University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

Investigations of the Ichthyofauna of Nicaraguan Lakes

Papers in the Biological Sciences

1976

An Investigation into the Use of Artificial Habitats as a Means of Increasing the Fishery Productivity of the Great Lakes Complex of Nicaragua

Terrance M. Lim
University of California - Berkeley

Kenneth R. McKaye
University of California - Berkeley

Douglas J. Weiland
University of California - Berkeley

An Investigation into the Use of Artificial Habitats as a Means of Increasing the Fishery Productivity of the Great Lakes Complex of Nicaragua

TERRANCE M. LIM, KENNETH R. MCKAYE AND DOUGLAS J. WEILAND

INTRODUCTION

Protein deficiency is a major dietary problem in Central America where protein-rich foods are scarce and costly. Fish, however, represents a rich source of animal protein that is not being utilized to a significant extent. Moreover, it is a source that could be made available to large portions of the populations of these countries if improvements of the present fishing and distribution methods were realized. Prerequisite to expansion, however, is a basic understanding of the ecosystems and their components. It is at this preliminary stage that the situation presently lies. Once this understanding has been achieved, means of maximizing production can be developed. This paper examines one means toward that end.

The concept of the artificial reef as a way to increase the productivity of sport and, to some extent, commercial fisheries has been explored in recent years (Randall, 1963; Carlisle *et al.*, 1964; Turner *et al.*, 1969; Stone, 1972, 1973; Buchanan, 1973). Marine artificial habitats have usually been constructed of waste materials such as old tires, construction rubble, or wrecked car bodies (Turner *et al.*, 1969). Freshwater structures have made more use of natural materials such as fallen logs and piles of brush, but man-made devices are also common (Rounsefell and Everhart, 1953).

The features of artificial structures that seem to be most important in attracting fish are shelter, areas of calm water, visual reference points, and food (Stone *et al.*, 1974). Thigmotropism and schooling behavior are also important (Carlisle *et al.*, 1964).

Studies by Lin (1961) and INFONAC (1971, 1974) have shown that Lake Nicaragua (largest lake in Central America) and Lake Managua are being underutilized in terms of potential food yield. Barlow (1976) suggested that the potential of these fisheries could be increased through the introduction of artificial reefs in areas having little relief or plant cover. With these points in mind and in view of the importance these lakes could have in providing nutrition, a pilot project was carried out to assess the feasibility and promise of artificial habitats in these tropical inland waters.

Efforts were concentrated on cichlid fishes. They are the most important food species because of their great fecundity, high level of trophic efficiency, and marketable size (Baylis, 1973; Barlow, 1976). This contrasts with the current emphasis of the fishermen on the sawfish, *Pristis perotteti*, which is now showing signs of overfishing (INFONAC, 1974).

The study was carried out in Lake Jiloá, a small crater lake adjacent to Lake Managua. The study could not be performed in either of the Great Lakes due to poor visibility, and the presence of sharks and sawfish in Lake Nicaragua makes underwater activities there hazardous.

Description of the study area.—Laguna de Jiloá, is situated in the Great Lakes Basin on the Pacific side of Nicaragua. The most conspicuous features of this lake complex are the two Great Lakes, Nicaragua and Managua. All the other lakes are of volcanic origin and are comparatively small. Lake Jiloá, one of these crater lakes, has an area of about 380 hectares (Riedel, 1964) and lies immediately adjacent to Lake Managua. There is relatively high species diversity and visibility in the lake, making it the best suited lake for underwater study.

Visibility in Lake Jiloá averages 2-3 m during the dry season (November or December to April or May) and increases to 3-4 m during the wet season. Light intensity decreases with depth but remains sufficient to carry out observations down to about 20 m without artificial lighting during peak daylight hours (10:00 - 14:00). Water temperature is a fairly constant 28°C during the dry season from the surface to approximately 25 m (Barlow *et al.*, 1976).

The bottom profile of Lake Jiloá is transitional between that of the two shallow Great Lakes and that of the steep-sided crater lakes. On the southeast shore, which is closest to Lake Managua and consequently similar to it, the bottom consists mostly of silt and sand and slopes gently toward the depths. As one moves westward along the southern shore, a rocky area is encountered. This rocky area, with large jumbled boulders and rock formations descending rapidly to the depths, is typical of crater lakes. Maximum depth is approximately 92 m (Riedel, 1964). The open sand-silt area and the jumbled rock area are the two natural habitats with which the artificial habitat was compared. The jumbled rocks comprise the prime habitats in the lake as judged by number of species and biomass.

The flora of Lake Jiloá, as with most of the lakes, is sparse. Phytoplankton, *Aufwuchs*, three species of algae, an unidentified subaquatic grass, emergent rushes, and algal detritus make up the bulk of plant matter in the lake. The invertebrate fauna is also limited. One species of crab, *Potamocarcinus nicaraguensis,* and numerous small snails whose shells make up a significant portion of the substrate, are the most conspicuous. Insect larvae are abundant. The only vertebrates in the lake besides the fish are the toad, *Bufo marinus*, the frog, *Smilisca baudini,* and the turtle, *Pseudemys scripta.*

The ichthyofauna of the lake consists of nine cichlid species: *Cichlasoma longimanus, C. rostratum, C. nicaraguense,* *C. nigrofasciatum, C. citrinellum, C. centrarchus, C. dovii, C. managuense,* and *Neetroplus nematopus*; the catfish, *Rhamdia nicaraguensis*; the atherinid, *Melaniris sardina*; the clupeid, *Dorosoma chavesi*; the molly, *Poecilia sphenops*; the swamp eel, *Synbranchus marmoratus*; and the eleotrid, *Gobiomorus dormitor* (Villa, 1968). Lake Jiloá has fewer fish species than either of the Great Lakes but more than any other crater lake. Predictably, its fauna is similar to that of Lake Managua with which it may have once been connected (Villa, 1968). The nine cichlid species and the eleotrid are the most important elements of the lake from a commercial point of view.

