arrangement of reef components evidently affects the numbers of fish attracted to the units. Several researchers have found that the effectiveness of reefs in concentrating warmwater sport fishes decreases after initial installation (Wilbur et al., 1973; Prince, 1976). Prince (1976) found that winter storms and wave action had dispersed many reef units within a year after construction, with apparent reduction in abundance of fish. Such dispersion of reef units can be avoided by stringing all units together with polypropylene line either before or after installation, or adding ballast to reef units to keep them in place, or both. Reefs built with continuous components (structures bound together) are usually most efficient in concentrating fishes.

Use of ballast is more important for units placed on hard bottoms than for those placed on soft mud substrates, since the mud assists in holding reef units in place. Reefs placed on exposed points adjacent to large expanses of open water are subjected to greater wave action and require more ballast than do reefs in protected coves.

6. *Location and Depth of Reefs.* To be of greatest value, reefs should be in both shallow water (5 feet or 1.5 m) and deep water (20 feet or 6 m or more), since the preferred temperature of most species changes during the year (Prince, 1976). A good mixture of deep and shallow reefs results if the reefs are constructed parallel to shore in shallow water, and if a wing is extended perpendicularly out into deeper water.

In some instances, reefs can be used to augment existing habitat, or to take advantage of a potential food source (such as weed beds), and thereby concentrate increased numbers of fish (Prince, 1976).

7. *Reefs Built on Mud Substrate.* Where reefs must be built on soft mud bottoms or in places subject to siltation, component structures should rise well above the bottom to insure prolonged effectiveness.

8. *Water Fluctuations.* Decreases in water level may expose reef structures, thus creating boating hazards and detracting from the appearance of an area. Lakes or impoundments with large fluctuations in water levels may therefore not be ideally suited for artificial reefs. However, this problem may be averted by using floating tire artificial reefs which are unaffected by changes in water levels (Figs. 6 and 7). Floating artificial reefs, initially used as breakwaters (Kowalaski and Ross, 1975), were recently used to concentrate warmwater sport fishes such as catfish, sunfish, and crappie (Prince et al., 1975; R. D. Candle, Goodyear Tire and Rubber Co., personal communication). Floating tire breakwaters may have a future as freshwater artificial reefs for pelagic species; Wickham et al. (1973) and Hammond et al. (1977) found that mid-water artificial reefs concentrated pelagic species in the ocean.

Legal Considerations

1. *Permits.* A permit to install artificial reefs in navigable waters must be obtained from the U.S. Army Corps of Engineers. A letter of application signed by the person(s) responsible for the reef should be submitted to the District Engineer, Corps of Engineers. The letter of application must be accompanied by a complete plan, including exact location and size of the proposed reef. Clearance over the top of the reef at mean low water level must also be stated. Format of the application was given by Parker et al. (1974). Permits may also be required by the state in which the project is proposed. Inquiries should be addressed to the water regulation section of the state's Department of Natural Resources.

2. *Buoys.* In navigable waters, reefs should be clearly marked with permanent buoys, as required by the U.S. Coast Guard. Buoys also assist sportsmen in locating the reef. Myatt and Cupka (1975) give detailed specifications for buoy construction.

3. *Liability and Precautionary Factors.* Reefs should be constructed away from navigation channels. State, county, and municipal authorities should be consulted to insure complete compliance with all appli-

cable laws. Reefs should not be installed near hydroelectric turbine intakes.

Lakefront property owners should be consulted before reefs are installed near their properties. Usually, however, inundated lands are owned by, or come under the jurisdiction of, power companies or the U.S. Army Corps of Engineers, or other federal or state agencies.

The owners of private waters are responsible for the safety of their premises and should mark any structures that present a hazard to swimmers or boaters.

General Considerations

1. *Benefits.* The reef should justify the time, effort, and cost of installation.

2. *Durability of Construction Materials.* Durable construction materials should be used. Artificial reefs with prolonged utility lower prorated costs.

INTEREST GROUPS

The owners of fee-fishing areas usually wish to provide good fishing for their clients. Fishing dock operators and retail stores catering to fishermen should be able to acquaint fishermen with good fishing spots, if they wish to effectively sell goods and services. Professional fishing guides must be able to provide clients with good fishing. All these people have vested interests in artificial reef construction. Sportsmen's clubs (formed by such groups as fishermen and scuba divers) may also want to create fishing or diving areas for their members. Service clubs (Scouts, Kiwanis, Elks, and Rotary) often get involved in such projects (Prince and Brouha, 1974). Federal or state fish and game agencies also build reefs to maintain or improve fishing. Municipal governments encourage and participate in many projects to improve recreational facilities. Because artificial reefs have the potential to concentrate fish, their construction in freshwater should be of special interest to these groups, and could provide substantial economic incentives for some of them (Buchanan, 1973).

COMMON MATERIALS AND DESIGNS

Materials that have been used in freshwater reefs include tires, brush, trees, concrete and clay pipes, cement blocks, stake beds, automobile bodies, and old boats. Selection of construction design and material depends on the costs and availability of labor, material, funds, and equipment (barges, cranes, etc.). The estimated cost of several reef structures is given here, but no labor or transportation costs have been included because of the variation in these costs among different reef construction projects. All estimated costs are approximate and apply to 1974; allowance should be made for inflation. If the reef becomes a community action project, sufficient manpower and materials may be donated to complete a project at relatively little cost (Stroud, 1976; Maughan et al., 1976). Since reef construction requires a great amount of work, the planner should try to organize a labor force that will participate over an extended period. In a long-term project, some people tend to lose interest more quickly than others. For this reason, a dynamic overseer is desirable to maintain participation by the work force. Work incentives such as prizes, parties, or refreshments should be considered to keep participation high until the project is complete.

