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# Artificial Reefs in Lake Erie: Biological Impacts of Habitat Alteration

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*Abstract*.—From 1984 to 1989, artificial reefs were constructed at two locations in central Lake Erie by Ohio State University's Sea Grant College Program. The goals of the construction projects were to improve sportfishing opportunity in nearshore waters, evaluate the effectiveness of reefs as fish-concentration devices, and eventually assist other coastal communities in developing artificial reef programs. From 1992 to 1995, we conducted evaluations to assess the effectiveness of these artificial reefs as sport fish attractors and to establish their value in sport fishery enhancement projects. Underwater VHS video was used by scuba divers to identify and enumerate fish at both artificial reef sites and at adjacent nonreef control sites. Observation dives were done monthly, weather permitting, from May through October each year. *T*-tests were used to determine seasonal differences in fish abundance between the reef and control sites. At both sites, total seasonal numbers of fish were significantly higher (20–50 times more) at the reef site than the control site ($p = 0.05$). Smallmouth bass *Micropterus dolomieu* were the dominant species at both reef sites, comprising over 80% of the observations during most months. Total seasonal numbers of smallmouth bass were also higher during spring and fall than in midsummer, suggesting seasonal patterns and preferences for artificial structure. We conclude that, when properly planned and located, artificial reefs would provide beneficial fish habitat along most of Lake Erie's nearshore zone and may have application Great Lakes-wide.

Lake Erie is well known for its sportfishing. The shallow western basin (average depth 8 m) with its numerous islands, shoals, and natural reefs, provides excellent angling opportunities, and the Port Clinton–Sandusky area has been rated among the top 10 sportfishing locations in the world. The central basin (average depth approximately 30 m) is also a productive sport fishery, yet it lacks the islands and natural reefs around which many fish congregate. Most of the angling effort in the central basin is concentrated far offshore. The bottom of the central basin is relatively flat and featureless.

In 1982, the newly formed North Central Ohio Sea Grant Advisory Committee reviewed a variety of strategies to enhance tourism and local economies by improving angling opportunities in the central basin of Lake Erie. Artificial reefs were discussed as a strategy that could permanently increase habitat diversity and provide permanent habitats that would concentrate fish and improve angler success rates (Prince et al. 1977; Myatt 1981). Ohio Sea Grant began the Lake Erie Artificial Reef Program in mid-1982 with assistance from the Ohio Department of Natural Resources and the U.S. Army Corps of Engineers.

An extensive body of literature evaluating artificial reef materials, design, and construction has been produced in recent years and is reviewed by Seaman and Sprague (1991). Although the beginning of this project predated many of these papers, construction methods and materials used in this project generally are in agreement with currently accepted guidelines for reef construction and monitoring (Gannon 1990; Bohnsack et al. 1991).

Initial tests for the program began in a small way with a project we refer to as our experimental project. Approximately 3,000 metric tons of broken sandstone material was placed offshore of Lakewood, Ohio in 12.2 m of water. This rubble was placed with a large, 6-compartment dump scow, creating 12 small, 1-to-2-m-high piles of material that were not connected to each other at their bases. These reefs were extremely difficult for anglers to locate. A two-year investigation on these reefs during 1985–1986 (Gerber 1987) and further literature review (Matthews 1981; D'Itri 1985) suggested the structures needed to be larger in profile, connected at the bases, on firmer bottom substrate, and in shallower water.

This paper discusses and evaluates artificial reef development efforts initiated in 1986 using the results from the above experimental study. We refer to these post-1986 projects as demonstration projects because studies like these are needed to determine whether artificial reefs are indeed a useful tool for habitat and sportfishing enhancement in Lake Erie.

| Location (Potential artificial reef sites)<br>Identify each site using land-based information and location data<br><br>Global positioning system coordinates:<br>-each potential site: latitude and longitude<br><br>↓ Description of site criteria considerations ↓ | Site #1 | Site #2 | Site #3 |
|---|---|---|---|

Criteria: Determined for each potential site

1. Distance from safe harbor (nautical miles )
2. Availability of boater access sites
3. Commercial navigation conflicts
4. Recreational use conflicts
5. Water depths (feet and meters)
6. Months in which reef may be below thermocline
7. Necessary permits from regulatory agencies:
    - U. S. Army Corps of Engineers
    - U.S. Coast Guard
    - Shipping associations
    - Ohio Division of Wildlife
    - U.S. Environmental Protection Agency
8. Waves and currents
9. Ice scour effects
10. Shoreline property ownership onshore from reef site: potential conflicts
11. Reef goals and objectives:
    - recreational benefits
    - habitat benefits
    - biological benefits
    - economic development
12. Target users: anglers, scuba divers, researchers
13. Target species: walleye, yellow perch, smallmouth bass, others
14. Angler and diver use by season: potential conflicts
15. Bottom substrate type and contours
    -current geological maps available
    - fathometer paper graph recordings
    - substrate measurement:
        - Matthew's hand method (diver)
        - Penetrometer method (diver)
        - other unique bottom features
16. Water quality concerns
17. Present use of potential site
18. Possible historic or ecological impacts
19. Potential impacts from exotic species
20. Aquatic macrophyte attachment and growth
21. Reef shape and size
22. Distance from water intakes and discharges
23. Sediment plumes
24. Possible erosion deposition effects
25. Marine contractor secured?
26. Who pays for marine contractor?
27. Concrete or rock rubble secured?
28. Waterfront storage location for rubble?
29. Other sponsor or funding organizations
30. Other considerations and concerns

FIGURE 1.—Simple decision matrix for artificial reef development in Lake Erie (criteria not listed in order of priority).