The site of the project was on the southeastern shore. The location was selected for two reasons: (1) the site is isolated from the prime natural habitat, enabling us better to judge its attractiveness to fish, and (2) the transport of heavy materials to almost any other part of the lake would have posed major logistical problems.

The artificial habitat was approximately 15 m from shore over a sand-silt bottom sloping 30°. Visibility was less than in other areas (1.0-2.5 m) because the north wind kept the bottom slightly stirred up. Water temperature was as in the rest of the lake (28°C).

The sand-silt bottom extended in all directions from the artificial habitat. About 300 m to the west there was a patch of *Chara*, and about 150 m further on, the rock habitat began. To the east there was a stand of emergent rushes about 200 m away. Beyond the habitat the empty bottom continued sloping down to undetermined depths.

Methods and Materials

Construction.—The artificial habitat was composed of old truck tires, acquired *gratis* from a local trucking company, and concrete blocks, purchased from a nearby brickyard. Each tire had an outside diameter of 107 cm, an inside diameter of 57 cm (25 cm sidewalls) and a tread width of 22 cm. The size of the access to the interior of the tires varied from approximately 6 to 15 cm, and a number of the tires had small holes cut into the tread. Each concrete block was 10 by 20 by 40 cm with three 5 by 10 cm holes in it. Calculations from previously acquired field data indicated that units of these dimensions approximated the preferred breeding hole sizes of a number of the species under study.

Four persons were involved in the placement of the materials on 28-29 March, 1974. Single and double-tire units were employed to assess the effects of the different amounts of cover. The double-tire units consisted of one tire atop another secured with plastic line. The blocks were placed upright in the center areas of twelve units.

When completed, the habitat consisted of eight rows of tires with four units, two singles and two doubles, alternating in each row. A single odd tire was placed by itself in a

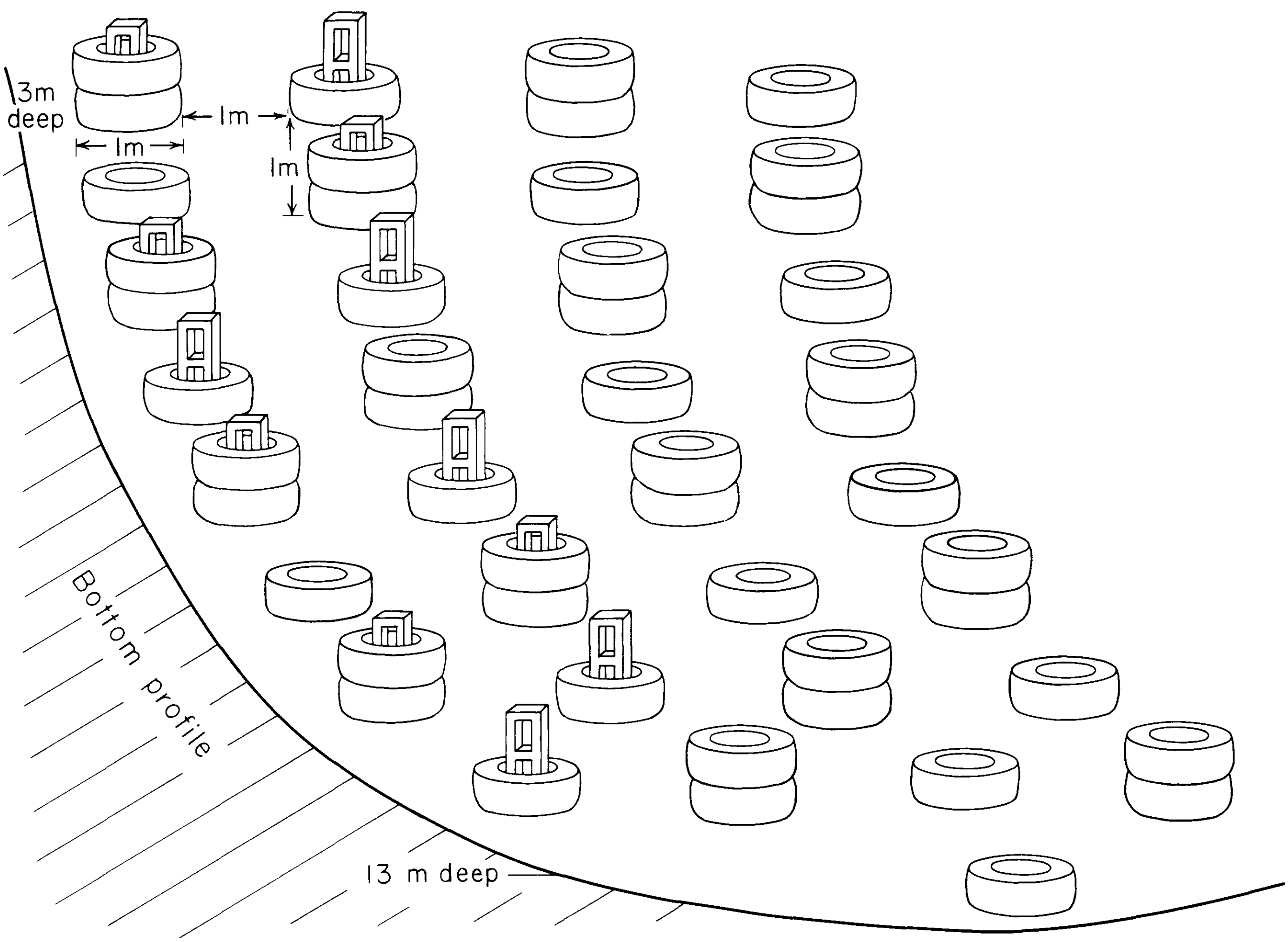

FIG. 1. A schematic view of the artificial habitat showing the matrix of tires, some containing concrete blocks.