Tires

Scrap tires are available free, in large quantities. Committees formed to arrange for the construction of artificial reefs have sometimes been paid by the dealers to collect tires because this method may cost them less than other means of disposal. Scrap tires can be readily assembled into many different configurations, and are easy to ship to the construction site and to install. Since tires are inert, they do not rust, corrode, leach harmful toxicants or decompose in water (Stone et al., 1974; Nozaka et al., 1973). Consequently, scrap tires are one of the most popular artificial reef construction materials (Edmond, 1967; Parker et al., 1974; Stone et al., 1974; Prince et al., 1975; Wilbur, 1975). Number 10 cans and 5-gallon cans, used for ballast, can usually be obtained from restaurants or school cafeterias. The amount of ballast we recommend should be considered conservative.

The construction of six types of tire units is discussed. Many more configurations can be developed by imaginative reef builders. These units may be joined together with synthetic rope (nylon or polypropylene) and anchored to the bottom.

1. *Single tire unit* (*Fig.* 1)

Data on materials and cost are from Stone and Buchanan (1971).

Materials	**Estimated Cost**
Old tires (1 per unit)	0
No. 10 can	0
Concrete (amount needed to fill one No. 10 can)	$0.07
TOTAL per unit	$0.07

A No. 10 can of concrete between the sidewalls serves as ballast for this unit. Additional concrete is sometimes needed. Two large holes are drilled or cut in the tread on the side of the tire opposite the can, to allow escape of trapped air. Parker et al. (1974) used a manual tire punch made of one-inch pipe and scrap lumber. A ¾-inch (19 mm) auger mounted in an electric drill can also be used, but the auger must be sharpened frequently. After the tire has been drilled and weighted, the unit is ready to be installed.

2. *Triangle unit* (*Fig.* 2)

Data on materials and costs are from Prince and Brouha (1974).

Materials	**Estimated Cost**
Old tires (3 per unit)	0
No. 10 can (3 per unit)	0
Concrete (amount needed to fill 3 No. 10 cans @ $0.07 per can)	$0.21
Polypropylene line, 8 feet, ¼-inch diameter @ $0.02 per foot	0.16
TOTAL per unit	$0.37

Three tires are tightly lashed together to form a triangle of tires sitting nearly upright (tread portions in contact with the bottom). One No. 10 can filled with concrete is used for ballast (2 or 3 cans may be necessary in areas of current). To ensure sinking, drill large holes through the tops of all three tires to allow air to escape.

3. *Tire chain unit* (*Fig.* 3)

Data on materials and costs are from Davis (1969).

Materials	**Estimated Cost**
Old tires (6 per unit)	0
Concrete (amount needed to fill 3 tires) @ $0.11 per gallon	$0.11
Polypropylene line, 24 feet, ¼-inch diameter @ $0.02 per foot	0.49
TOTAL per unit	$0.60

After holes have been drilled in six tires to allow air to escape, the tires are connected to form a single unit. Five units can be lashed together with polypropylene line to form a pyramid-shaped structure. Three concrete-filled tires are attached to one end of the line to serve as an anchor.

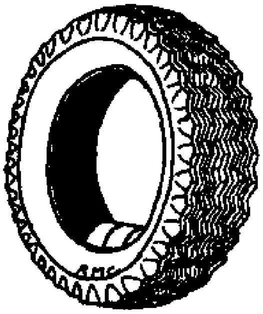

Figure 1. The single tire unit — the simplest design.

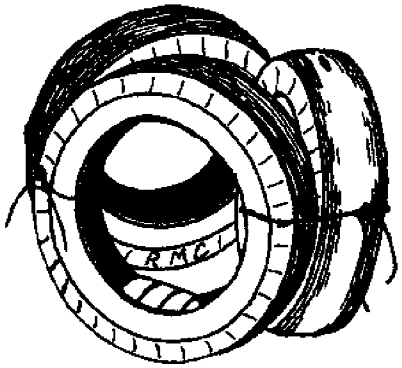

Figure 2. The upright triangle unit.

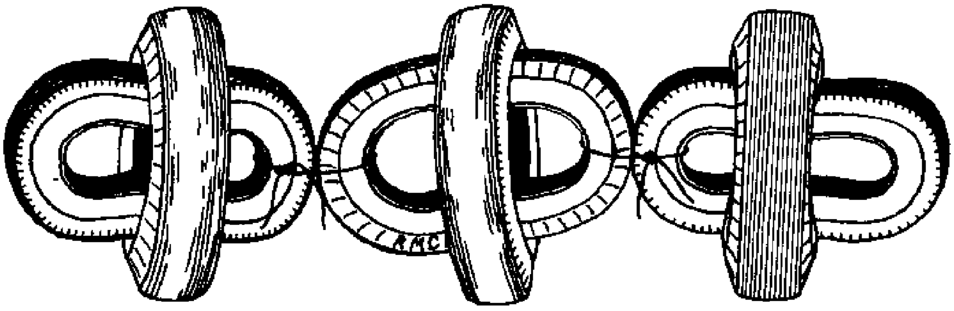

Figure 3. The tire chain unit — six tires linked.

4. *Pyramid tire unit* (*Fig.* 4)

Data on materials and costs are from Prince and Brouha (1974).

Materials	**Estimated Cost**
Old tires (9 per unit)	0
No. 10 can (6 per unit)	0
Concrete (amount needed to fill 6 No. 10 cans) @ $0.07 per can	$0.42
Polypropylene line, 40 feet, ¼-inch diameter @ $0.02 per foot	0.80
TOTAL per unit	$1.22

Three tires form a cylindrical assembly for this unit. Two of these 3-tire assemblies are then roped together to form a base of six tires. A third assembly is then lashed on top to form a pyramid. Six No. 10 cans filled with concrete are forced between the sidewalls of the base tires to anchor the unit. The upper tread portions of all but the middle tire of the top assembly are drilled to allow air to escape. The air trapped in the undrilled tire assures that the unit will sink in an upright position.

