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Use of Artificial Structure to Enhance Angler Benefits in Lakes, Ponds, and Reservoirs: A Literature Review

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Artificial structure has been used in the United States since the 1930s to modify benthic habitats in freshwater systems in attempts to enhance both sport and commercial fisheries. Since then, the use of artificial structure has become widespread throughout the country in a variety of waters and fish communities. Proposed advantages of installing artificial structure include increasing angler catch per effort, providing cover to increase survival of juvenile fish, and providing spawning habitat to increase natural production. Structure materials vary from brush piles and evergreen trees, to tires, hay bales, and manufactured plastic forms. The most effective types of artificial structure resemble natural structure with varied complexity and interstitial spaces. The success of structure projects is dependent upon the type of fish community present, the slope and depth at which the structure is placed, the amount and size of structure installed, and the type of structure that will best meet the goals of the project. The most successful structure projects are those which are implemented with clearly defined management goals. Those goals can only be formulated after an assessment of the fish community and the existing structure, and it has been determined that the addition of more structure will have a positive impact.

Keywords spawning habitat, cover, juvenile fish cover, interstitial space, increased catch per effort

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Introduction

Since ancient times, fishermen have realized that fish are captured more readily near natural structures such as rocks, boulders, reefs, fallen trees or floating debris, than in areas devoid of such structures. This realization led to the placement of artificial structures in waters to attract and concentrate fish and improve fishing efficiency. The first documented artificial structures were installed in Japan in the late 1700s, and have subsequently been introduced into waters worldwide (Meier, 1989). Artificial structure uses include breakwaters, solid waste disposal, habitat restoration, recreational diving opportunities, and scientific research (Bohnsack et al., 1997). They are also used more specifically in fisheries management to alter spatial and temporal distribution of target species, improve harvesting efficiency, and create new fishing sites (Polovina, 1991).

The first artificial structures installed in this country were log cribs that were placed as fish attractants in marine waters off South Carolina in 1860 (Stone, 1986). The first documented freshwater use of an artificial structure in the United States was by the Michigan Conservation Department in the 1930s, in the form of gravel and brush piles (Hazzard 1937 cited in Wilbur, 1978). In 1936, Eschmeyer (in Pardue, 1973) stated that adding brush shelters would provide food and cover for small fishes. From the 1950s through the 1970s, the installation and study of artificial structure became widespread throughout the United States. Currently, artificial structures are installed into public and private waters by local, state, and federal agencies, universities, and private interests (Stone, 1986). Types of artificial structures include evergreen trees, wooden pallets, tire bundles, brush piles, log cribs, stumps and whole trees, stake beds, rock piles, spawning boxes, gravel and cobble, cinder blocks, car bodies, cement blocks, hay bales, floating objects, mid-water reefs and a variety of commercially produced plastic fish-attracting devices (Wilbur, 1974; Brouha and von Geldern, 1979; Helfman, 1979; Stone, 1986; Moring and Nicholson, 1994; Bassett, 1994; Richards, 1997).

In many cases, artificial structure has been introduced into lakes and reservoirs without clear objectives and realistic expectations regarding what it can and cannot provide. Our objectives are to:

1. discuss the advantages and disadvantages of using artificial structure in freshwater for obtaining specific management objectives;
2. describe specific types of structure and their use;
3. provide information to help freshwater management biologists determine if specific waters in their area could benefit from the addition of artificial structure, and if so, what type of structure would best fit their goals.

Possible Benefits to Installing Artificial Structure

Increased Catch Per Effort

Artificial structure has been used as a management technique in inland waters for many years to concentrate fish and increase catch-per-effort (CPE) in both sport and commercial fisheries (Wilbur, 1978; Prince and Maughan, 1978; Prince et al., 1986; Moring et al., 1989; Polovina, 1991). This is best accomplished in structure-deficient waters where CPE is low and the fish community is spread out and under-exploited (Prince and Maughan, 1978).

Fishes are often attracted immediately after installment of the artificial structure, sometimes within hours (Richards, 1997), and the increased fish density often results in increased catch rates. Paxton and Stevenson (1979) placed limestone rip-rap in an up-ground reservoir in Ohio and found that angler success was significantly better for smallmouth bass (*Micropterus dolomieui*), rock bass (*Ambloplites rupestris*), and bluegill (*Lepomis macrochirus*) at the structured areas, than at the nonstructured areas. Wege and Anderson (1979) also found that angling CPE for largemouth bass (*Micropterus salmoides*) and bluegill was significantly better near artificial structures of brush piles, tire beds, and stake beds, than at areas without artificial structures. Richards (1997) compared commercially constructed artificial structure modules (fish spheres, Hartman, Arkansas) with evergreen tree structures and control sites, for angling CPE of largemouth bass and crappie (*Pomoxis* spp). He found that the fish spheres yielded a CPE of 9.8 fish/hr, the evergreen trees yielded 18.9 fish/hr, while the control sites produced an angling CPE of <1 fish/hr. Observational video also verified that both adult and young-of-the-year fish were attracted to the trees sooner, and in larger numbers than to the spheres.

The ability of artificial structure to attract and concentrate fish is dependent not only upon the availability of natural habitat, but also on the species composition of the fish community and their general abundance (Prince and Maughan, 1978; Johnson et al., 1988). Artificial structure works best to concentrate bottom and structure-oriented species like bluegill, catfish, largemouth and smallmouth bass, rock bass, pumpkinseeds (*Lepomis gibbosus*) and black and white crappie (Walters et al., 1991; Bassett, 1994). Species associated with both open water and structure, such as yellow perch (*Perca flavescens*), walleye (*Stizostedion vitreum*) and white crappie, move between the two areas, but congregate around artificial structure enough to significantly increase aggregation and angling CPE for these species (Werner et al., 1977; Prince and Maughan, 1978; Johnson et al., 1988; Walters et al., 1991; Richards, 1997). Artificial structure rarely concentrates open-water species such as trout (Moring et al., 1989; Viavant, 1995).

Increasing Cover for Juvenile Fish

Some researchers suggest that the addition of artificial structure may increase juvenile fish survival in lakes where cover is limited (Eschmeyer in Pardue, 1973; Brouha and von Geldern, 1979; Wege and Anderson, 1979; Lindberg, 1997). In these situations, the addition of cover could theoretically increase juvenile survival by creating refuges from predation (Brown et al., 1970; Savino and Stein, 1982; Mestl, 1983; Walters et al., 1991; Miranda and Hubbard, 1994).