last row. Each unit was placed 1 m from the adjacent one and the rows were also set at 1 m intervals. As mentioned, blocks were placed in the centers of twelve of the units (Fig. 1). The area of the completed artificial habitat was 105 m^2 (7 by 15 m) with a minimum depth of 5 m and a maximum depth of 13 m. A limited number of tires and necessary consideration of decompression limits underwater restricted the depths at which units could be placed.

Censuses.—All censuses of the artificial habitat were performed by the senior author during the 7-½ week period from 29 March to 19 May, 1974. Beginning at the deepest row, the number of fishes present was determined by slowly walking just below each row of tires and counting all of the fish seen in the 1 m wide swath containing the tires, and in the 1 m wide area between that row and the next shallower one. The area covered on each transect thus was 2 by 7 m. Results were recorded by species on a plastic slate. Care was taken not to disturb the fish; a 3 minute interval was observed between the censusing of each row to let the fish recover from any disturbance that may have been created.

Censuses over the rock and sand habitats were made by a pair of divers during the periods 19 February to 21 May and 20 March to 20 May, 1974. A 25 m transect line was utilized over the rocks and a 50 m line over the sand. The first diver laid out the line along a constant depth contour while the second diver waited at the starting point. The first diver returned by swimming parallel to the line at least 4 m away. A 5 minute interval was observed before proceeding with the census in which the two divers swam parallel to each other on opposite sides of the transect line counting and recording all of the fish sighted within 2 m of the line. These censuses were made at 3 m depth intervals from 35 to 1.5 m. Only the results from those censuses made at depths corresponding to those in the artificial habitat are reported here.

Behavioral watches.—Approximately 35 hours were spent underwater observing feeding and territorial behavior, parental care of young, and movements of the fish in and through the artificial habitat. Each watch was 15 minutes long with the observer staying 0.5-1.5 m from the subject. Observations were recorded on plastic slates and later transcribed to paper.

Tagging.—Sleeping fish were captured with hand nets at night, measured, and marked with plastic color-coded tags to determine their patterns of movement in the artificial habitat. Species, tag color and position, depth, and location of sighting were recorded upon all subsequent sightings.

Gill netting.—A small amount of gill netting was done at the end of the study to collect fish for the analysis of stomach contents and to give indications of the movements of the fish. An 8 by 50 ft net with 1″ mesh was placed perpendicular to shore just outside the westernmost column of tires to detect along-shore movements. A 2″ mesh net was placed parallel to shore, just below the deepest row of tires, to capture fish moving between shallow and deep water. Large live fish were tagged, measured, and released while small ones were simply measured and released. Dead fish were removed and preserved in 10% formalin for later study.

Results

Artificial habitat censuses.—Every fish species known to Lake Jiloá, except the eel, *Synbranchus marmoratus*, was seen in the artificial habitat at some time. The first species appeared the morning after construction. These first arrivals were *G. dormitor*, *N. nematopus*, and *C. citrinellum*. The next day, *C. rostratum*, *C. dovii*, and *C. nigrofasciatum* were seen, followed a day later by *C. nicaraguense*. Subsequently, *C. managuense*, *C. longimanus*, and *C. centrarchus* were observed.

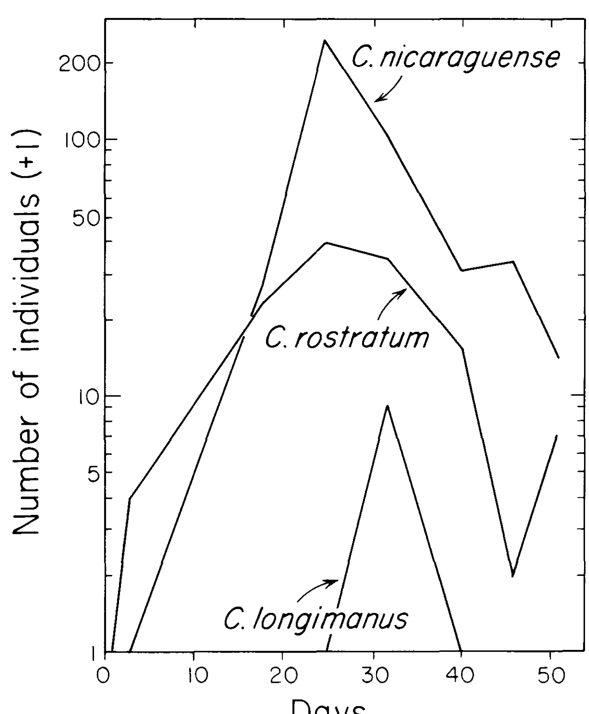

FIG. 2. The abundance of the three sand-dwelling cichlids at the artificial habitat during the period 29 March to 19 May, 1974.