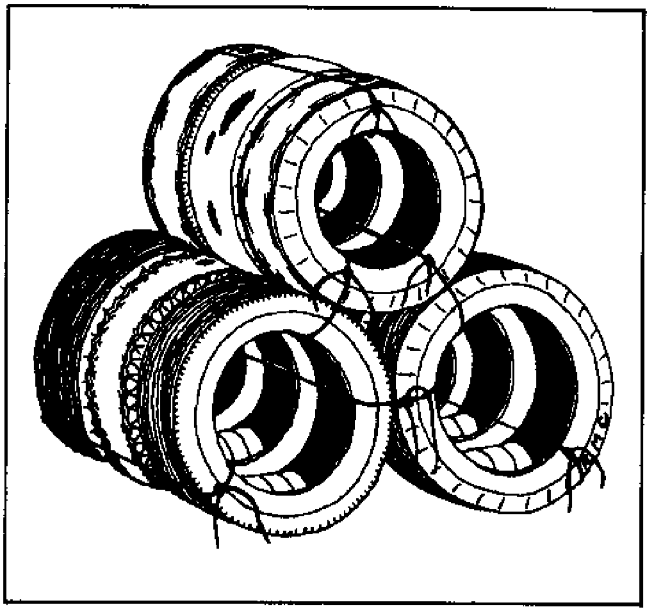

Figure 4. The nine-tire pyramid unit.

5. *High-profile tire unit* (*Fig.* 5)

Data on materials and costs are from Prince and Lambert (1972) as modified by Prince and Brouha (1974).

Materials	**Estimated Cost**
Old tires (13 per unit)	0
Concrete (about 40 gallons necessary to fill base tire) @ $0.11 per gallon	$4.40
Reinforcing bar, 40 feet, ½-inch diameter @ $0.10 per foot	4.00
Total per unit	$8.40

In the construction of this unit, a large truck tire (10.00x20) is placed horizontally on the ground as a base. Four holes are drilled in the upper sidewall, dividing the tire into quarters. The holes are then enlarged by cutting out a wedge toward the center of the tire with a saber saw (use knife blade insert). Four 10-foot (3 m) long sections of reinforcing bar are inserted into the holes of the base tire. Each bar is bent toward the center of the tire and then an acety-

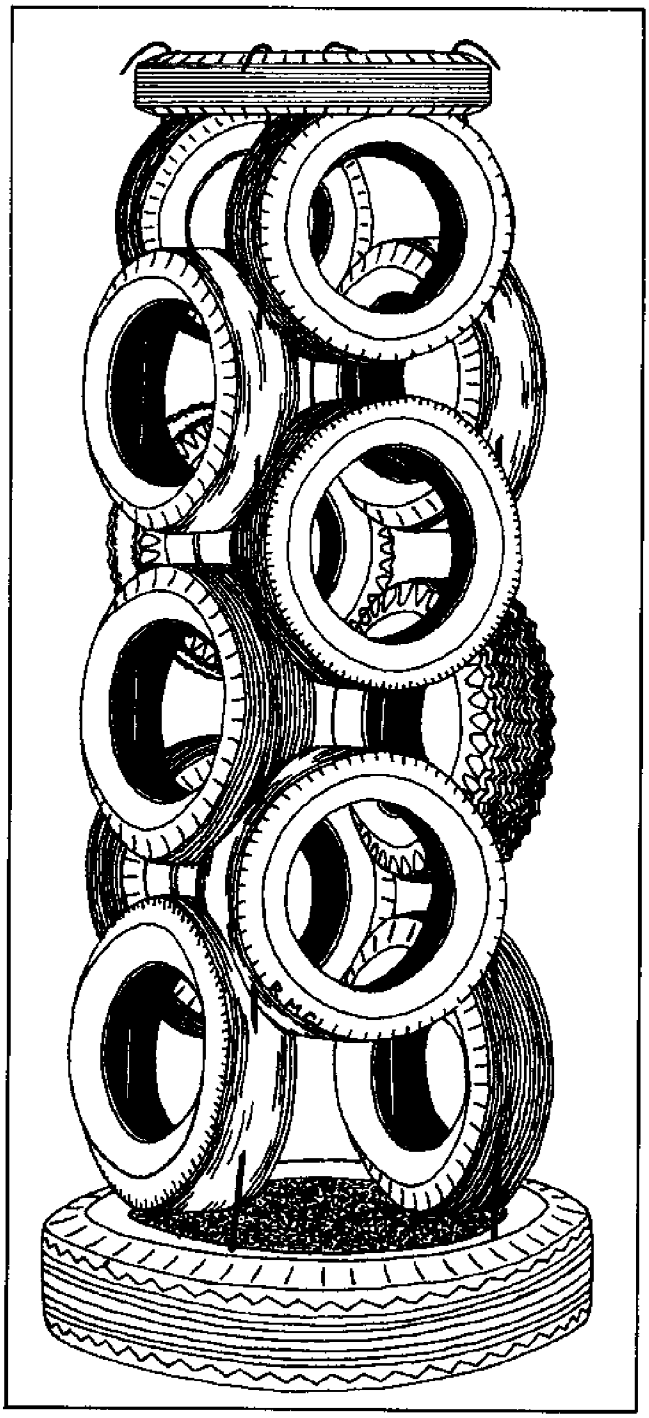

Figure 5. The high-profile tire unit, with a truck tire base.

lene torch is used to weld the ends of the bars together. The base tire is then filled with concrete. Tires are drilled and slashed to allow two reinforcing bars to be driven through each tire, and tires are then threaded down the reinforcing bars. Parallel tires are successively forced down the rods at right angles to the tires immediately beneath them (Fig. 5). A tire threaded over the ends of the reinforcing bars in a horizontal position is used to cap the unit. The tips of the reinforcing bars are then bent outward to hold the cap tire in place. The completed unit weighs several hundred pounds and must be handled with heavy equipment. Units may be delivered to the reef site by floating platform or barge. This unit differs from that of Prince and Lambert (1972) in that no stabilizing tires are used. They are not necessary when the unit is placed on level bottoms or is not subject to strong current.