The possibility that artificial structure could help increase juvenile fish survival is based in part on the large amount of information available regarding the value of vascular plants as cover and refuge habitat for fishes. Various studies have shown that the presence of aquatic plants can increase survival of juvenile fish (Swingle 1968 cited in Pardue, 1973; Durocher et al., 1984; Miranda and Pugh, 1997). Flooding of terrestrial vegetation has also improved survival of juvenile fish, most notably largemouth bass (Aggus and Elliott, 1975; Vogele and Rainwater, 1975; Miranda et al., 1984). In contrast to these studies, Hoyer and Canfield (1996) found no significant relationship between the amount of macrophyte cover and largemouth bass abundance or standing crop in 56 Florida lakes <300 ha total area.

Of those studies where benefits of aquatic plants were reported, most indicate that coverage of an intermediate amount of the lake's total area provides the greatest benefits to warmwater sport fish communities. Both Crowder and Cooper (1979) and Bettoli et al. (1992) found that feeding efficiency and growth of fish was maximized at intermediate levels of structural complexity in the form of aquatic plants and was reduced at higher levels of structural complexity. Miranda and Pugh (1997) examined overwinter survival, growth, and recruitment of age-1 largemouth bass in small coves with plant coverage of 0–65%. These values were highest in coves with 10–25% plant coverage. A model developed by Wiley et al. (1984) to measure the effect of different macrophyte levels on sport fish populations in small Illinois ponds, showed a parabolic relationship between largemouth bass production and plant standing crop, with largemouth bass production highest at 36% macrophyte coverage. However, they found that insectivorous forage fish production increased directly with increasing macrophyte coverage up to 100%. Although total production of small panfish can increase at high macrophyte densities, structural complexity increases to the point that feeding efficiency and growth are reduced (Crowder and Cooper, 1979).

Less is known about the benefits of artificial structure as cover for juvenile fish, although some researchers (Wilbur, 1974; Wege and Anderson, 1979) suggest that artificial structure in adequate amounts should function similar to aquatic plants. Unfortunately, it is often impractical to add enough structure to approach theoretical optimal levels of 20–50% coverage (Miranda and Pugh, 1997). For example, Walters et al. (1991) calculated that it would require 11,200 trees to provide 5% coverage of a 40 ha lake. Therefore, the addition of enough cover to increase survival of an entire lakes' juvenile fish population would probably be practical only in small ponds and lakes.

Very few studies were found that documented changes in juvenile fish survival and growth following the addition of artificial structure. Miranda and Hubbard (1994) examined the difference in winter survival of different sizes of age-0 largemouth bass exposed to predators in 0.06 ha ponds containing various amounts of brush. They found that survival of largemouth bass <100 mm total length (TL) was greatest in waters where brush was added to cover 26% of the total area. Cover had a negligible effect on the overwinter survival of the largemouth bass over 125 mm TL. In a 10 ha Michigan lake, the standing crop of 200–250 mm TL bluegills increased, but that of 150–200 mm TL bluegills declined, following the addition of log cribs and pine trees (C. Bassett, USDA Forest Service, unpublished data). However, changes in the overall biomass of largemouth bass and bluegill were not detected.

Possible Drawbacks to Installing Artificial Structure

Overfishing

The most commonly cited drawback to artificial structure is that it aggregates fish, making them more susceptible to overfishing (Wege and Anderson, 1979; Wege, 1981; Polovina, 1989; Walters et al., 1991). Ironically, it is often lowered CPE resulting from overfishing that drives the installation of artificial structure (Polovina, 1991). Because fish can be more aggregated near structure, CPE goes up and the potential for overharvesting increases. Wege and Anderson (1979) estimated they could remove 40% of stocked bass by angling 3.5–9.5 h in 0.2 ha ponds containing brush attractors, whereas 14–14.5 h were needed in ponds without artificial structure. In a 1,374 ha Ohio reservoir, overall angling success for bluegills was 4.3 times greater in an area with dense artificial structure than around isolated artificial structures (Lynch and Johnson, 1988a) and for harvestable-size bluegill it was 6.3 times greater. Increased CPE increases the possibility of over-harvest. Management plans need to be implemented to prevent this from occurring.

When populations are overharvested, habitat is not the limiting factor; therefore, adding more structure will not increase numbers of harvestable fish, and may even decrease them further (Polovina, 1989; Walters et al., 1991; Lindberg, 1997). In conditions like this, more structure may further concentrate remaining fish and exacerbate overfishing (Bohnsack, 1989; Polovina, 1989). The addition of structure in these situations is not recommended. Fishing effort restrictions and/or protecting and renewing broodfish numbers may be the most effective long-term solution to increase the population and CPE in overharvested lakes (Polovina, 1991).

Slowed Fish Growth

Increasing structural complexity in overpopulated fish communities contributes to inefficient feeding by predators. This exacerbates overpopulation, competition, and stunting of fish growth, particularly of forage species (Crowder and Cooper, 1979; Savino and Stein, 1982; Walters et al., 1991). If the majority of fish being harvested from a lake are small, when compared to the average size for the area or species, stunting is likely the problem (Lagler et al., 1962) and adding structure is not recommended (Walters et al., 1991). Furthermore, if aggregating fish to increase angler success is the management goal and stunting is occurring, the addition of artificial structure may exacerbate the problem (Walters et al., 1991).

Adding artificial structure may concentrate the fish, but the stunting will continue because by increasing structural complexity, the feeding efficiency of piscivorous fish is reduced, resulting in increased numbers but reduced growth and biomass of the forage species (Crowder and Cooper, 1979; Savino and Stein, 1982; Bettoli et al., 1992). Also, when stunting is occurring, even though the fish are more aggregated and the catch rate could go up, increased angler harvest is usually reduced because few if any "keeper-size" fish are caught. That is, anglers are catching more fish but the fish are small and normally returned to the water, and the angler goes home empty-handed (Walters et al., 1991).