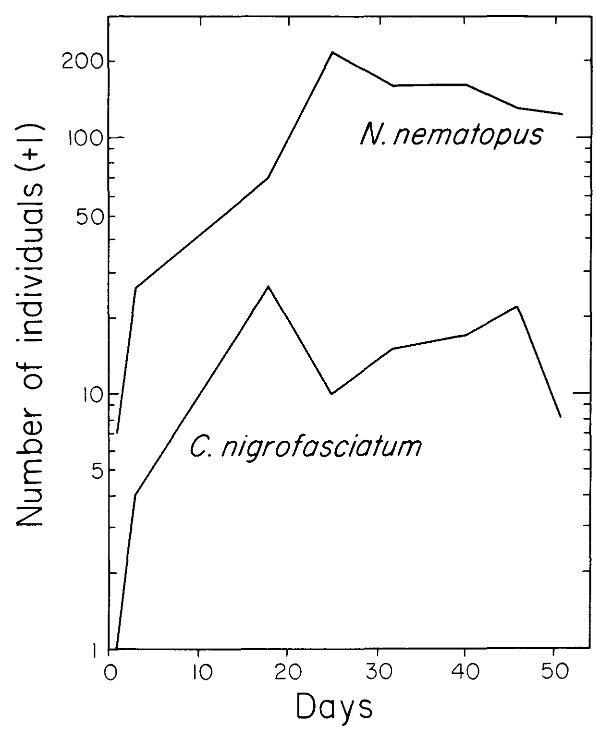

FIG. 3. The abundance of two small herbivorous rock-dwelling cichlids at the artificial habitat from 29 March to 19 May, 1974.

M. sardina was never observed at the habitat proper, probably because its habits confine it to the surface or to shallow water. *P. sphenops, D. chavesi,* and *R. nicaraguensis* were probably present before they were first detected because they all avoid divers. In addition, the latter two are generally nocturnal.

The general trend of the cichlid populations was a gradual increase in the population peaking at around the fourth week and then dropping and levelling off in the fifth and sixth weeks (Fig. 2-6). The trend shown by *G. dormitor* was almost the complete opposite.

Rough estimates of the size ranges of the most numerous species yielded 40-60 mm standard length for *Neetroplus nematopus*, 60-140 mm for *C. citrinellum,* and 80-180 mm for *Gobiomorus dormitor*. This corresponded to a predominantly adult population of *Neetroplus* and *C. citrinellum,* and to nearly even adult-juvenile proportions in the *Gobiomorus* population. Each of the populations mentioned above, therefore, contained a sizable proportion of potential breeders.

Comparison of the natural and artificial habitats.—The results of the censuses at depths of 3-13 m in the rock, sand, and artificial habitats were used to calculate and compare the mean densities of each species in each area (Table 1). With the exception of *C. nigrofasciatum*, the most abundant species over the natural habitats were also among the most numerous species at the artificial habitat. The number of individuals, however, was greatest over the rocks ($551.3/100m^2$), lowest over the sand (9.5% of rocks), and intermediate over the artificial habitat (63% of rocks).

The results from the individual censuses were used to calculate an index of species diversity to compare the evenness of distribution of species in the three habitats. The Shannon-Wiener index, H', takes into account both the number of species present and their relative abundance:

$$H' = -\Sigma n_i/n \log_2 n_i/n$$

where n_i = number of individuals of the ith species counted in the census,

n = total number of individuals counted in the census,

$\overline{H'} = 1/n\Sigma H'_i$ (n = number of censuses).

The artificial habitat had a more even distribution of species than did the natural habitats. It also had more species present, or at least visible (Fig. 7).

Feeding behavior.— The feeding behavior of the fishes at the artificial habitat appeared to be the same as that exhibited in their natural habitats. *C. citrinellum* (see Barlow, 1976, for a more complete description), *C. rostratum* and *C. nicaraguense* were seen feeding primarily off of the sustrate and only occasionally from the tires or blocks. Preliminary analyses of stomach contents indicate that *C. citrinellum* ingests snails, algae, occasional fish, and substrate. *C. rostratum* stomachs contained mostly substrate and algae. *C. nicaraguense* stomachs had almost nothing but algae.

C. nigrofasciatum and *N. nematopus* seemed to spend most of the daylight hours in feeding, both from the sand-silt substrate and from the artifacts. *Neetroplus* often fanned the substrate before picking out food items, apparently to move away silt, whereas *C. nigrofasciatum* would plunge its snout right in. The stomach contents of both these species consisted entirely of plant material.

Observations on the gill nets revealed that *Neetroplus* can feed on other materials. On a number of occasions fish in the gill nets were found to have their eyeballs missing. Watches on the nets disclosed that in most cases, one to 4 or 5 *N. nematopus* attacked a netted fish within minutes of its capture, darting in and biting at its eyes. Often fishes of other species, especially *C. citrinellum,* would also take part in the attacks. Occasionally a large *Neetroplus* defended a victim from other fishes apparently because it had claimed the victim as its own. *N. nematopus* also feeds on the eggs of *M. sardina* as they are released and preys on the fry of other cichlids (Barlow, pers. comm.).

G. dormitor juveniles fed on plankton and were often seen up in the water column making strikes at invisible prey. Adults preyed on small fish. They are sit-and-wait predators. They lurk motionless on the tires or the substrate, matching their color, until a fish comes within striking range, whereupon they dart forward and attempt to capture the prey. Few strikes by adults were seen in the artificial habitat.

C. managuense, C. dovii, C. centrarchus and *C. longimanus* were never observed feeding in the artificial habitat. Data from other areas, however, indicate that *C. managuense* and *C. dovii* are piscivores and that *C. centrarchus* and *C. longimanus* are herbivores.

Territorial behavior.—Distinct territorial behavior was seen only in one species, *N. nematopus*. These observations stemmed from two pairs of *Neetroplus* which bred in the artificial habitat. One pair was seen only with eggs, but the other pair had young. These were the only fish that bred in the artificial habitat during the study. Unfortunately, there was little breeding activity anywhere in the lake at that time.