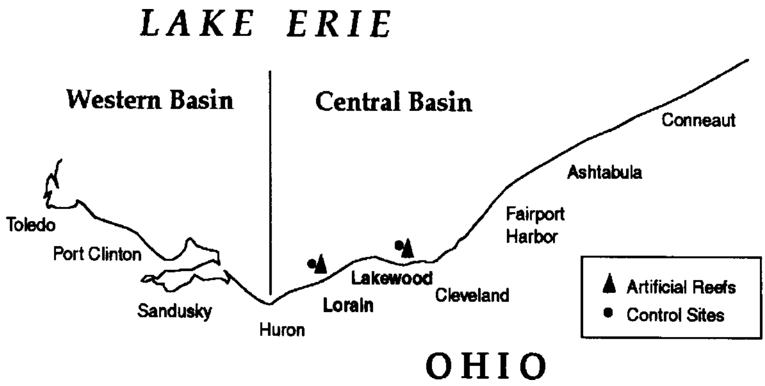


FIGURE 2.—Approximate locations of Lorain and Lakewood artificial reefs and control sites with respect to Lake Erie and the Ohio shoreline.

## Site Selection Criteria, Program Development, and Construction Methods

Reefs can serve many purposes; however, some controversy exists regarding the question of whether artificial reefs increase regional fish production or simply serve to aggregate existing fishes (Grossman et al. 1997; Lindberg 1997). The goals for these demonstration projects were to concentrate fish, enhance angler success, and stimulate the local economies. Although it is quite likely that some successful spawning is occurring on these reefs, due to the reefs' small sizes it is doubtful that this spawning will have a significant positive impact on populations in the central basin.

In siting reefs, it is important to consider a number of variables that may impact the physical structure, user groups, and the biological integrity of the reefs (Figure 1). The artificial reef sites chosen for these projects were located within 1.2 km of shore at Lorain and Lakewood, Ohio (Figure 2), and were selected using the decision matrix presented in Figure 1.

From 1983 through 1989, funding was solicited from private and public sources to support the project; over US$180,000 were contributed. Major contributors included the Cuyahoga County Commissioners, the Polish Fishermen's Club of Lorain, and the Ohio Division of Wildlife. Funding was also secured from sportfishing tournaments, donations from local angler organizations and conservation clubs, collections at marinas and tackle shops, corporate donations, and private donations. Permits in the name of the Ohio Department of Natural Resources, Division of Wildlife, were obtained from

FIGURE 3.—Materials used for construction of artificial reefs at Lorain and Lakewood; reefs consisted of clean concrete, rock, and brick rubble. (Photo courtesy of D. O. Kelch, Ohio Sea Grant.)

FIGURE 4.—Flattop barge and front-end loader used at the Lorain and Lakewood artificial reef sites to better control placement of reef materials. (Photo courtesy of D. O. Kelch, Ohio Sea Grant.)

the U.S. Army Corps of Engineers for both reef locations. Sites to store donated reef material on land before construction were donated by the Ford Motor Company and Ontario Stone Company for the Lakewood reef and by the Lorain Pellet Terminal (LTV Steel Company) for the Lorain reef.

Materials used to construct Lake Erie's artificial reefs consisted of clean rock, concrete, and brick rubble (Figure 3). These materials were chosen to resemble naturally occurring reef material and topography, a concept later validated by Bohnsack et al. (1997). Materials were donated by a number of public entities, private businesses, and private citizens. In total, over 10,900 metric tons of rubble were donated, ranging in size from bricks to large concrete slabs measuring 2.0 m by 3.0 m by 0.4 m. All materials were inspected by the U.S. Army Corps of Engineers before placement in Lake Erie to ensure that quality standards were met.

Knowledge gained from the experimental reef project and research during 1984–1986 was used to modify the methods of artificial reef placement during 1986–1989. The first phase of the demonstration project began in 1986 with the placement of over 1,814 metric tons of reef material at Lorain. The reef site is located 1.6 km west of Lorain Harbor and 1.2 km offshore, in 8.5 m of water.

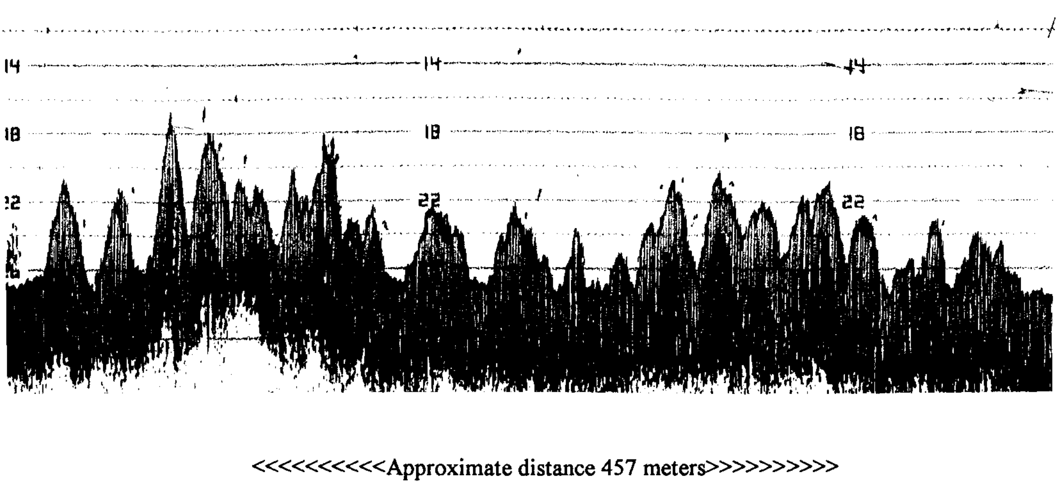


FIGURE 5.—Original paper graph fathometer profile of the Lorain artificial reef, June 1990. (Lowrance Electronics model X-15 paper graph recorder; measurements in feet.)