Decreases in Aesthetic Enjoyment and Hazards to Navigation

Various surveys designed to ascertain why anglers visit lakes and participate in fishing activities revealed that sociological and aesthetic as well as biological factors need to be considered when managing fisheries resources (Hendee et al., 1977; Mongillo and Hahn, 1988). In one study, up to 80% of fishermen cited reasons other than fishing as why they recreate at lakes (Hendee et al., 1977). Because aesthetic enjoyment of the natural surroundings is a major consideration (Mongillo and Hahn, 1988), seeing artificial structures, or knowing they are present in the waters in large quantity may reduce many peoples' enjoyment of these areas, particularly during reservoir draw-down. Forest Service biologists in the Midwest have rarely used tires, particularly in clear water lakes, because they are considered unsightly (Bassett, 1994). Wilbur (1978) stated that after interviewing thousands of fishermen familiar with the best fishing areas in Lake Tohopekaliga, Florida, most preferred not to utilize what they considered to be "gimmicky" fish attractors.

Artificial structures installed for fisheries management can also become hazards to navigation. Tires, trees, or brush piles that are not properly anchored can move because of wind and wave action or float because they are too buoyant (Mathews, 1986; D. A. Walters, Ohio Division of Wildlife, personal communication). Artificial structures can also become a navigation problem in reservoirs where draw-down and water level fluctuation occur, rendering a formerly deep water structure a shallow water structure, or exposing it completely (Mosher, 1985).

Leachate from Artificial Structures

Water quality concerns have been raised about possible harmful leachates from different artificial structure materials, mainly tires. Few studies are available in the literature regarding the effects of tires on water quality (Nelson et al., 1994), and their conclusions vary greatly. Nelson et al. (1994) showed acute toxicity to *Ceriodaphnia dubia,* but little effect on fathead minnows (*Pimephales promelas*), leading them to conclude that the use of tires as artificial reefs in freshwater would not significantly affect water quality. Day et al. (1993) also reported no toxicity to fathead minnows or cladocerans (*Daphnia magna*), but found that tire leachate was lethal to rainbow trout (*Oncorhynchus mykiss*). Kellough (1991) also found that tire leachate was lethal to rainbow trout though his results were less conclusive. We could find no literature discussing leachates from other commonly used types of artificial structure materials.

General Guidelines for Planning Projects and Installing Artificial Structure

Determine Management Goals

Management objectives must be clearly defined to increase the chance for success of an artificial structure project and to determine if it may be beneficial to the management of a particular fishery (Lindberg, 1997). Managers need to know what changes in the fish community they would like to have occur, and realistically which changes could take place as a result of the artificial structure project. Knowing what benefits artificial structures can provide under various conditions are essential for developing workable management strategies (Bohnsack and Sutherland, 1985). For example, if there is sufficient natural structure to aggregate fish, adding additional artificial structure may have little effect. However, if there is minimal natural structure and the population could tolerate increased harvest, then concentrating the fish by using artificial structure would be an appropriate management strategy.

After formulating specific goals for the project, biologists are better able to determine the best type, quantity, and placement of artificial structure necessary to improve angling. This will help prevent initiating projects solely because there is surplus material, volunteer interest, or excess funds available.

Project Design/Analysis and Pre- and Post-Installation Surveys

Another important initial step in the development of an artificial structure project must be the inclusion of a specific project design including pre- and post-installation surveys of the fish community and an analysis of the data that will be collected. The project design and data analysis need to be robust enough so they will be of value once the data collection has begun. A biometrician should also be consulted during the planning stages to help verify that not only the design is sound, but also that the data collection and analysis will properly support the design.

The pre-installation survey(s) will provide information to assess the current status of the fish community. With this information, biologists are better able to determine if adding structure will be beneficial and assist in reaching the management objectives, or whether it may have a neutral or negative effect. The pre-installation survey should also include an estimate of the amount of existing natural structure and any artificial structure in the lake.

The post-installation survey(s) will provide valuable information about whether the addition of artificial structure has contributed to changes in the fish community (either positively or negatively); e.g., whether the target species of fish have become more aggregated, whether spawning activity has increased, and/or whether harvest and CPE levels have changed. The post-installation survey should be conducted at the same time of year as the pre-installation survey, for one or more years following the initial installation. This will provide the best comparison of the fish community over time, as the different species of fish in the lake will be in the same relative life stages as the pre-installation survey, providing a more accurate comparison of population estimates, length-frequency, growth, and catch-per-effort data.

Surveys over multiple years, both pre- and post-installation, provide the most valuable trend data about how, where, and when artificial structure is useful. Without these surveys, biologists are left with only anecdotal or speculative information regarding the effects on angling and the fish community since the installment of the artificial structure. This type of information is virtually useless, and worse, misleading, when attempting to attribute any changes that have taken place due to the presence of the artificial structure. Inaccurate information can lead to adverse ecological impacts and wasted funds. Also, a single pre- or post-installation survey is only one point in time and may or may not accurately represent true trend data. Continued monitoring of the artificial structure will also help future project planning, furthering understanding of effective artificial structure design, and help identify under what circumstances artificial structure is most useful (Bohnsack et al., 1991).

Because the primary effects of the addition of artificial structure (other than spawning habitat) are aggregation of fish and increased CPE, biologists must determine if increased harvest is possible and desirable. To establish if a fish community can tolerate increased harvest without adverse effects, biologists need to collect information similar to what would be needed when considering changes in harvest regulations. If for example, the fish in a popular lake have relatively fast growth rates and low catch rates, adding artificial structure to concentrate fish could result in heavier angling pressure on an already sparse population. If catch rates are good throughout the spring and summer, this indicates that anglers know where the fish are, and there would be no reason to concentrate the fish further. Conversely, if catch rates are good in the spring, but drop significantly in the summer, there could be a concentration problem, so the suitable placement of additional artificial structure to keep fish concentrated throughout the summer season may be appropriate. In addition, if growth rates are slow to average, and there appears to be high numbers of harvestable fish, adding artificial structure to increase harvest would be a proper strategy (B. Lynch, School of Natural Resources, Ohio State University, personal communication).

Harvest Rate Planning

Because artificial structures often aggregate fish, and CPE often increases after the installment of artificial structure, fishery managers should consider how harvest should be distributed and whether changes in regulations should be enacted to prevent overharvesting. These regulations may include gear and effort restrictions (Wege, 1981; Polovina, 1991). If over-harvesting has caused poor fishing conditions, then the addition of artificial structure may exacerbate the problem by concentrating what few fish remain. In this case, the installment of structure is not recommended (Wege, 1981; Walters et al., 1991).

Location, size, and number of artificial structures in a lake can directly affect the distribution of harvest and can be used to help regulate the catch-per-angler. For example, if the management goal is to create an opportunity for many anglers to catch at least a few fish, then installing many small artificial structures should be considered (e.g., a circular pattern of individual structures, or a small central structure). This strategy allows for structures in more locations around the lake or reservoir. It should disperse the overall concentration of fish throughout the water and still afford smaller concentrations at the structures. The drawback to this strategy is that unless the structures are marked, anglers may find it difficult to locate them (B. Lynch, School of Natural Resources, Ohio State University, personal communication).