The existence of feeding territories was not confirmed. As mentioned, defense of a gill-netted fish by large *Neetroplus* was occasionally seen. *C. nigrofasciatum* tended to occur in groups consisting of two adults plus juveniles per tire unit, never more. This may be evidence that this species

TABLE 1. A comparison of the mean densities per 100 m^2 of each of the studied species over the three main types of habitats and the per cent composition of each population.

Species	Sand	Artificial habitat	Rocks
C. longimanus	0.23 (0.43%)	0.95 (0.27%)	0.14 (0.02%)
C. rostratum	2.15 (4.10%)	14.05 (4.05%)	1.39 (0.25%)
C. nicaraguense	43.70 (83.44%)	51.31 (14.78%)	6.68 (1.21%)
N. nematopus	1.93 (3.68%)	105.12 (30.27%)	344.04 (62.41%)
C. nigrofasciatum	0.18 (0.33%)	11.30 (3.25%)	107.46 (19.49%)
C. centrarchus	0	0.12 (0.03%)	5.79 (1.05%)
C. citrinellum	1.88 (3.58%)	73.21 (21.08%)	74.29 (13.47%)
C. dovii	0	2.62 (0.75%)	0.61 (0.11%)
C. managuense	0	1.30 (0.37%)	0
G. dormitor	2.33 (4.44%)	87.26 (25.13%)	10.90 (1.98%)
TOTAL	52.38	347.24	551.30

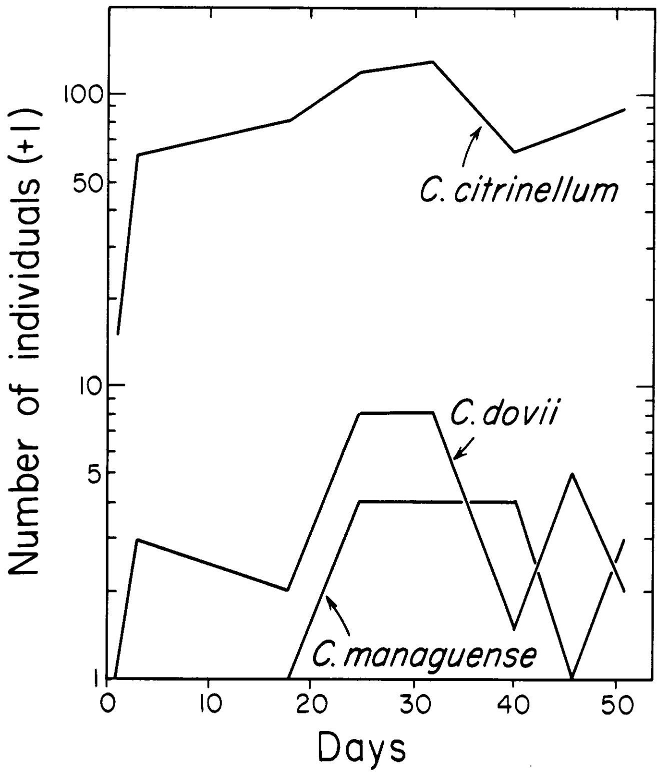

FIG. 4. The abundance of the three largest cichlids in the lake at the artificial habitat from 29 March to 19 May, 1974.

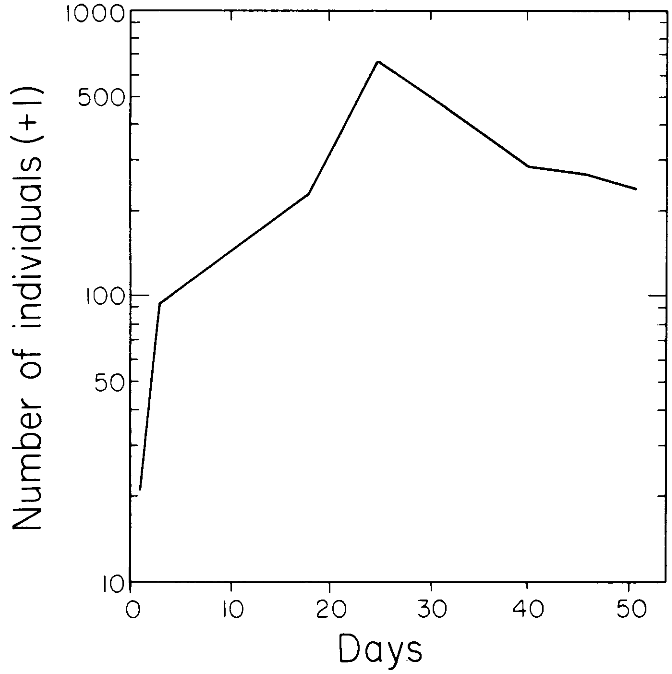

FIG. 5. The abundance of all cichlid species combined at the artificial habitat from 29 March to 19 May, 1974.

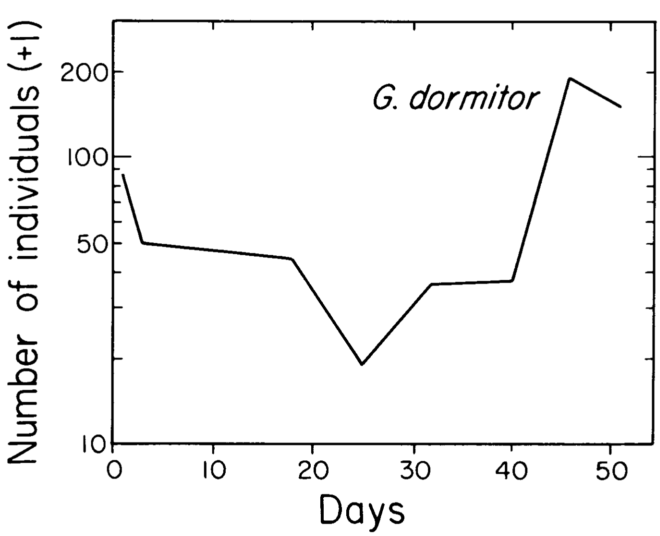

FIG. 6. The abundance of the ubiquitous lurking predator, *Gobiomorus dormitor*, at the artificial habitat from 29 March to 19 May, 1974.