TABLE 1.—List of common and scientific names of fishes (according to Robins et al. 1991) appearing in this study.

| Family | Common name | Scientific name |
|---|---|---|
| Catostomidae | White sucker | *Catostomus commersoni* |
| | Shorthead redhorse | *Moxostoma macrolepidotum* |
| Centrarchidae | Rock bass | *Ambloplites rupestris* |
| | Smallmouth bass | *Micropterus dolomieu* |
| Clupeidae | Alewife | *Alosa pseudoharengus* |
| Cyprinidae | Goldfish | *Carassius auratus* |
| | Carp | *Cyprinus carpio* |
| Gobiidae | Round goby | *Neogobius melanostomus* |
| Ictaluridae | Channel catfish | *Ictalurus punctatus* |
| Percichthyidae | White perch | *Morone americana* |
| | White bass | *Morone chrysops* |
| Percidae | Yellow perch | *Perca flavescens* |
| | Logperch | *Percina caprodes* |
| | Walleye | *Stizostedion vitreum* |
| Sciaenidae | Freshwater drum | *Aplodinotus grunniens* |

Materials were placed using a flattop barge rather than the dump scow that had been used for the first project. Concrete rubble was loaded onto the barge and towed to the reef location. The barge was secured into position using vertical spud bars, and the material was pushed off with a front-end loader (Figure 4). Marker buoys were placed on each side of the barge to ensure accurate placement of the rubble. The heights of the piles of reef material were determined using a bottom sonar graph recorder. This construction strategy proved far superior to the dump scow used previously and allowed us to create a reef with piles that were not only contiguous but also of desired height.

During 1987, the demonstration project at the Lakewood site began. The same basic methods used at Lorain in 1986 were employed, although the barge was larger and a crane was used in addition to a front-end loader. The crane was used to place material in the gaps between piles made by the front-end loader, thus making it easier to create a contiguous set of piles or mounds. Over 3,446 metric tons of concrete and rock rubble were placed at the Lakewood location, creating an artificial reef over 243 m in length. The reef site is located 3.7 km west of Cleveland Harbor and 3.7 km east of Rocky River, 0.8 km offshore in 8.5 m of water. This nearshore reef location is approximately 0.8 km south of the 1984 experimental reef site.

During 1988 and 1989, over 5,635 additional metric tons of material were added to the Lorain location, creating a second artificial reef at this site. The first reef, known as the Polish Fishermen's Club Reef, is approximately 457 m in length. The second reef, called The Mountain, is approximately 243 m in length and is located parallel to and 91 m north of the first reef. The additional construction at Lorain was possible due to reduced marine contracting costs. This completed the construction phase of the demonstration project.

Both the Lorain and Lakewood artificial reefs are parallel to shore in 8.5 m of water (Figure 2). From above, the reefs appear to be in a snaking, sawtooth arrangement. The reef material is in contiguous mounds connected at the bases, allowing fish to move along the entire length of the reefs. The mounds vary in height from approximately 2–4 m (Figure 5).

## Anecdotal Information from Anglers

Within two weeks after the first materials were placed in 1986, the authors began to receive reports from anglers of catches of yellow perch *Perca flavescens* and smallmouth bass *Micropterus dolomieu* from the artificial reef at

TABLE 2.—Total numbers of taxa and fish observed in 1992 at the Lorain artificial reef and Lorain control sites using mobile and stationary cameras. (Totals are less and greater than 100% due to rounding.)

| Species | Artificial reef number | Control site number | Artificial reef % of total | Control site % of total |
|---|---|---|---|---|
| Smallmouth bass | 1,057 | 16 | 93.62 | 29.10 |
| Yellow perch | 17 | | 1.51 | |
| Logperch | 17 | | 1.51 | |
| Walleye | 6 | 2 | 0.53 | 3.64 |
| Freshwater drum | 5 | 28 | 0.44 | 50.91 |
| Rock bass | 4 | | 0.35 | |
| Unidentified | 23 | 9 | 2.03 | 16.36 |
| Total | 1,129 | 55 | 99.99 | 100.01 |

Lorain. Similar reports were received shortly after the Lakewood reef was constructed in 1987. Reports of catches of numerous smallmouth bass, yellow perch, walleye *Stizostedion vitreum*, rock bass *Ambloplites rupestris*, freshwater drum *Aplodinotus grunniens*, white bass *Morone chrysops*, white perch *Morone americana*, and channel catfish *Ictalurus punctatus* have continued to come in from both sites. In addition, since 1996, anglers have frequently caught and submitted specimens of the round goby *Neogobius melanostomus*, documenting the westward expansion of this nonindigenous species from the waters offshore of Fairport Harbor, Ohio, where it originally was reported (Charlebois et al. 1997). Fish species pursued and caught by local anglers vary by season. (Table 1 lists common and scientific names of all fishes cited in this study.)

The artificial reefs have attracted more than just fish and anglers. When the artificial reefs were planned in 1982, zebra mussels had not yet invaded Lake Erie. Discovered in Lake Erie's western basin in 1988 (Snyder et al. 1990), the mussels rapidly spread throughout the lake. By 1991, zebra mussels had covered an estimated 75–80% of the artificial reef substrate at both reef locations. With greater water clarity induced by zebra mussel filtration, scuba divers found the artificial reefs to be good places to visit. For divers, the reefs provide an abundance of fish life to observe and photograph, a great location to search for lost anchors and fishing lures, and a marked, shallow-water area close to ports. Furthermore, few angler–diver use conflicts have been reported.