6. *Floating tire units and breakwaters (Figs. 6 and 7)*

Data on materials and costs are from R. D. Candle (Goodyear Tire and Rubber Co., personal communication) and from Kowalaski and Ross (1975).

Materials	**Estimated Cost**
Old tires (number variable)	0
Polypropylene line, length variable, ¾-inch diameter; or ½-inch chain may be substituted; from $1.10 per pound	variable
Danforth anchor, two 35-inch total length, @ $31.60 each	$63.20
TOTAL per unit	from $350 to $700

Kowalaski and Ross (1975) estimate floating breakwater construction costs from $4 to $30 per linear foot (30 cm). R. D. Candle (Goodyear Tire and Rubber Co., personal communication) states that one reef consisting of about 340 tires costs between $350 and $700. This amount includes cost for buoys. These costs vary, depending on the type of tying material, bridle, and moorings used. Tying material for the floating reefs makes up about half the total cost, and the mooring system the other half.

Sets of 18-20 tires make up symmetrical assemblies which form the base unit of these reefs (Fig. 6). No holes are cut in the tires since the trapped air serves as flotation for the reef. These assemblies are then tied together with other assemblies of the same type until the reef reaches the desired size. The circular floating reef (Fig. 6) consists of about 17 assemblies or 340 tires. After the number of assemblies making up the completed reef is tied together, a bridle (nylon or polypropylene line) is threaded through the outside tires around the perimeter to prevent individual bundles from separating and drifting away. The reef is then moored in place with two anchors. For detailed description of construction, refer to Kowalaski and Ross (1975).

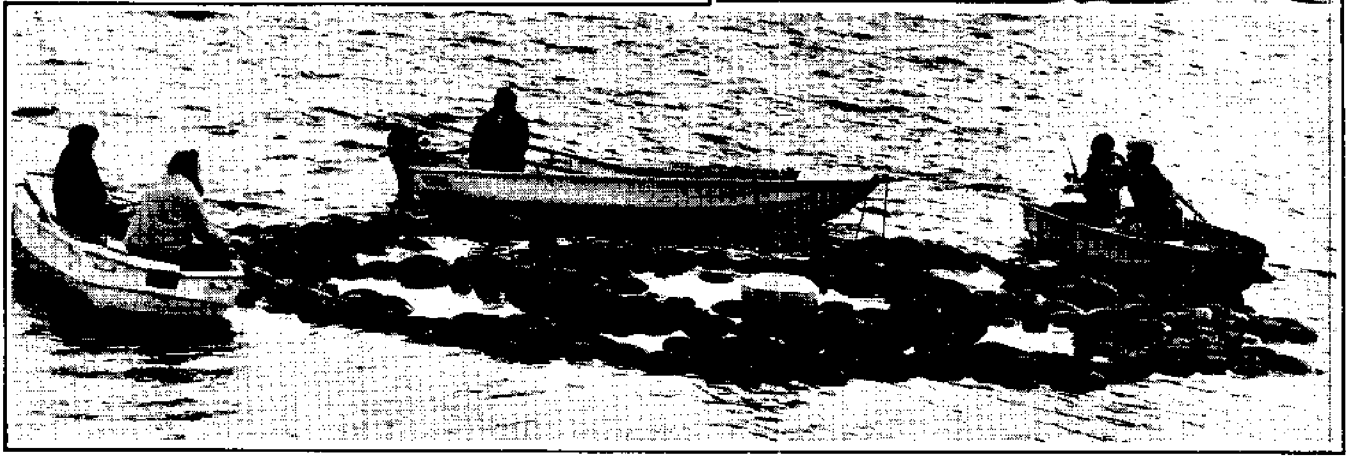

Figure 6. Floating artificial tire reef in Wing Foot Lake, Ohio. Photo courtesy of R. D. Candle, Goodyear Tire and Rubber Company, Akron, Ohio.