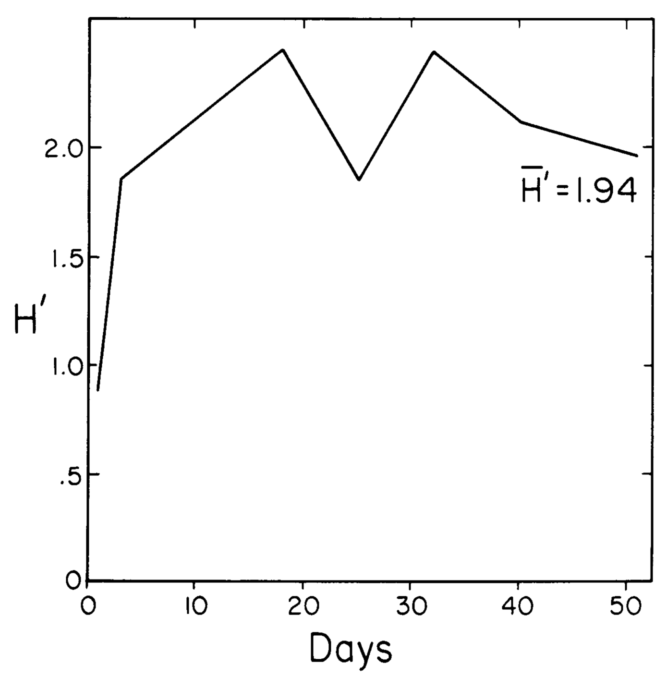

FIG. 7. The Shannon-Wiener index of species diversity calculated for each census of the artificial habitat. $\overline{H}'$ for the rock habitat is 1.42. $\overline{H}'$ for the sand habitat is 1.02.

maintained feeding territories. There was never any overt defense of a clearly delineated area by any fish in the artificial habitat except for the breeding pairs of *Neetroplus*. This is not surprising since Barlow (1974) mentioned that territoriality in nonbreeding adults is generally transitory and difficult to recognize.

Movements.—*C. nigrofasciatum* and *N. nematopus* tended to remain in a limited area in and around one or two tire units in groups of 2–5 and 5–15 individuals, respectively. They were constantly in motion and spent most of their time feeding. *Neetroplus* did appear to be more vagile than *C. nigrofasciatum*, however.

C. nicaraguense and *C. rostratum* are schooling species and ranged over considerable distances, stopping only to feed. *C. nicaraguense* usually travelled in aggregations of individuals of about the same size. *C. rostratum* was commonly seen in mixed groups of adults and juveniles. These tendencies lessened the difficulties of identification caused by the morphological similarity of the juveniles of the two species. Identifications could be made on the basis of the composition of the school sighted. Adult *C. rostratum* sometimes separated from a school and joined aggregations of *C. citrinellum* hovering 10–60 cm above the bottom in random orientations.

C. longimanus, the third sand-dwelling species, was rarely seen at the artificial habitat. The few observations made, however, showed it to be another schooling species and indicated that its behavior is similar to that of *C. nicaraguense* and *C. rostratum.*

C. citrinellum appeared to frequent the artificial habitat during the day but to move elsewhere at night. During the day, sizable numbers were usually found hovering over, around, and in the tires in random orientations. Few were found in the habitat at night.

C. dovii and *C. managuense* were inclined to stay within the shadowy interiors of double-tire units when at the artificial habitat. They emerged occasionally to swim through the lower areas of the habitat, but returned to the shadows of the same tire unit from which they began. Both of these species are often found in caves over the rock habitat although *C. managuense* is the more secretive.

Gill net captures indicated that large *C. managuense* and *C. citrinellum* spent most of their time in the deep water beyond the artificial habitat and came up into the shallow areas early in the morning. Direct observations confirmed the occurrence of large *C. citrinellum* at depths of 20–30 m.

G. dormitor was almost always seen sitting motionless on the tires or substrate. This behavior is typical of the species in all habitats. It seems to trust its crypticity for defense since it generally did not flee from a diver or fish unless directly confronted or actually contacted. It is a solitary fish. Even when a number of them were in close proximity there was no obvious cohesiveness. This is not true of the juveniles, however. The fry school, as do the fry of all of the cichlid species.

Early tagging studies were inconclusive. Before gillnetting, 17 fish were tagged, including 5 *G. dormitor*, 7 *C. citrinellum*, and 5 *C. rostratum.* There were two subsequent sightings of the *Gobiomorus*, two of the *C. citrinellum*, and four of the *C. rostratum.* The longest period between tagging and sighting was five days, but the average was nearer to one or two days. These data suggest that tagged fishes remained in the region for short periods (Table 2).

Tagging efforts during the period that the gill nets were in place indicated residency in the artificial habitat by two species, *N. nematopus* and *G. dormitor.* These results must be viewed with caution, however, because the presence of the nets, the resulting numbers of dead fish, and the general disturbance of the habitat by netting and collecting activities undoubtedly affected their behavior. While we have reservations about the results of tagging during the netting there are grounds for accepting the major findings. Direct observations on *Neetroplus* indicated that they remained in the habitat, and other tagging studies over the rock habitat have shown that *Gobiomorus* also tends to stay within a particular area for extended periods.