If the management goal is to create an opportunity for fewer anglers to catch more fish, then installing fewer large artificial structures may be the proper strategy (e.g., a structure row or large structure). Large artificial structures may attract more fish, increasing the possibility of angler success. Another advantage of larger structures is that they are easier to locate, even without the benefit of marker-buoys or signs (B. Lynch, School of Natural Resources, Ohio State University, personal communication).

Marking or signing artificial structures also makes them easier to avoid by boaters if they are in water shallow enough to create a navigation hazard. A disadvantage to marking artificial structure locations is that too many anglers may concentrate their efforts in fewer places, increasing the possibility of overharvest. An option to prevent this problem would be to sign some structures, but not all.

Lake Size and Amount of Structure Needed

Lake size and the amount of natural and artificial structure needed to reach management goals also need to be considered when planning an artificial structure project. It may be more economically and logistically feasible to expect positive results from the installation of artificial structure in small lakes than in large lakes. In larger bodies of water, it may be more reasonable to only try to improve the fishery of an isolated section, such as a bay, cove, or end of a lake, as was done in the Smith Mountain Lake project (Prince, 1975; Prince and Maughan, 1979a). Adding enough artificial structure to alter the entire fish community of a large body of water may be impractical (Miranda and Pugh, 1997). For example, Walters et al. (1991) stated it would take 11,200 evergreen trees to get the conservative coverage of 5% in a 40 ha lake.

There are a few positive examples of artificial structure being placed into large bodies of water for aggregation; Bull Shoals and Norfork Lakes, Arkansas, 18,000 and 8800 ha, respectively (M. Oliver, Arkansas Game and Fish Commission, personal communication) and Smith Mountain Lake, Virginia, 8,100 ha (Prince, 1975; Prince and Maughan, 1979a; Prince and Maughan, 1979b). An example of large system structure placement to increase fish production by providing spawning habitat where it did not previously exist was at Brevoort Lake, Michigan, 1,700 ha (Bassett, 1994). However, the amount of money and structure needed to make a significant increase in CPE or survival of target species may be prohibitive for many programs. The Brevoort Lake spawning structure covered 9600 m^2 and cost $350,000. The Arkansas project placed over 70,000 trees at 600 sites and its development phase cost $160,000 over five years while relying on considerable community involvement to lessen the cost and divide labor. The labor force was a combination of volunteers and contractors paid by donated money (M. Oliver, Arkansas Game and Fish Commission, personal communication). The Smith Mountain Reservoir project covered 9500 m^2, used 7000 tires, and 400 evergreen trees. Like the Arkansas project, most of the materials and labor were donated for this project, so the total cost in 1974 was only $4,998 (Prince and Maughan, 1978).

There is little information on recommendations for specific quantities of artificial structure to place into waters for fish community enhancement (Bassett, 1994), but as previously mentioned, there is considerable information on optimal levels of aquatic plants as cover and habitat for fish (Crowder and Cooper, 1979; Durocher et al., 1984; Wiley et al., 1984; Bettoli et al., 1992; White, 1996; Miranda and Pugh, 1997). These habitat values could be used as guidelines for quantities of artificial structure. The amount of artificial structure needed for a project should be determined only after a survey to estimate the amount and type of existing natural structure in the project area. The survey techniques used for a habitat inventory would be dependent on the size of the lake or reservoir. Possible techniques include electronic profiling using hydro-acoustics equipment, visual inspection via scuba diving or snorkeling, or visual inspection during reservoir draw-down (B. Lynch, School of Natural Resources, Ohio State University, personal communication).

Larger structures may be an aggregate of many individual units (e.g., creating a circular pattern). They could also be installed as structure rows, starting in shallower water and extending out to deeper water or extending along a specific depth contour (Figure 1). An optimal depth range for structure rows may be from a depth of four to seven meters, depending on the slope and the amount of material available (Lynch and Johnson, 1988a). For optimal value though, care should be taken not to place the structure below the summertime thermocline.

Interstitial Space

The size and number of interstitial spaces provided by artificial structure is important in determining what types of structure to be installed. Space size will influence which species, age-groups, and size groups are attracted to the artificial structure. Space size and number will also significantly affect the predator-prey interaction in the fish community (Savino and Stein, 1982; Johnson et al., 1988). The specific habitat requirements for all life stages of the target species of fish is often not well known and usually not considered in planning an artificial structure project.

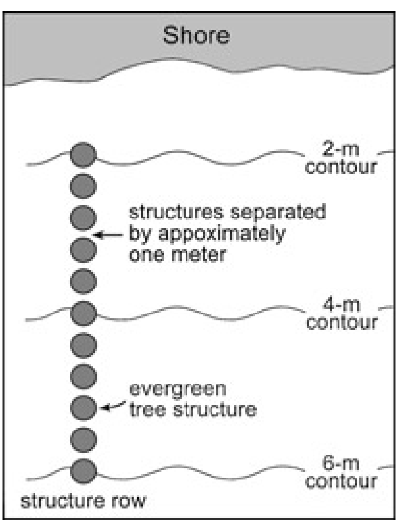

Figure 1. Diagram showing a shallow to deep water structure row. The total number of structures used is dependent upon the slope of the lake bottom (e.g., fewer structures would be needed on a steeper slope). Structure rows can also be placed parallel to shore along a specific depth contour.

If the project goal is to provide habitat for smaller fish, such as *Lepomis* spp., and juveniles of larger species, such as largemouth and smallmouth bass, then the structure must have a variety of interstitial space sizes (e.g., a range of 40–350 mm provided by evergreen trees or brush piles) (White, 1996), but the majority should be small. Even if aggregation is the impetus for adding artificial structure, larger (harvestable size) fish are usually attracted to smaller fish, and smaller fish need smaller spaces to avoid predation. However, larger "lay-in-wait" predators such as largemouth bass also need larger spaces in the artificial structure and/or can also use shade produced by higher profile artificial structure as effective cover (White, 1996).