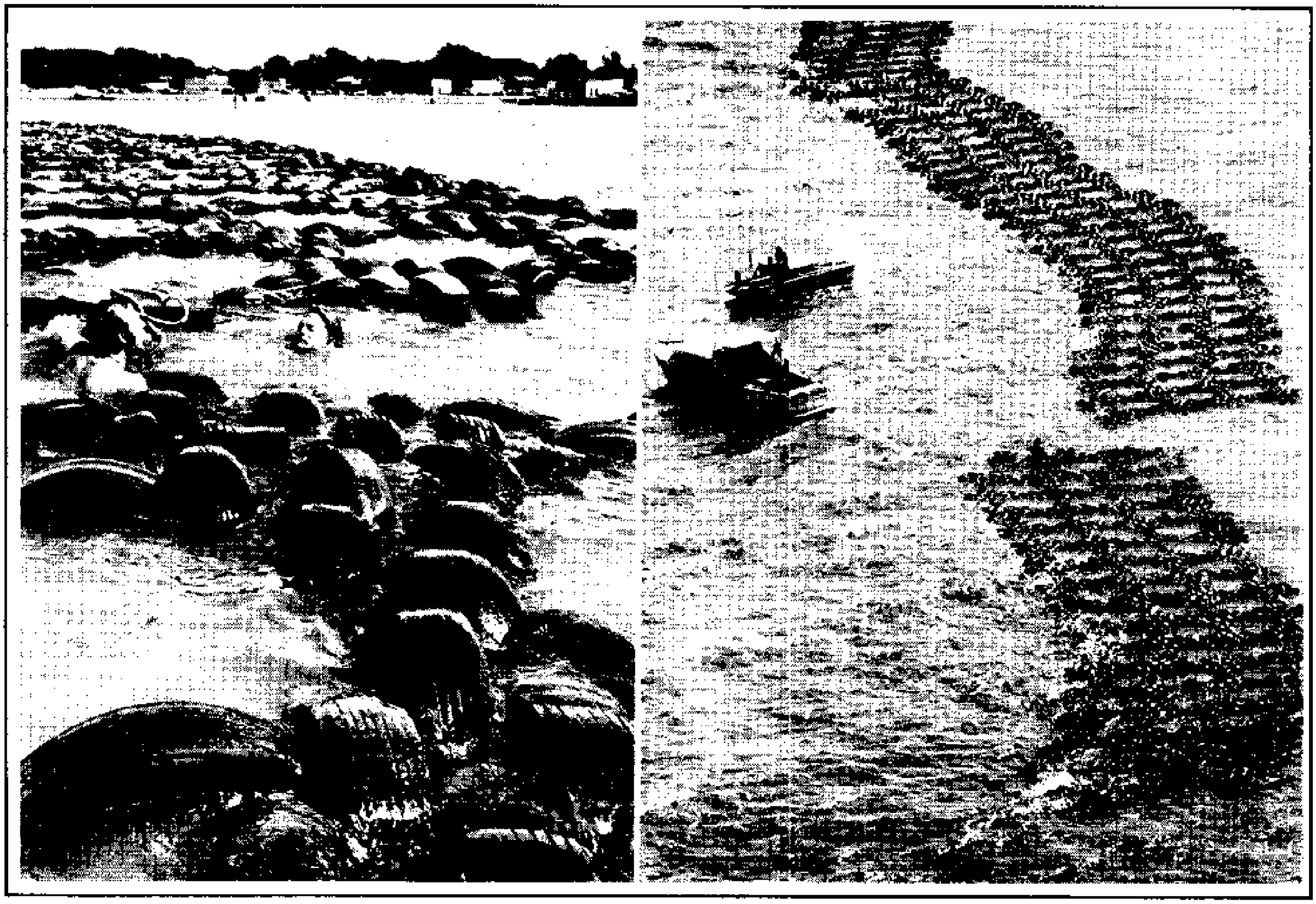

Figure 7. Floating tire breakwaters. Photo courtesy of R. D. Candle, Goodyear Tire and Rubber Company, Akron, Ohio.

Brush

As previously mentioned, brush is usually available; however, brush is difficult to handle, and maintenance costs are high because the reefs deteriorate rapidly. A design problem results from the nature of the material. The material in brush units must be firmly attached to a frame and well anchored. Unless such care is taken, pieces of the reef may float away and become navigational hazards. Freshly cut green wood is the best wood for reef construction because it is dense enough to sink in water after the addition of only a small amount of weight. If oak is not available, other freshly cut dense hardwoods should be substituted. The use of dry wood should be avoided because it does not sink readily.

Six brush structures are described in detail:

1. *Square frame structure*

Rodeheffer (1945) described a frame reef which was placed in Douglas Lake, Michigan:

> "Scrub oak and maple poles were used for the frames, which consisted of an inner unit 9 feet [3 m] square, with the ends of the poles protruding beyond the square, and a surrounding frame 11½ feet [3.5 m] square. The larger unit was fastened to the protruding ends of the smaller one in such a way as to make a sturdy base for the brush. The brush, consisting of maple, scrub oak, tag alder, and cherry, was placed in bundles about 18 inches [400 mm] in diameter at the butt end and laid on this frame, with the tops pointing away from the center. Each bundle was securely wired to the pole of the inner frame with number 9 galvanized wire. All bundles were placed as close together as possible, so as to form a complete circle. The outer edges were trimmed, making each shelter 18 feet [5.5 m] in diameter."

2. *Stacked brush frame* (*after May,* 1968)

To construct these units, brush is stacked to a height of 5 or 6 feet (1.5-2 m) on a 5 x 10 foot (1.5 x 3 m) frame, and securely fastened by wire clothesline.

3. *Bundled brush structure*

Brush may be assembled into bundles, bound together with synthetic rope, and weighted with ballast.

4. *Christmas tree unit (Fig.* 8)

Data on materials and costs are from Prince and Brouha (1974).

Materials	**Estimated Cost**
Old Christmas trees	0
Steel bar stock, 1-foot, ¼-inch diameter @ $0.05 per foot	$0.05
Concrete (about 4 gallons per 5-gallon can) @ $0.11 per gallon	$0.45
5-gallon can	0
TOTAL per unit	$0.50

A ⅜-inch (10 mm) hole is drilled at the base of the trunk of each Christmas tree and a 12-inch (30 cm) piece of steel bar stock is forced into the hole, to begin construction of these units. The butt of the trunk is then put into a 5-gallon (18.9 liter) can and the can is filled with concrete to three-quarters of its capacity (the steel bar prevents the base from loosening when the cement shrinks). Single Christmas tree units have been reported to be very unstable (Maughan et al., 1976) because of the relatively small diameter of the base. Therefore, we recommend that three or more of these units be tied together in order to keep them upright on the bottom.