## Biological Assessment Methods

Fish population assessments were done during 1992 and 1993 at the Lorain artificial reef and during 1994 and 1995 at the Lakewood artificial reef. Water clarity due to reductions in phosphorous loading and filtration by zebra mussels made possible the use of underwater VHS video to identify and enumerate fish on the artificial reefs and adjacent, nonreef control sites.

Professional scuba divers from Underwater, Inc., based in Elyria, Ohio, were contracted to perform the monthly underwater VHS video assessment. The divers were expert underwater photographers and were instructed in research procedures by the first author, who also accompanied them on many dives. The camera used for the project was a Sony CCD-V99 high resolution, 8-mm video camcorder, housed in an Aqua-Video underwater housing that provided full external control features.

Data collection occurred on the 15th day of each month, ± a 5-d window of opportunity, from May through October. Weather and water clarity conditions dictated when the dive was made within the 10-d period. Adverse conditions prevented some data collection. All dives were conducted between the hours of 10:00 a.m. and 2:00 p.m. Data were collected during 1992–1993 at the 457-m Lorain artificial reef and during 1994–1995 at the 243-m Lakewood artificial reef. Control sites, located 1,800 m from each artificial reef, also were assessed to provide nonreef comparisons. Each control site was located in the same depth of water and had the same bottom composition as the artificial reef site but possessed no features higher in profile than 0.3 m. For each dive, the research vessel was secured to a permanent marker buoy, which was located in the center of the artificial reef system.

During the 1992–1993 study of the Lorain artificial reef, two underwater video assessment strategies were employed: (1) a stationary video camera assessment with the camera mounted on a tripod in the same location each month, and (2) a mobile assessment with the diver swimming with the camera along a predetermined and repeatable route. The stationary camera technique was used to identify and enumerate any fish species that might avoid divers. After the camera was placed on the tripod, the divers returned to the vessel, and the camera recorded for one hour before being retrieved.

Immediately following the stationary assessment, the divers swam with the underwater camera along a 91-m transect on the south (or nearshore) side of the artificial reef. The divers then crossed over the top of the reef and swam back to the starting point on the open-lake (or north) side of the artificial reef. The entire dive took approximately 30 min, and throughout the dive the divers maintained their relative position along the sides of the reef approximately 2–3 m from the top. The diver operating the camcorder panned the camera slowly from left to right, and also up and down, at a 30$^{o}$ angle. This permitted us to record fish slightly above and to the sides of the camera. Immediately following the reef dive, the divers moved to the control site, where the same assessment procedures were performed.

A review of the data from the 1992 and 1993 assessments at the Lorain site showed that the stationary camera observations were of little value—no fish spe-

TABLE 3. —Total numbers of taxa and fish observed in 1993 at the Lorain artificial reef and Lorain control sites using mobile and stationary cameras. (Totals are greater and less than 100% due to rounding.)

| Species | Artificial reef number | Control site number | Artificial reef % of total | Control site % of total |
|---|---|---|---|---|
| Smallmouth bass | 1,366 | 112 | 94.60 | 58.64 |
| Logperch | 16 | | 1.11 | |
| Rock bass | 9 | | 0.62 | |
| Shorthead redhorse | 9 | | 0.62 | |
| Alewife | 6 | | 0.42 | |
| Yellow perch | 5 | | 0.35 | |
| Freshwater drum | 5 | 60 | 0.35 | 31.41 |
| Carp | | 4 | | 2.09 |
| White sucker | 3 | | 0.21 | |
| Walleye | 2 | 3 | 0.14 | 1.57 |
| White perch | 1 | | 0.07 | |
| Unknown | 22 | 12 | 1.52 | 6.28 |
| Total | 1,444 | 191 | 100.01 | 99.99 |

cies were observed that had not also been observed by the mobile camera. Consequently, the stationary camera technique was not used during our 1994 and 1995 assessments at the Lakewood artificial reef site.

## Results

### *Lorain Artificial Reef, 1992 and 1993*

One of our initial concerns with our observation technique was whether the underwater VHS camcorder could provide images of fish clear and sharp enough to allow identification to the species level and thus result in quantitative data suitable for statistical analysis. A review of the 1992 and 1993 data (Tables 2 and 3) showed that this was not a problem as we were able to identify 97–98% of all fish observed each year to the species level (D. O. Kelch and F. L. Snyder, unpublished data). Differences in mean numbers of fish observed on the reefs versus the control sites were subjected to the Student's *t*-test (Mendenhall and Ott 1972), which determines significant differences among small-sample means.