Community structure and predator-prey interaction may also influence the efficacy of interstitial spaces. Small spaces are needed if the community is "predator-crowded," so the smaller number of forage fish will have shelter to increase their survival. If the community is "prey-crowded," then a lower density of small spaces (e.g., 150-mm diameter openings) to aggregate forage species may help give an advantage to predators, allowing the community to move toward a more balanced state and increasing the growth rate and size of the predators (Lynch and Johnson, 1989). In the absence of largemouth bass, White (1996) found that yearling bluegill preferred interstitial spaces from 40–150 mm, but in ponds with largemouth bass, yearling bluegill used the smaller spaces almost exclusively. The smaller spaces reduce vulnerability to predators (Walters et al., 1991) by disturbing the visual keys of the predators and decreasing their feeding efficiency (Crowder and Cooper, 1979). Other *Lepomis* spp. and bullhead also prefer dense material with smaller spaces, such as evergreen trees or brush piles, to maximize habitat function for these species. These structures have a variety of interstitial space sizes, ranging from 40–350 mm between branches, and also provide physical relief from the bottom, which in-turn provides shade, cover, and concealment for and against predators (Johnson et al., 1988; White, 1996). Both black and white crappie use the full range of interstitial space sizes, so material installed to attract bluegill, pumpkinseed, and bullhead should also work well for crappies (Walters et al., 1991). In clearer water, *Lepomis* spp., such as bluegill and juveniles of other species, seek out the smaller spaces (40-mm openings) for refuge.

Depth and Slope Considerations

Lynch and Johnson (1988a) determined that depth is an important factor for placement of artificial structure. After studying structures installed in two, four, and seven meters of water, and structure rows extending continuously from two to seven meters (Figure 1), they recommend placing artificial structure at depths of four to seven meters (for attracting bluegill, crappie, and largemouth bass). They found significantly more and larger fish at the four meter structure than at the two meter structures. Prince and Maughan (1979a, 1979b) also found that largemouth bass preferred structure at a depth of four to six meters. Structures that are placed in shallow water also need to be designed to withstand more wind and wave action and not present a navigation hazard, whereas deeper structures are not as sensitive to these issues (Bohnsack and Sutherland, 1985).

There are several advantages to using artificial structure placed in rows to encompass a variety of depths. Artificial structure rows extending to seven meters are often deeper than the typical late-summer metalimnion, which many fish prefer, particularly white crappie, pumpkinseed, yellow perch, and *Ictalurus* spp (Lynch and Johnson, 1988b). Lynch and Johnson (1988a) also found that as the metalimnion deepened, there was virtually no use of the structures by crappie at the four-meter depth. Extending a row of artificial structure from shallow to deeper water also will help keep the fish concentrated in the same area.

This may occur not only later in the summer, but also throughout each day, as many fish (including bluegill and white crappie) migrate horizontally, as well as vertically, on a diel basis (Baumann and Kitchell, 1974; O'Brien et al., 1984).

The slope of the bottom where an artificial structure is placed can also influence fish attraction. Lynch et al., (1988) found that angler success for both bluegill and white crappie was better on artificial structure placed on a steep gradient (e.g., a 3:1 slope) near shore, rather than on a shallow gradient (e.g., a 25:1 slope), as it tended to concentrate fish more in a smaller area (from end to end) and kept fish near the structure. Three other important advantages to placement of structure on a steep slope are (1) a lesser amount of structure can be used to cover more depth, (2) both boat and shore anglers have easy access as the entire structure will be closer to shore, and (3) fewer structures need to be placed in high-boat-traffic areas (Lynch et al., 1988). If shore angler accessability is a priority, this needs to be considered during the project's planning process.

Types of Structure and Their Use

Although artificial structure has been shown to increase fish aggregation and CPE over non-structure-enhanced areas, and increase spawning opportunity in some waters, differences exist between different types of structure and the effects they have on different fish communities. There are both benefits and liabilities associated with various types of artificial structures. For example:

- To aggregate adult largemouth bass and bluegill for improved angling success, structurally complex cover such as brush piles and evergreen trees are superior to stake beds or tires (Wege and Anderson, 1979; Johnson and Lynch, 1988; Lynch and Johnson, 1988b; Johnson and Lynch, 1992). Largemouth bass also prefer taller profile structures (Prince et al., 1986), such as evergreen trees, which provide shadows for cover.
- If increasing survival of juvenile sunfish and bullheads is the goal, the low profile and small interstitial spaces provided by brush piles is superior to stake beds, evergreen trees, and tires (Walters et al., 1991).
- Nest site selection by smallmouth bass and walleye is determined more by bottom substrate material (such as gravel and rock), than by proximity to habitat cover (such as brush) as it is for largemouth bass and bluegill (Vogele and Rainwater, 1975; Bassett, 1994).

In Fish Lake, Michigan, a rock reef attracted more fish species and larger numbers of invertebrates than the nearby sand substrate (Bassett, 1994). Bassett (1994) also reported that evergreen trees felled into lakes in Michigan and Minnesota provided structure that attracted and concentrated a variety of centrarchids, including juvenile black bass (*Micropterus* spp), bluegills, rock bass, and black crappies (*Pomoxis nigromaculatus*), in depths <1.5 m. The adults of these species were attracted and concentrated in deeper water at the outer ends of the trees. Submerged pulpwood logs in a lake in Maine concentrated a variety of nongame and game fish throughout the year (Moring et al., 1989). Johnson and Lynch (1992) found through diving surveys that both bluegills and white crappie (*Pomoxis annularis*) were much more attracted to the brush piles and evergreen trees installed in Alum Creek Reservoir, Ohio, than to the nearby natural structure or open water.

In an experiment comparing simple artificial structure (stake beds) with more complex artificial structure (brush piles), Wege and Anderson (1979) found that both bluegill and largemouth bass were far more abundant in and around the more complex structure. Marzolf

(1957) found that channel catfish (*Ictalurus punctatus*) readily used dense natural cover that excluded light. Brown et al. (1970) later showed that channel catfish would enter certain types of artificial structure, particularly if the structure was large enough for an entire school of fish (he used a large cylinder with one closed end and the other end pinched down).

Evergreen Trees

Evergreen trees provide good substrate structural diversity for a variety of species. Species that are attracted to evergreen trees include large and smallmouth bass, bluegill, pumpkinseed, black and white crappie, yellow perch, and even channel catfish, which have been observed nesting under the trees (Day, 1983; Johnson and Lynch, 1988; Walters et al., 1991; B. Lynch, School of Natural Resources, Ohio State University, personal communication).