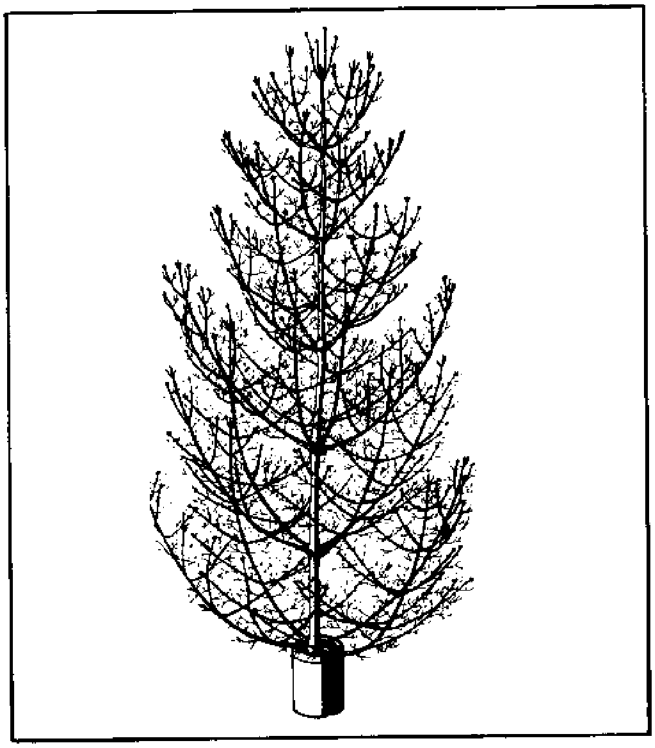

Figure 8. The Christmas tree unit — tie three or four together.

5. *Wisconsin log crib* (Fig. 9)

The frame for these units is constructed as a 6-8 foot (1.8 - 2.4 m) log square. Seven sapling poles are laid across the square to create a floor. Log walls are added to the structure until the desired height of 4-6 feet (1.2 - 1.8 m) is reached. Each square of logs is secured at the corner with galvanized wire or drilled and pegged with a ½-inch concrete reinforcing bar. The interior of the resulting roofless log cabin is filled with brush, and saplings are fastened across the top of the structures to hold the brush in place.

In southern waters where no winter ice cover forms, construction of the log crib units may be begun on a temporary log ramp which extends out into the water from shore. The structure may be progressively moved into the water as logs are added. Such a strategy takes advantage of the neutral or slightly positive bouyancy of the wood. When this reef is completed, it may be attached to the underside of a flat-bottomed boat and towed to the installation site. If the structure floats, rock or concrete blocks may be attached for ballast.

In more northern climates where winter ice forms, the log crib reef may be constructed on the ice over the desired location (Fig. 9). The structures will sink to the bottom as the ice thaws. Alternatively, structures may be constructed in a shallow water location and towed to their installation sites after the ice melts.

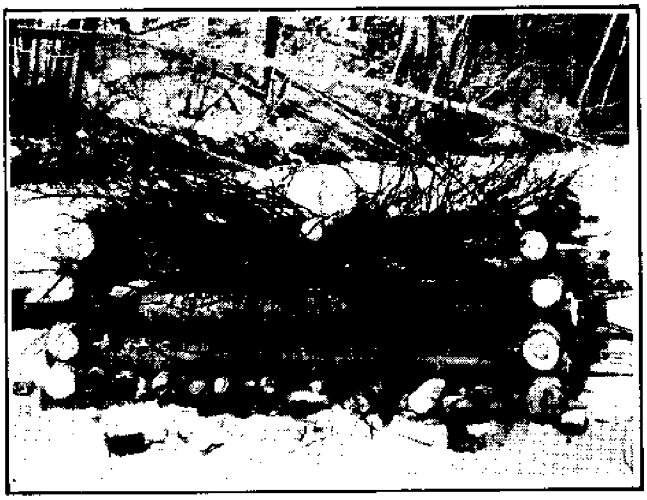

Figure 9. Wisconsin log crib being constructed on winter ice. Photo courtesy of Paul Brouha, Wisconsin Department of Natural Resources.

6. *Shoreline timber (Figs.* 10 and 11)

In many areas, one of the easiest ways to construct artificial reefs is to fell shoreline trees into the water. The use of shoreline timber eliminates transportation of construction materials to the lake. In northern climates, shoreline trees can often be conveniently cut during the winter. The trees are then positioned on the ice and weighted with concrete blocks (Fig. 10). The trees sink into position during the spring thaw. In steep-sided reservoirs that have fluctuating water levels, shoreline timber provides structures even when partially exposed during drawdowns (Fig. 11).

Figure 10. Shoreline timber on winter ice (top) and after the spring thaw (bottom). Photo courtesy of Wisconsin Department of Natural Resources.

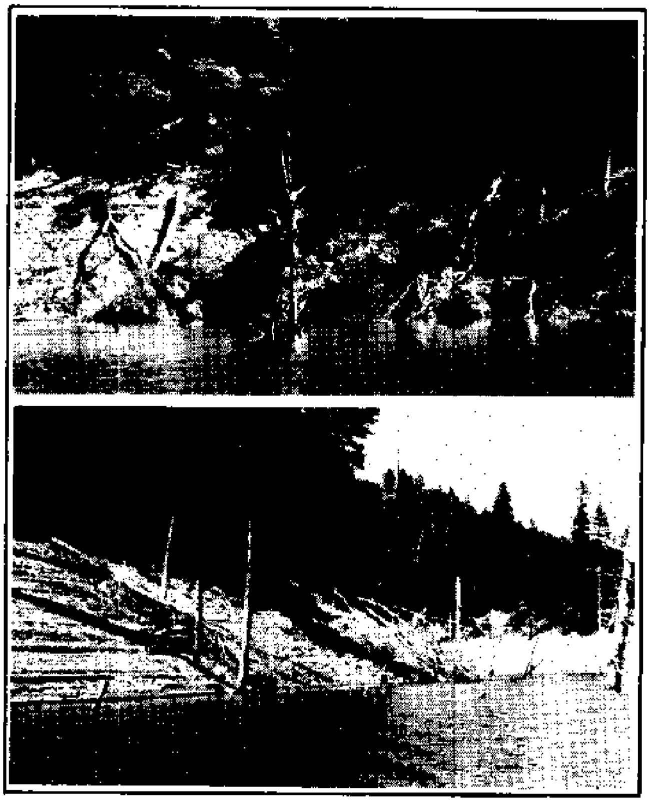

Figure 11. Shoreline timber on the banks of a steep-sided California reservoir. Photo courtesy of California Department of Fish and Game.