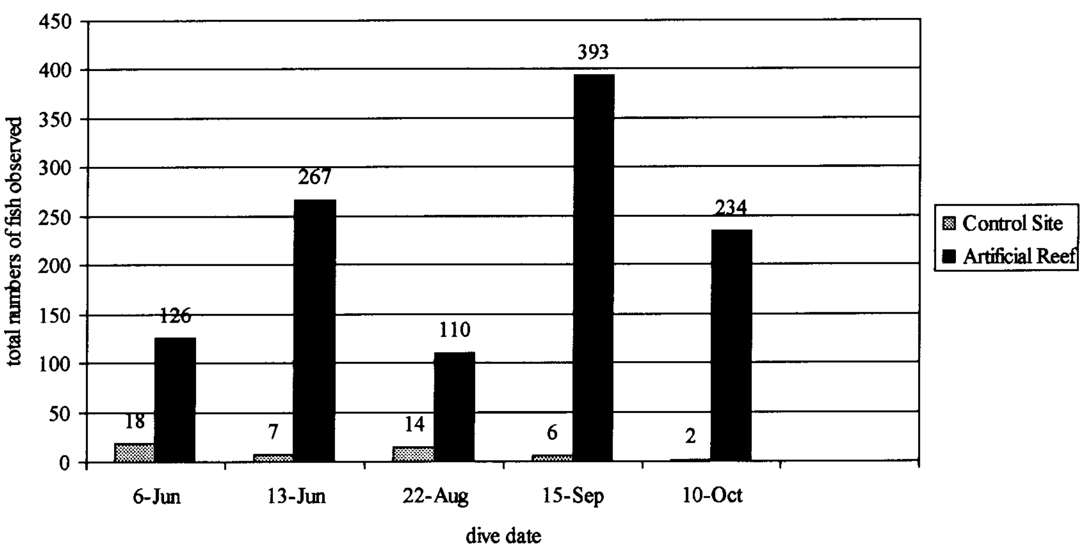


FIGURE 6.—Total numbers of fish observed in 1992 at the Lorain artificial reef and control sites using mobile and stationary cameras.

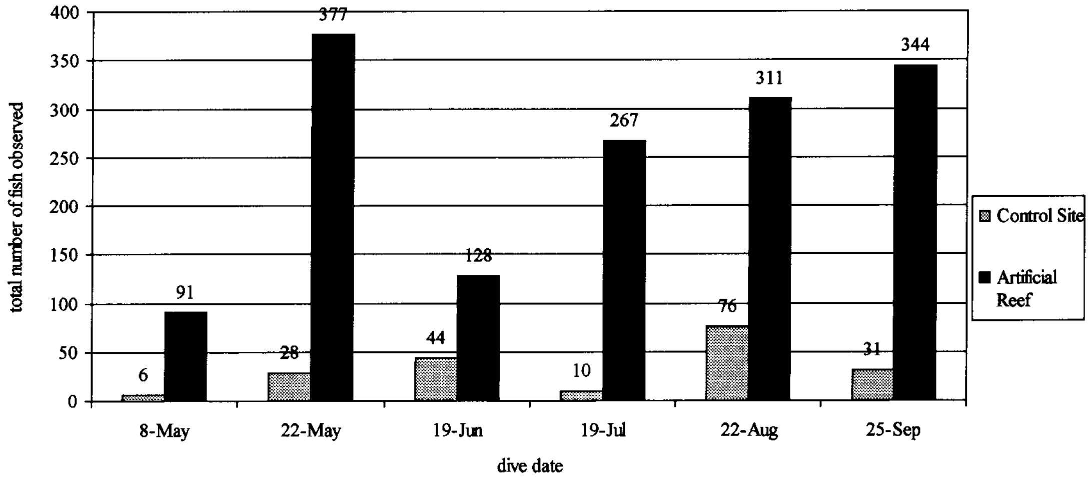


FIGURE 7.—Total numbers of fish observed in 1993 at the Lorain artificial reef and control sites using mobile and stationary cameras.

A summary of the data from 1992 showed more total fish observed at the reef than at the control site (Figure 6). Smallmouth bass was the most abundant species observed at the reef site (1,057 individuals or 93.6% of all fish observed), while freshwater drum were the most numerous at the control site (28 individuals or 50.9% of all fish observed) (Table 2). Furthermore, in 1992 the reef site attracted significantly more fish when all species were combined (1,129) than the control site (55) (a = 0.01). We also evaluated the ability of the reef to concentrate smallmouth bass. Numbers of other fish species were too low for statistical analysis. Results indicated the reef held significantly more smallmouth bass than the control site (a = 0.01).

The 1993 data summary (Figure 7) revealed similar results to the 1992 observations. Smallmouth bass were again the most abundant species at the artificial reef site, comprising 1,366 individuals or 94.6% of all fish observed (Table 3). Numbers at the control site also were dominated by smallmouth bass (112 individuals or 58.6% of all fish observed), with freshwater drum second in abundance (60 individuals or 31.4% of the total) (Table 3). Again in

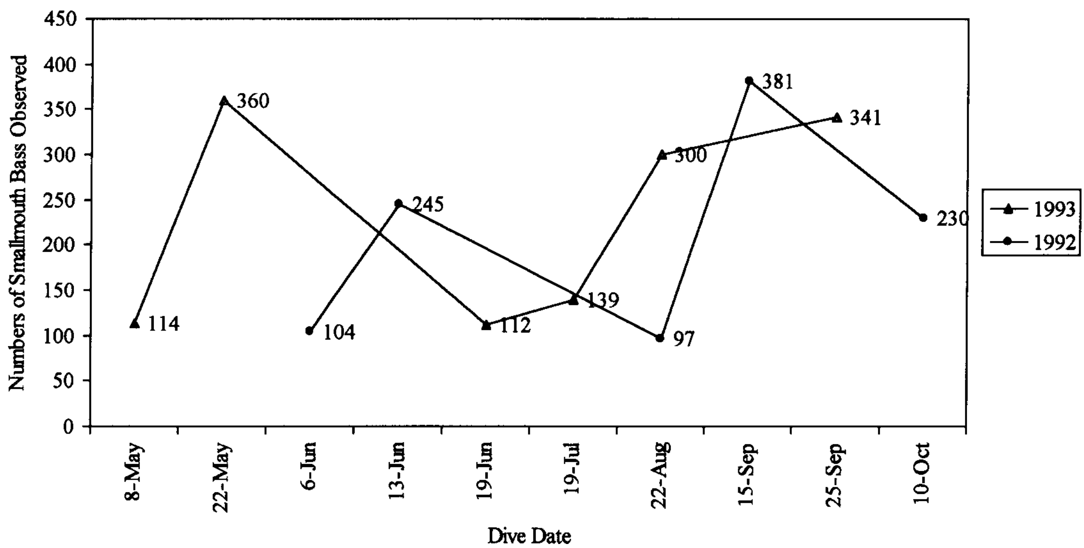


FIGURE 8.—Seasonal trends in smallmouth bass, 1992 and 1993, at the Lorain artificial reef using mobile and stationary cameras.