Evergreen trees have many advantages over other structure types. Several studies have shown that evergreen trees attract fish sooner after installment and provide higher CPE than other structures that are normally used, because they provide a dense cover that is attractive to panfishes such as bluegill (Johnson and Lynch, 1988, 1992). In addition to providing cover for small fish within the branches, their density and tall profile creates shade and darkness for concealment. This is an advantage for larger piscivorus fish that would not normally use the cover of the interstitial spaces (White, 1996). Evergreen trees have also been shown to be effective spawning substrate for yellow perch (Day, 1983). Other advantages include ready availability and minimal cost.

There are two particular formations that have been productive for aggregating a variety of species. In one, the trees are placed in groups of seven to ten, then a space of about one meter, then another group along the same depth contour. Using this formation, Lynch and Johnson (1988b) arranged trees in a circular pattern, close enough to each other so the branches of adjacent trees overlapped about 0.1 m. When using this group formation, it is good to place several groups in close proximity to each other to prevent overfishing of the area (B. Lynch, School of Natural Resources Ohio State University, personal communication). The other formation option is to create artificial structure rows. The rows should be two to three trees wide, with a two-tree space every seven to nine trees. The space between tree structures in both structure formation types allows space for predators such as white crappie and adult largemouth bass to hunt or lay-in-wait.

Probably the most significant disadvantage to the use of evergreen trees is that they normally need to be replaced every three years because the branches and needles fall off, rendering the trees far less effective as fish habitat. Fishing tackle is also easily snagged in tree structures. Some researchers believe that placing evergreen trees standing upright is superior to laying down, though we found no data to support this. Because of this though, evergreen trees are not recommended where reservoir draw-down would expose them. This would likely cause them to be knocked or blown over to a horizontal position. They would also be exposed to wind, waves, and ice, more rapidly reducing their effectiveness. Also, branches on horizontal trees flatten out and do not provide cover as effectively as vertical tree branches (D. A. Walters, Ohio Division of Wildlife, personal communication).

Brush Piles/Woody Debris

Brush piles, felled trees, log cribs, and other types of woody debris also provide excellent cover and diversity as artificial structures, and appeal to a wide variety of fish species and life stages. Species that use interstitial spaces in brush piles include bluegill, black crappie, pumpkinseed, and juvenile largemouth bass (Wilbur, 1978; Bassett, 1994; Moring and Nicholson, 1994). Species that use the outer perimeter of brush piles include yellow perch, white crappie, adult largemouth bass, smallmouth bass, and catfish (Wilbur, 1978; Johnson and Lynch, 1988; Lynch and Johnson, 1988a, 1988b).

There are many advantages to using brush piles and woody debris for artificial structures. These structures contain a wide range of interstitial space sizes that can be used by a variety of different species and different life stages, from juvenile to adult. Fish are readily attracted to brush piles, sometimes only days or hours after installation (Richards, 1997). Brush and woody debris are also often available on surrounding land, reducing cost, labor, and logistical problems associated with obtaining and transporting other types of structure to the project site. Collecting and installing brush and woody debris lends itself well to including volunteer groups, such as fishing clubs and other local interests. Brush piles and woody debris also tend to last longer than other types of natural structure such as evergreen trees. Piles made from hardwood branches and saplings can last over 10 years (B. Lynch, School of Natural Resources, Ohio State University, personal communication).

Woody debris consists of two main types of material, whole trees and brush or shrubbery. In certain places, whole trees can be felled directly into the water from shore. This closely approximates the way this type of structure enters the aquatic environment naturally. Felled trees provide surface area for attachment of periphyton and invertebrates which provide food for fish. They also provide nutrients from the rotting wood. Branches provide good structural complexity and felling several trees together increases the complexity further. If several feet of the trunk are left on the shore, it helps stabilize the tree in the water so it will not be shifted by wind and wave action (Bassett, 1994).

Offshore woody debris can be brush piles, log cribs filled with evergreen trees, or brush and logs together. The amount of material in the cribs can vary depending on the desired range of interstitial spaces. The cribs used by the USFS were rectangular, 2–4 m per side in length and 1–2 m tall, and were constructed of green hardwood logs 8–15 cm diameter, stacked "log cabin" style (Bassett, 1994). Logs can be bound together with galvanized wire, polypropylene rope, nails, or rods pushed through holes drilled through all the logs. In another style of crib, log ends stick out 1–2 m past the corners of the crib providing extra surface area and structure for larger fish. Cribs can be weighted down with sand bags or cement blocks (Bassett, 1994).

Brush piles can consist of brush, shrubs, branches, or small tree tops bound together with polypropylene rope and weighted with concrete building blocks (Bassett, 1994) (Figure 2). The individual weighted units should be a size which can be easily installed. The size of the overall structure can be determined by how many individual units are used and how they are placed in relation to each other. Structure formations of brush and woody debris can be similar to those with evergreen trees. A circular shape is probably the easiest to assemble, although as with evergreen trees, a structure row can be placed along a specific depth contour, or it could stretch from shallow to deep water.

Brush piles, log cribs, and trees have few disadvantages compared to other types of structure. Likely the biggest drawback to brush piles (depending on the type of brush) is the difficulty in creating small interstitial spaces. The majority of the spacing will be medium to large (greater than 80–90 mm), while many smaller fish prefer spaces less than 50 mm. Angling CPE is not as high for brush piles as for evergreen trees, although CPE associated with brush piles is better than many other types of structure. One reason CPE has been lower on brush piles is that anglers tend to snag fishing gear easier on brush piles than evergreen trees, causing loss of gear and associated lower CPE (Wilbur, 1978; Mosher, 1985; Johnson and Lynch, 1992).

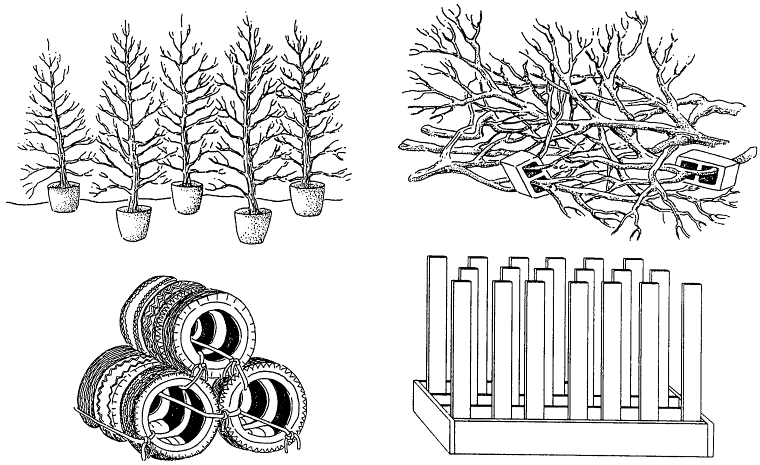

Figure 2. Artificial structures that most closely resemble productive natural structure include evergreen trees and brush piles. They offer more complex structure with smaller interstitial spaces and a higher CPE than other types of structure.