Vitrified Clay Pipe and Concrete Blocks

Damaged clay sewer pipes and concrete blocks (Fig. 12) may be used as construction material for artificial reefs (Wilbur et al., 1973). Many manufacturers now reprocess these seconds, but if advance arrangements are made, materials may often be obtained from manufacturers at little or no cost.

1. *Clay pipe structure*

Clay pipes are bundled together with plastic banding material to form a pyramid; 20 bundles of 6 pipes per bundle are generally used. Half of the bundles should be made of 6-inch (15 cm) diameter pipes and half of 4-inch (10 cm) diameter pipes. Other larger diameter pipes, up to 3 feet long (1 m) may be randomly distributed around the reef site.

2. *Block-brush structures*

Concrete block structures may be combined with brush structures by placing up to 700 concrete blocks in a pile and surrounding them with weighted brush bundles. The result is a pyramid of blocks fringed with brush (Fig. 12).

Stake Beds

Stake beds have been used by the Tennessee Game and Fish Commission to concentrate crappies and other warmwater sport fishes. For these structures to be economically feasible, lumber must be free or obtainable at little cost. Petit (1972) described several methods of construction:

1. *Driven stake bed*

About 15 stakes (4-7 ft. or 1.2-2.1 m long) can be driven into the lake bottom during winter drawdown to create a bed 4 by 8 feet (1.2 x 2.5 m).

2. *Prefabricated bed* (Fig. 13)

Stake beds also can be made by nailing stakes to a 4 x 8 foot (1.2 x 2.5 m) wooden frame. The portable prefabricated bed can then be floated to the desired spot and sunk with concrete blocks.

Automobile Bodies

Automobile bodies can be used to create artificial reefs (Charles, 1967); however, the cars must be stripped of upholstery and steam-cleaned to rid

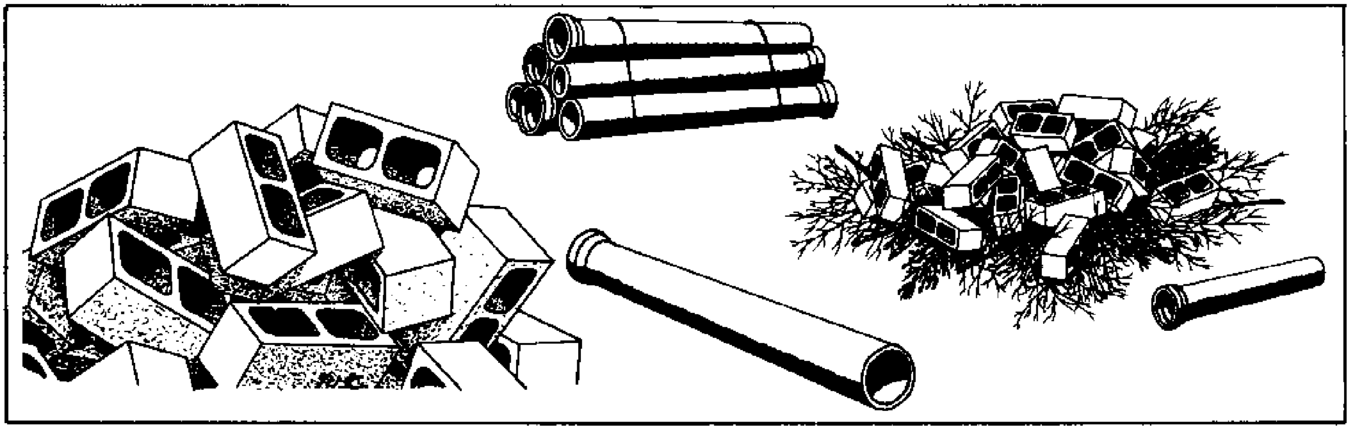

Figure 12. Clay pipe bundle and concrete block pyramid, fringed with brush.