TABLE 2. Results of the tagging studies in the artificial habitat before and during the gill netting period.

Species	Number tagged before gill netting	Number of returns	Number tagged during gill netting	Number of returns
G. dormitor	5	2	63	75
C. citrinellum	7	2	16	2
C. rostratum	5	4	3	1
N. nematopus	0	0	2	5
C. nicaraguense	0	0	9	1
C. managuense	0	0	5	0

An interesting aside is that all of the *C. citrinellum* seen in the artificial habitat were of a green or yellow hue with black spots and/or bars on their sides ranging from barely visible to prominent. No normally colored *C. citrinellum*, with prominent black bars and spots displayed on a grey background, were seen except for juveniles. This polychromatic species has been studied by Barlow (1973) and he has suggested (pers. comm.) that the color changes may be in response to the light color of the substrate.

DISCUSSION

The artificial habitat must have attracted fish from both the rock and sand habitats. The features of man-made habitats enumerated in the introduction seem sufficient to explain why. Rock-dwelling species appear to be held near the structure by their preference for areas affording shelter, concealment, suitable breeding sites, and food. The relatively high concentrations of the three sand-dwelling species at the habitat may be explained by its utility as a visual reference point for these mobile species in the otherwise featureless sand habitat. That these schooling species often passed through but did not appear to seek shelter or concealment within the structures supports this view.

The attraction of the predatory species, *C. dovii, C. managuense* and *G. dormitor*, to the artificial habitat would appear fairly obvious. Large numbers of smaller fish occurring there provide a good hunting ground. The behavior of the two large cichlids indicates that they seek concealment within the tires. Whether this is a hunting technique or simply a preference for dark areas is unknown. It is not likely that they are seeking refuge because they have no natural predators in the lake, as adults.

Of the six remaining species of fish in the lake, only one appeared to be attracted to the artificial habitat. The catfish, *R. nicaraguensis*, was seen there regularly on the night dives. It apparently visited the area to forage. It avoided divers, however, so no observations on its behavior were possible. In the rock habitat they were found deep in holes and crevices during the day.

P. sphenops, M. sardina, D. chavesi and *C. centrarchus* were seen only occasionally in the habitat and never appeared to be attracted to it. *S. marmoratus* was never seen in the habitat.

Probably the most important factor in attracting fish to the artificial habitat was that it was a new, unoccupied area of shelter and potential breeding sites. The rock habitat is crowded with fish competing for living space. Food does not appear to be the factor immediately limiting population levels. Although visible algal growth was not readily apparent on the tires until the third week, fish were browsing from them during the first week. Over the rocks, plant food appears abundant and well distributed. On the other hand, competition for breeding sites is keen. Data taken during the breeding season in previous years (McKaye and Hallacher, 1973; McKaye, unpublished) indicate that competition for suitable breeding sites limits the number of fish that can successfully breed and raise young. The introduction of artificial habitats, therefore, should increase productivity. If the artificial habitat is not attractive as a breeding area, the additional algal growth on it should at least be attractive for feeding.

The general trend of cichlid colonization of the artificial habitat was an increase, overshoot, and levelling off reminiscent of island recolonization patterns (Simberloff and Wilson, 1970). The reason for the seemingly synchronous peak of most of the cichlid species in the fourth week is unknown. No noteworthy environmental changes were detectable. The seemingly negatively correlated abundance of *G. dormitor* was not surprising because of the active aggression toward it by many of the cichlid species.

The order and rate of discovery of the artificial habitat was correlated with the patterns of movements of the fish. The quick appearances of *G. dormitor* and *C. citrinellum* were predictable from *Gobiomorus*'s attraction to environmental disturbances and the numerous *C. citrinellum*'s wide-ranging daily movements. The delayed arrivals of *C. nigrofasciatum, C. centrarchus, C. dovii*, and *C. managuense* were also predictable. Both *C. nigrofasciatum* and *C. centrarchus* tend to remain within restricted areas in shallow water. Thus, the isolation and relatively deep placement of the habitat may have been barriers to colonization. *C. dovii*, which occurs in deep water over the rocks, and *C. managuense*, which also occurs over the rocks but in shallower water, would have been expected to appear only after the smaller fish arrived because of their predatory nature.

Unexpected, however, was the quick appearance of *N. nematopus* in the artificial habitat. *Neetroplus* was rare over the sand and tended to remain within small areas in its natural habitat. The great numbers of *Neetroplus* over the rocks, however, may have created pressure to disperse. This hypothesis is supported by the occurrence of large shoals of *Neetroplus* over the rock habitat and the fact that any odd obstructions over the sand, such as fallen logs, brush, or debris, were normally populated by *Neetroplus.*

The delayed appearances of the mobile sand-dwelling species was also unexpected. *C. longimanus*, rare throughout the lake, was understandably uncommon in the artificial habitat. *C. rostratum* and *C. nicaraguense*, however, were common. Possibly they initially avoided the habitat because of the abundance of the predatory *G. dormitor.* Sampling error may also be involved. The schooling nature of these species made them seem abundant only if the time of the census coincided with the occurrence of a school of them travelling through the habitat.

The comparatively high species diversity at the artificial habitat is attributed to the design of the structure. The spacing was such that both rock-like and sand-like habitat features were exhibited. This resulted in a more even distribution of species, giving the high $\overline{H}'$ value.