Tires

Automobile tires have been used to attract both marine and freshwater fish for many years. However, this popularity was based mostly on the availability of the material rather than any valid design criteria of biological responses (Bohnsack, 1987; Buckley, 1989). They provide some degree of diversity and physical relief in a structureless environment, but lack structural diversity for fish that prefer smaller spaces. Species that swim into and around tires are usually fish that would be attracted more to the feeding opportunities on smaller fish or the periphyton, than the cover. These include large and smallmouth bass, yellow perch, bluegill, pumpkinseed, and crappie (Moring and Nicholson, 1994).

The perceived advantages of using tires to aggregate fish are their ready availability, low cost, and durability. They provide a large amount of surface area for the growth of periphyton and phytoplankton and the attachment of invertebrates (Prince and Maughan, 1978).

Assembly of underwater tire structures is easy, and there are numerous configurations in which tires can be bound together before installment. These include upright in a cellular arrangement (side-by-side), one tire forced inside of another, four tires arranged in a tetrahedral, rows of tires forming a triangular prism, strung together in a random pile, and high profile stacking (Edmund, 1967; Prince et al., 1977) (Figure 3). To bind the tires together, material that will not easily rot or corrode such as polypropylene rope and stainless steel cable are best. Tires can be anchored by placing rock or concrete inside and lashing building blocks to them (Edmond, 1967; Prince and Maughan, 1978; Mueller and Liston, 1994).

There are several disadvantages of using tires for artificial structure. Some evidence suggests that water soluble leachates from tires are lethal to a variety of aquatic organisms, particularly rainbow trout (Day et al., 1993). Tires do not provide the complex structure and small interstitial spaces required by many fish, particularly juveniles, to escape predation. Also, unless they are securely weighted, wind and wave action can move them into shallow areas where they become a navigation hazard or common waste on the shoreline (D. A. Walters, Ohio Division of Wildlife, personal communication). Another possible drawback

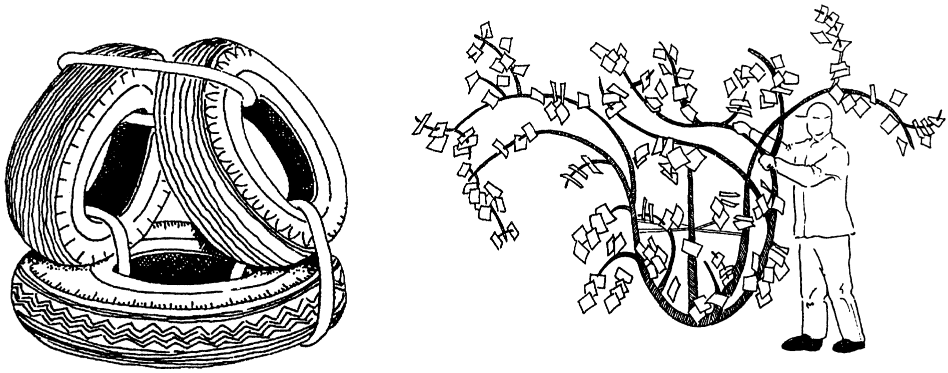

Figure 3. Tire formations and stake beds offer readily available material, but have little complex structure and result in low CPE. Manufactured artificial structures also lack smaller interstitial spaces and have a low return to the creel. They can also be cost prohibitive.

is the unapproved use of tires by private citizens trying to enhance their favorite fishing hole. This can be more of a problem with tires than other types of structure, likely because of their easy availability (D. A. Walters, Ohio Division of Wildlife, personal communication). Also, tire structures can be unsightly, particularly in reservoirs where water level draw-down would leave them exposed on the beaches or banks (Bassett, 1994).

Commercially Manufactured Artificial Structures

There are a variety of artificial structure components that are manufactured by private companies for use in both marine and freshwater environments. They vary considerably in size, design, cost, and material. Common designs include a round weighted base with ribbon-like, four to eight foot strands floating upward, emulating aquatic plant material, concrete material shapes similar to children's building blocks with holes for the fish to swim through, and plastic conical-shaped structures with holes. One manufacturer produces modular plastic tubing so its shape can be varied from spherical to wave-like, with smaller protrusions holding small square "leaves" to provide surface area for periphyton growth (Figure 3). It appears that this type of structure would provide more complex structure than most other manufactured structures.

An advantages to the use of fabricated structures is their longevity. These structures can be used in conjunction with fishing piers without need of replacement for many more years compared with natural material, such as evergreen trees and brush piles.

The most prominent drawback in the design of most manufactured structures is that they lack complex structure and small interstitial spaces. Another drawback of commercially manufactured structures compared to other types of material is their high cost. Also, most manufactured individual structures are relatively small, so it often takes many individual structures to provide enough habitat to be useful. Mosher (1985) found that a 3 m × 3 m plot of cedar brush cost $0.50 while a Fish Hab^{TM} structure of that size would cost $92.33. Installment of manufactured structures can be logistically difficult, particularly concrete structures. In addition, manufactured structure often does not attract fish as well as natural material. Richards (1997) compared a fabricated sphere structure (The Sphere^{TM}) with evergreen tree structures and found that both types attracted both black crappie and largemouth bass, but the tree structures also attracted many YOY black crappie and bluegill. Angling CPE was also much higher on the evergreen tree structures than the fish spheres (18.9 fish/hr compared to 9.8 fish/hr). Rold et al. (1996), in comparing brush piles with fabricated polypropylene modules, found that brush piles attracted 3–6 times more fish than the modules, and 7–24 times more than control areas without structures.

Other Types of Structure

As listed in the introduction, there are many other types of materials that have been used as artificial structure, such as wooden pallets, stake beds (Figure 3), cinder blocks, waste concrete, car bodies, cement blocks, hay bales, and derelict boats (Wilbur, 1974; Moring and Nicholson, 1994; Bassett, 1994; Richards 1997). These items have been shown to attract fish to some degree and provide relief in an otherwise structureless environment; however, specific information on their use has not been included because they are usually not feasible due to their environmental impact, high cost, or lack of effectiveness. For example, the high cost of stake beds and their low creel return (Johnson and Lynch, 1992) make them an undesirable choice.