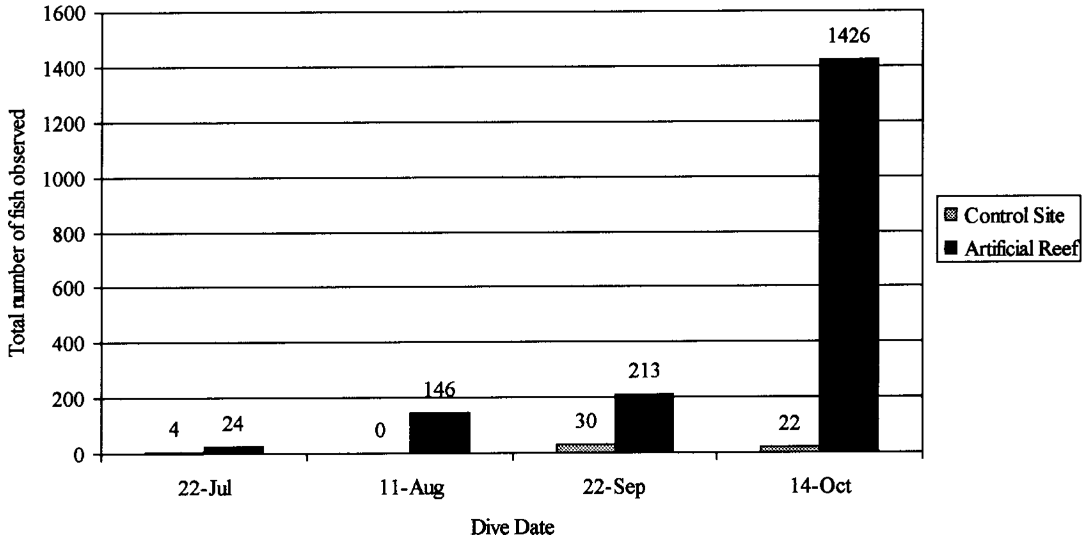


FIGURE 9.—Total numbers of fish observed in 1994 at the Lakewood artificial reef and control sites using mobile camera only.

1993, the reef site attracted significantly more fish (1,444) than the control site (191) (a = 0.05) and significantly more smallmouth bass (a = 0.05). Total numbers of smallmouth bass also were observed to be higher during the spring and fall months, especially in 1993, suggesting possible seasonal preferences (Figure 8). Anecdotal angler data reported to the authors also support this observation of seasonal preferences.

*Lakewood Artificial Reef, 1994 and 1995*

The same assessment techniques and methods used at Lorain were employed during 1994 and 1995 at the Lakewood reef site, except, as previously discussed, the stationary camera was not used. Observations from Lakewood during both 1994 (Figure 9) and 1995 (Figure 10) showed considerably more fish at the reef than the control site. A summary of the data from 1994 revealed that smallmouth bass

TABLE 4.—Total numbers of taxa and fish observed in 1994 at the Lakewood artificial reef and Lakewood control sites using mobile camera only. (Totals are greater than 100% due to rounding.)

| Species | Artificial reef number | Control site number | Artificial reef % of total | Control site % of total |
|---|---|---|---|---|
| Smallmouth bass | 1,477 | 51 | 81.65 | 91.11 |
| Rock bass | 205 | | 11.33 | |
| Walleye | 53 | | 2.92 | |
| Freshwater drum | 22 | 4 | 1.22 | 7.14 |
| Catostomidae sp. | 12 | | 0.67 | |
| Carp | 7 | 1 | 0.39 | 1.79 |
| Shorthead redhorse | 6 | | 0.33 | |
| Yellow perch | 4 | | 0.22 | |
| Goldfish | 2 | | 0.11 | |
| Percidae sp. | 1 | | 0.06 | |
| Unknown | 20 | | 1.11 | |
| Total | 1,809 | 56 | 100.01 | 100.04 |

TABLE 5.—Total numbers of taxa and fish observed in 1995 at the Lakewood artificial reef and Lakewood control sites using mobile camera only.

| Species | Artificial reef number | Control site number | Artificial reef % of total | Control site % of total |
|---|---|---|---|---|
| Rock bass | 282 | | 30.45 | |
| Smallmouth bass | 278 | 14 | 30.02 | 56.00 |
| Logperch | 178 | | 19.22 | |
| Yellow perch | 95 | 1 | 10.26 | 4.00 |
| Freshwater drum | 35 | 5 | 3.78 | 20.00 |
| Walleye | 25 | 1 | 2.70 | 4.00 |
| Carp | 14 | | 1.51 | |
| Shorthead redhorse | 2 | | 0.22 | |
| Catostomidae sp. | 6 | | 0.65 | |
| Channel catfish | 1 | | 0.11 | |
| Round goby | | 1 | | 4.00 |
| Unknown | 10 | 3 | 1.08 | 12.00 |
| Total | 926 | 25 | 100.00 | 100.00 |

was the most abundant species observed at the reef site (1,477 individuals or 81.6% of all fish observed), followed by rock bass (205 individuals or 11.3% of all fish observed) and walleye (53 individuals or 2.9% of all fish observed) (Table 4). Smallmouth bass was also the most abundant species observed at the control site during 1994 (51 individuals or 91% of all fish observed) (Table 4).