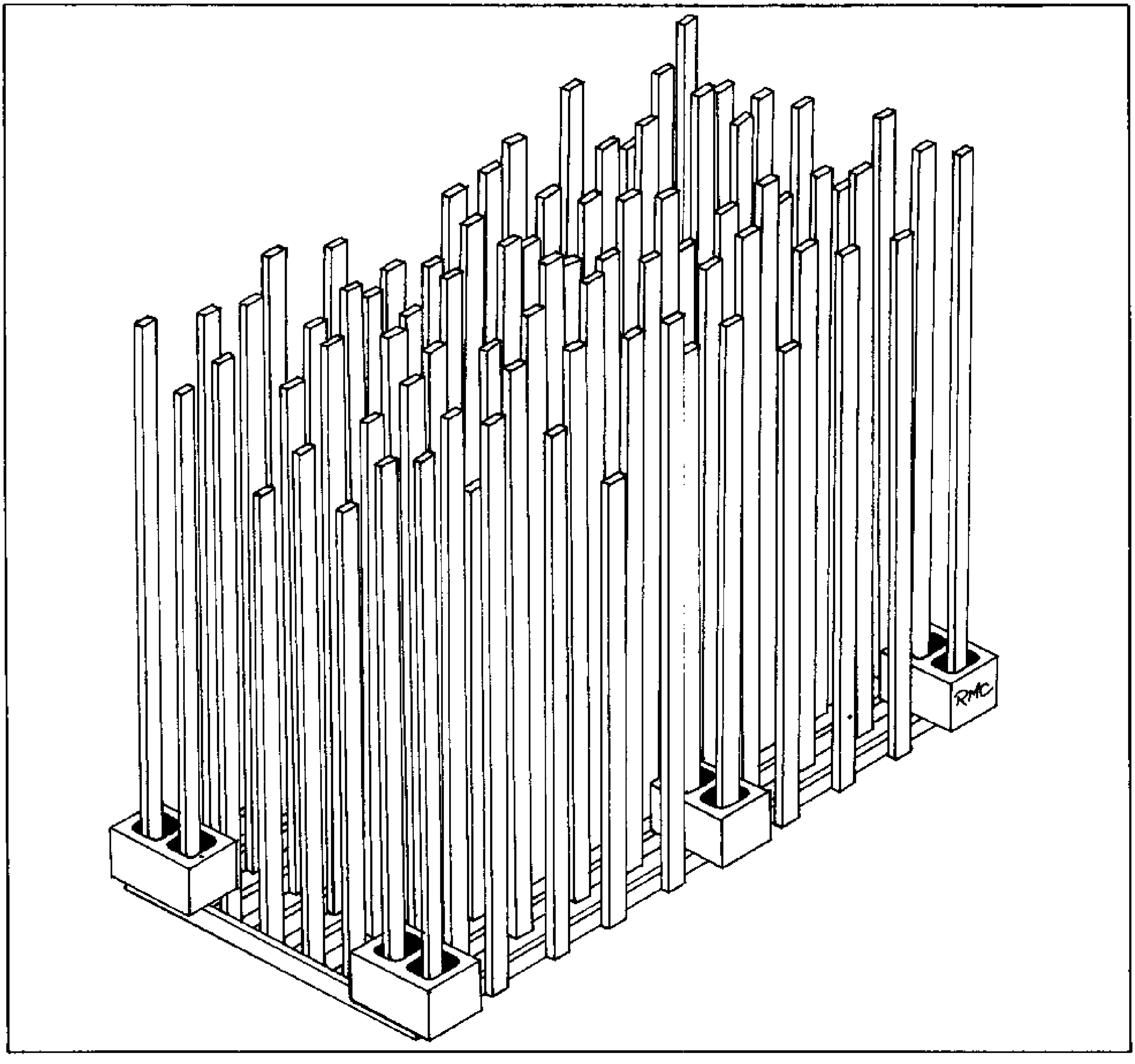

Figure 13. The prefabricated stake bed unit.

them of grease or oil before they are transported to the construction site. Costs of transportation and handling are usually high because of the size and weight of each unit. Usually a crane is required to install the car bodies at the reef site.

Old Boats

Old boats can be a convenient source of structures. Boats must be cleaned of extraneous floatable materials, grease, and oil. Then they may be towed to a specific site, weighted, and sunk. In Smith Mountain Lake, boat wrecks were used in combination with other materials to diversify reefs and increase the total surface area.

Other Materials

Plastics have been used to create artificial aquatic plants and other types of structures (Brashears and Dartnell, 1967). The use of plastic aquatic plants has been curtailed somewhat, because attachment of organisms tends to flatten the plants and reduce their efficiency in attracting fish.

Concrete houses have also been built specifically for fish. Many of these structures may not be ideally suited for freshwater environments because of prohibitive costs or logistics.

Additional Reef Construction Literature

Additional references dealing with various phases of artificial reef construction (marine and freshwater) include the following:

Marine
- Edmond, 1967
- Hammond, Myatt, and Cupka, 1977
- Kowalaski and Ross, 1975
- Myatt and Cupka, 1975
- Parker, Stone, Buchanan, and Steimle, 1974

Freshwater
- Brouha and Prince, 1974
- Wilbur, 1975

Two bibliographies on artificial reefs by Steimle and Stone (1973) and Richards (1973) offer important sources of reference for those interested in any aspect of artificial reefs. Steimle and Stone are currently updating their bibliography and plan to have a more extensive second edition available in the near future. This will be an important reference source since, among other things, it will include the proceedings from the Second International Conference on Artificial Reefs held in Brisbane, Australia, in September 1977.

SUMMARY

Any reef project must be carefully thought out and many items considered before the final decision is made. From a logistical viewpoint, plans must be made to obtain materials, move them to the construction site, and store them for extended periods. After the reef units have been constructed, they must be positioned. In areas with sufficient winter ice, the units may be built over the ice or hauled out to the desired location and allowed to sink during the spring thaw. Reefs may also be planned directly in conjunction with reservoir construction, and the units trucked to the installation site before the reservoir basin is flooded. If certain areas of the reservoir are left uncleared during reservoir construction, artificial reefs may be unnecessary. In a reservoir with significant water fluctuation, the reef might be installed on the exposed bottom during the winter drawdown.

All construction projects cost money, but costs of materials and equipment can be drastically reduced by making the project a community endeavor, and by actively soliciting support from businesses or from municipal, state, or federal agencies (Prince and Brouha, 1974). In a community sponsored project, volunteer manpower and donated materials and equipment often greatly reduce labor and construction costs. The economic aspects of the Smith Mountain Lake, Virginia, artificial reef project illustrate this point well. Over 50 percent of the reef construction costs of the Smith Mountain Lake project were donated by various segments of the community.

It must be reiterated that an artificial reef is not a panacea; it is simply one of the potentially valuable tools available to the fishery manager. Decisions regarding management of individual inland waters should be made by trained personnel. We have emphasized that our guidelines are general and subject to modification as new information becomes available. Some of the problems we have considered do not yet have conclusive solutions, but perhaps these can eventually be obtained if investigations are continued.

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DISCLAIMER

The use of any of the artificial reef structures described in this booklet, and in our first edition, shall be at the sole risk and responsibility of the user; no liability is accepted by the Virginia Polytechnic Institute and State University or the U.S. Fish and Wildlife Service.

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