Conclusions

Artificial structure has been used in the U.S. to the benefit and detriment of a variety of freshwater fish communities since the 1930s. Advocates of artificial structure have suggested that it may provide a wide range of benefits from increased primary production and spawning habitat to increased survival of juvenile fish. These benefits have proved difficult to demonstrate with any certainty. Clearly the most attainable goal and primary benefit has been to concentrate the existing fish community to increase angler harvest. Best results are achieved by attracting bottom and structure-oriented species such as largemouth bass, bluegill, pumpkinseed, sunfish, black crappie, and catfish. Walleye, yellow perch, smallmouth bass, and white crappie, which move between open water and structure, can be attracted to artificial structure enough to significantly increase angling CPE of these species. Open water species such as trout are rarely if ever attracted to structure.

Because increased aggregation and CPE is the most common use of artificial structure, overfishing is the most commonly cited drawback. Therefore, increasing CPE is only recommended in fish communities that can withstand increased harvest with little adverse effect. Artificial structure is not useful in managing populations of trout or altering out-of-balance and/or stunted fish communities or communities with "problem species" such as carp, goldfish, tench, etc.

If the results of habitat and fish community surveys indicate (see Appendix for guidance in determining the need for structure; a proper goal; under what conditions it would be helpful; what species it could benefit; and the best type of structure to use) that artificial structure could be beneficial to a particular fish community, a management plan with clearly defined goals needs to be established. Pre- and post-installation surveys need to be included. The proper data needs to be collected and analyzed. The best location, quantity, and type of structure needs to be determined. After this, acquisition of the appropriate permits, acquisition of the structure material, and planning and executing the installment of the material are all necessary steps in the process.

Due to all the planning required to insure that the addition of artificial structure would indeed be beneficial, and because of the expense, material, and labor required for a proper artificial structure project, adding artificial structure to a fish community is not a management strategy that should be taken casually. It is also important to understand that it is not a management strategy that will automatically increase juvenile survival, increase spawning, increase production, increase CPE, and create a balanced fish community in a mixed species environment. It can assist in some of these areas if the conditions are right, but it is not a "quick fix" to eradicate all the day to day challenges that freshwater biologists face while managing a natural resource that is dynamic and continually changing.

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Appendix

Key to Assist in Determining the Need and Type of Artificial Structure

The purpose of this key is to help determine if a particular water may benefit from the addition of artificial structure by outlining what conditions should be present to increase the possibility of success. Simply start at the top of the key and follow the prompt that is appropriate for the water in question.

1a. Species in need of enhancement include various trout species 2

1b. Species in need of enhancement include various species of cool and warm-water gamefish, such as largemouth bass, bluegill, black crappie, yellow perch, walleye, and channel catfish 3

2. Trout are not normally associated with or use artificial structure, so it will have no direct effect on their management and should not be considered as a trout management tool (Moring et al., 1989; Viavant, 1995).

3a. The management goal is to increase harvest 9

3b. The management goal is to increase production 4

4a. The management goal is to increase primary productivity 5

4b. The management goal is to increase “other” types of production. 6

5. No studies have shown definitive quantitative increases in primary production throughout a water body attributable directly to the presence of artificial structure in fresh water (although Prince et al. (1986) showed that primary productivity of the reef’s periphyton communities, as measured by analysis of oxygen production and consumption, total phosphate, total Kjeldahl nitrogen, and total solids, was higher than phytoplankton production in adjacent littoral areas).

6a. The management goal is to increase spawning habitat in waters where it is limited 7

6b. The management goal is to increase survival of juvenile fish by increasing cover 8

7a. The target species is smallmouth bass . . . spawning boxes, half-logs, gravel beds, cobble and/or rip-rap can be used as per description on pages 24 and 25 (Hoff, 1991; Bassett, 1994).

7b. The target species is walleye . . . rock reefs, gravel beds, cobble and/or riprap can be installed as per description on pages 5, 24, and 25 (Weber and Imler, 1974; Bassett, 1994).

7c. The target species is channel catfish . . . cavity-type structures can be installed as per description on pages 6 and 25 (Marzolf, 1957; Dillard, 1966; Sakai, 1972; Prince and Maughan, 1978; Huner and Dupree, 1984).

7d. The target species is yellow perch . . . evergreen trees and other similar structure give perch places to lay their strings of egg masses as per description on pages 5, 6, and 24 (Day, 1983).

7e. The target species is largemouth bass. . . . Even though largemouth bass have benefitted from the addition of artificial structure for spawning (Vogele and Rainwater, 1975; Bassett, 1994), in most waters, the preferred substrate of sand, gravel, rubble, roots and aquatic vegetation (Carlander, 1977; Wydoski and Whitney, 1979) is present and adding structure or material to improve spawning habitat is not necessary. There is also no defined relationship between numbers of spawners and recruitment for largemouth bass.

8 In order to increase the survival rate of juvenile fish in water without sufficient natural cover, the percentage of bottom covered by structure and/or aquatic plants should optimally be 20–50% (Crowder and Cooper, 1979; Wiley et al., 1984; Bettoli et al., 1992). This may be possible in smaller lakes but impractical in larger lakes (Walters et al., 1991).

9a. Fish community is already overharvested. Artificial structure will exacerbate the problem by concentrating the remaining fish. A better management strategy would be protective regulations or supplemental stocking.

9b. Fish community is dispersed, underexploited, and can withstand increased harvest without detriment. Artificial structure can effectively increase aggregation of fish, thereby increasing angler opportunity and catch rate. Proper placement of artificial structure can greatly increase the probability of achieving the management goal10

10a. Artificial structure can be placed in a location that gives access to shore anglers, e.g., in shallower water (2–4 m or water) if the gradient is shallow (e.g., 25:1), and/or deeper water (4–7 m) if the gradient is steeper (e.g., 3:1). A structure row extending from shallow to deep not only provides opportunity for shore anglers but also keeps fish around the structure more of the day as they migrate from deep to shallow diurnally (Lynch et al., 1988).

10b. Artificial structure can be placed off shore and marked, so anglers in boats may access it. Also, if money is available, building docks to access deeper water structure (4–7 m) can be a very effective management strategy to increase harvest by increasing access.