Although many more fish were observed on the reef in 1994 (1,809 total, 1,477 smallmouth bass) than at the control site (56 total fish, 51 smallmouth bass), the differences were not statistically significant due to small sample size and wide variability, induced by a seasonal peak of smallmouth bass during autumn (Figure 9). The empirical differences, however are quite clear.

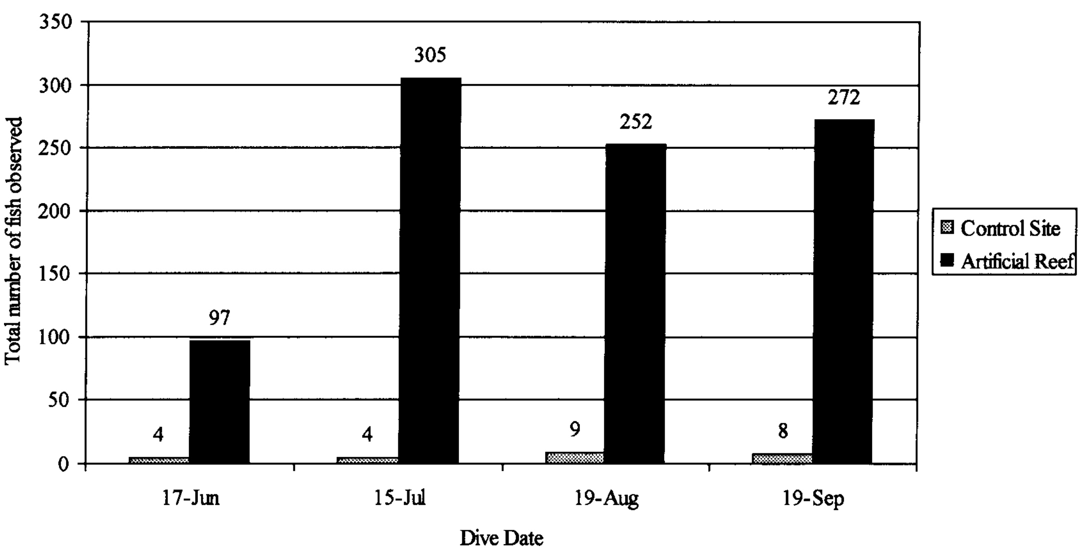


FIGURE 10.—Total numbers of fish observed in 1995 at the Lakewood artificial reef and control sites using mobile camera only.

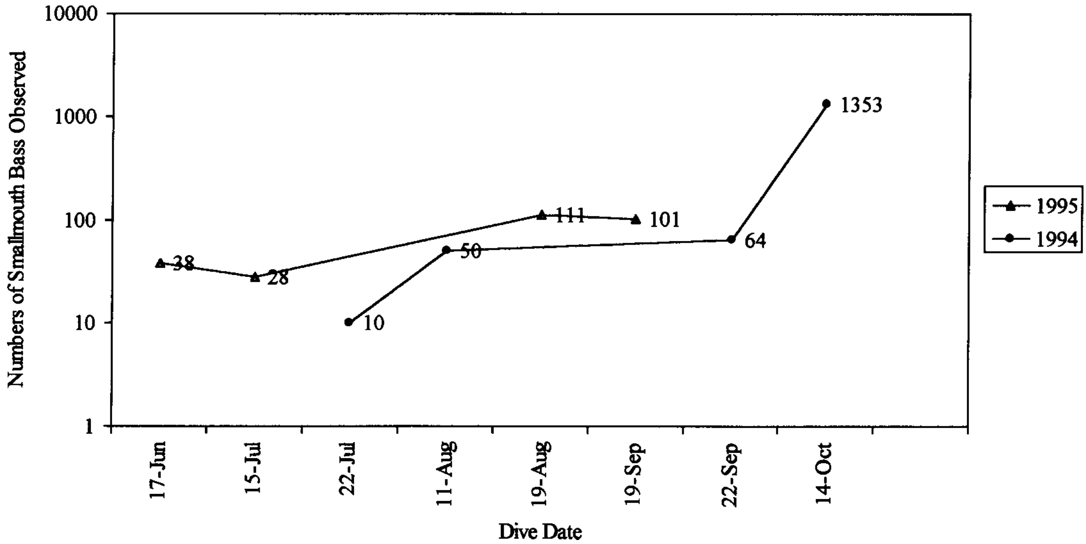


FIGURE 11.—Seasonal trends in smallmouth bass, 1994 and 1995, at the Lakewood artificial reef using mobile camera only.

A summary of the data collected during 1995 showed that rock bass was the most abundant species (282 individuals or 30% of all fish observed) on the artificial reef, followed closely by smallmouth bass (278 individuals or 30% of all fish observed, Table 5). At the control site, smallmouth bass was again the most abundant species (14 fish or 56% of all fish observed) (Table 5). In 1995, the total number of fish observed at the reef (926) and the total number of smallmouth bass (278) were both significantly greater (a = 0.05) than the corresponding numbers from the control site (25 total fish and 14 smallmouth bass) (Table 5).

Seasonal preference by smallmouth bass for the Lakewood artificial reef during 1994 and 1995 (Figure 11) are similar to preference observed at Lorain during 1992 and 1993 (Figure 8)—more abundant during the late spring and fall. However, the absence of Lakewood data from May during both years, in June during 1994, and in October during 1995 (Figures 9 and 10) due to boat breakdown and weather and visibility conditions makes this comparison difficult. Despite this lack of video data, anecdotal data from Lakewood artificial reef anglers tend to support the suggestion that the preference exhibited by smallmouth bass toward the Lakewood reef is similar to the preference exhibited by smallmouth bass toward the Lorain reef.

## Discussion

During 1992 and 1993, the Lorain artificial reef concentrated fish in numbers, depending upon the observation period, 20–60 times greater than the nonreef control site. Observations at Lakewood from 1994 and 1995 indicated that total fish numbers observed on the artificial reef were 32–37 times greater than those observed at the control site. These artificial reefs also concentrated smallmouth bass, depending upon the observation period, from 12 to 66 times more than the control site at Lorain, and from 20 to 29 times more than the control site at Lakewood. Furthermore, these differences were statistically significant for three of four years (1992, 1993, and 1995) and empirically significant for all four years, for both smallmouth bass and total fish. These results clearly demonstrate that artificial reefs constructed of clean concrete and rock rubble and placed in the nearshore waters of the central basin of Lake Erie are effective fish aggregators, particularly for smallmouth bass.

Recent literature has examined concerns that artificial reefs may serve primarily as fish attractors while contributing little to overall fish production (Lindberg 1997; Bortone 1998). In some cases this attraction could result in local overharvest of sport fish. These artificial reefs were developed as fish concentration devices for sport angler use and were not intended to provide spawning habitat that would measurably increase fish production. Lake Erie fish stock overviews published by the Ohio Department of Natural Resources, Division of Wildlife (ODNR 1998) portray popular sport fish species as being stable or increasing and not subject to overharvest. Anecdotal angler reports indicate that a variety of fish species are being caught on and around the artificial reefs, including walleye, yellow perch, and white bass.

An economic evaluation by Glenn et al. (1994) revealed that during 1992, the most sought-after and kept species by anglers fishing the Lorain artificial reef was walleye, followed by yellow perch and then by smallmouth bass. Our data, however, contained few observations of walleye or yellow perch and instead clearly showed a preponderance of smallmouth bass and rock bass using the reefs (Tables 2, 3, 4, and 5). This supports observations by Bohnsack et al. (1991) that centrarchids respond particularly well to artificial reef structures. Annual Lake Erie smallmouth bass harvest statistics show a steady increase both in harvest and angler effort directed at smallmouth since 1985. Creel survey data suggest that 8 of 10 smallmouth bass caught are released by Lake Erie anglers (ODNR 1998), which can reduce the impact of fishing effort.

Data collection using underwater video to enumerate and identify fish to the species level proved to be an effective technique in Lake Erie. Ten years ago, before the invasion of zebra mussels and further reductions in phosphorus loading (which lowered plankton density), poor visibility would have made this technique impossible. The use of underwater video for research offers many advantages. In this study we were pleased with our ability to gather accurate data without harming specimens or damaging the habitat, as well as our ability to store the results in a format that allows other scientists, managers, and the general public to see the raw observations recorded on each dive.

A limitation of this study is that all data were collected between 10:00 a.m. and 2:00 p.m. to take advantage of maximum light availability and improve the quality of the video results. Therefore, it is possible that crepuscular and nocturnal species are underrepresented in our results.

The Lorain reef is very popular with anglers and has been an economic success, generating annual economic benefits 2.7 times the cost of developing the reef (Glenn et al. 1994). (For more details of the reef's economic benefits, see Hushak et al. 1999, this volume.)

## The Future of Artificial Reefs in Lake Erie and the Great Lakes

This assessment effort was designed to determine whether artificial reefs constructed in the central basin of Lake Erie could attract and concentrate fish in a manner that would improve the sport fishery in this portion of the lake. The artificial reefs constructed at Lorain and Lakewood have proven to be popular with recreational anglers and scuba divers. The reefs aggregate both fish and anglers, and research has shown the reefs' value.

Although we consider these reefs to be remarkable successes, we continue to recommend caution when considering artificial reef construction in the Great Lakes as we do not believe every reef will be as successful. In designing this program, we selected what we considered to be the best location for artificial reef construction in the Great Lakes—the central basin of Lake Erie—a basin with high production potential but little natural relief. Within that basin, we selected some of the most suitable locations by applying all of the site selection criteria from Figure 1. Recognizing that this was a demonstration and a test, we selected only the best materials for use in reef construction (Gannon 1990). These materials were designed to remain in the lake based on the knowledge that any reef program would be significantly harmed if reef materials were washed up onto local beaches.

We make the above points because anyone constructing reefs in the future will certainly be contacted, as we were, by individuals with unsuitable materials (e.g., old tires, wooden structures, boats, cars, etc.) that are not as permanent as the material used in these projects. We believe that properly constructed artificial reefs can be "environmental endowments," that is, they are paid for when constructed but produce benefits for the environment and local community well into the future. However, this certainly will not be the case if reefs are poorly placed or if inferior materials are used.

During February 1996, the city of Cleveland and the National Football League announced their plans to build a new football stadium. Ohio Sea Grant urged the city to consider using rubble from the old stadium to build artificial reefs offshore of Cleveland. Many months of investigation and feasibility studies followed. During October and November 1997, the city of Cleveland constructed three artificial reefs from the old stadium rubble, with a total length in excess of 355 m, in 9.7 m of water. The Ohio State University Sea Grant College Program has been charged with the biological assessment of these new reefs and will begin research efforts during 1998.

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