The materials used in the construction of the artificial habitat were selected with the idea of attracting particular species. *C. citrinellum* is the prime candidate for commercial exploitation because of its omnivorous habits and marketable size (Baylis, 1973; Barlow, 1976). Thus, we selected the truck tires because their central openings approximated the size of a normal *C. citrinellum* breeding site. They were also suitable because they provided surfaces for algal growth, were easily defended, had dark areas for concealment, and the inside walls provided suitable surfaces for egg deposition. The blocks were selected because they provided similar features for *N. nematopus, C. nicaraguense*, and *C. nigrofasciatum.*

It is important that optimal hole sizes and configurations be determined and the results applied to the construction of future artificial habitats in order to maximize reproductive activity in them. The spacing of individual units must be adjusted such that maximum density of breeding pairs with minimum loss due to predation and territorial aggression is obtained. Further work on the behavior and natural history of these fishes is required to make these determinations and others, such as optimal depth placement, growth rates, length-weight relationships, reproductive rates, and other optimum-yield factors. Also, the most efficient and least harmful methods of harvesting the yields must be determined. We have found that the size-specific nature of gill-netting makes for an efficient method of fishing.

It has long been accepted that fishes tend to congregate around natural reefs and sunken objects such as ships, so there was little doubt that the artificial habitat introduced into Lake Jiloá would attract fish. The importance of this study, however, is in demonstrating that species suitable for commercial exploitation and use as an important source of needed protein are attracted in numbers sufficient to make such exploitation economically feasible.

Turner *et al.*,(1969) estimated that the process of maturation for a man-made reef takes about five years in temperate marine waters. That is, five years after introduction, such a reef would be self-sustaining and would not depend upon recruitment from other habitats to maintain its population levels. We feel that this estimate of the time needed is too long for tropical lake systems, such as the one of which Lake Jiloá is a part.

Compared to a coral reef or similar marine habitat, the Nicaraguan lake habitats are fairly simple. Environmental conditions are relatively mild and steady, and species diversity is low. This lack of complex interrelationships results in an inherently less stable ecosystem that is more sensitive to changes. The fact that the reproductive output of the Lake Jiloá organisms seems to be limited chiefly by the shortage of suitable breeding sites, and the success of the habitat in attracting a wide variety of life, lead us to believe that a "mature" state could be realized in 1–2 years rather than five, depending on the design and size of the structure.

There are other methods of increasing fish productivity. Aquaculture, for example, should be considered. It has long been known to be an efficient method of harvesting large amounts of protein. *C. citrinellum* is, again, a prime candidate for cultivation (Barlow, 1976). Introduction of foreign species has already been attempted in Nicaragua (Riedel, 1964) and proved unsuccessful. Other introductions in Central American countries have resulted in drastic changes for the worse in the existing ecosystems (*e.g.*, Zaret and Paine, 1973). Thus, it is advisable that the introduction of foreign species not be considered as long as the benign alternatives of pond culture and artificial habitats are practicable.

This study was a victim of unfortunate timing in that it took place during a period of almost no breeding activity in the lake. Despite this, it has given clear indications that the use of artificial habitats in Nicaraguan lakes can be a viable means of increasing fishery productivity. We have been further encouraged by the observations of Thomas Hay (pers. comm.) who visited Lake Jiloá in October, 1974 and noted at least four pairs of *C. citrinellum* breeding in the tires of the artificial habitat.

Obviously, a long-term study is required. The brevity of this study precluded demonstrating the variety of ways artificial habitats can be valuable. By altering the size, configuration, and spacing of the units, particular species may be selected for. Areas previously depauperate of fish should, through the introduction of artificial habitats, be able to support sizable populations of fish that are easily accessible to local and commercial fishermen. Natural dispersal may be facilitated through the use of habitats as "stepping stones." These many possibilities can be tested and perfected to make them maximally effective in each of the Nicaraguan lakes. Resident scientists, who can monitor experiments year-round and analyze their progress, should take up where we have left off.

Acknowledgments

We would like to thank all of the people who helped and contributed to this research. They include Dale Roberts and Katherine Paulist who were at Lake Jiloá and helped us in many ways; Charles Kettle and the people at Productos Atmosféricos, Managua, who were so kind and patient in filling our many SCUBA tanks; Mary Lou Pressick who loaned us needed diving equipment; and Alfonso Solórzano, who acquired the tires for us and aided us in many other ways.

We would also like to thank INFONAC, especially Antonio Flores and Sergio Martínez of the Fisheries Division, for supporting our work, cutting much red tape, and providing us with weekend living quarters and laboratory space. John Matsui, Jeffrey Baylis, William Rogers, and Margaret Matsui were of great help in formulating and discussing ideas. Margaret Matsui, Teriann Asami, and Emily Reid also assisted us in preparing the manuscript and illustrations.

This research was supported in part by NSF Grant GB32192X to George W. Barlow, by NSF Predoctoral Grant GB41091 to Kenneth R. McKaye, and by the Center for Latin American Studies (UC Berkeley) Grant-in-Aid to K. R. McKaye. Special thanks go to George W. Barlow who reviewed the manuscript and made many helpful suggestions.

Summary

A small artificial habitat constructed of tires and concrete blocks was placed in Laguna de Jiloá, a small crater lake in Nicaragua, to determine the feasibility of habitat improvement as a means of increasing the productivity of a tropical freshwater fishery. During the seven week study period, from 29 March to 19 May, 1974, twelve of the thirteen fish species known in the lake appeared at the artifical habitat, including all ten of the important food species. The mean density of fishes at the artificial habitat increased seven-fold over the densitites of similar areas lacking an artificial habitat, and it approached the levels found in the prime natural habitat in the lake. Species diversity at the artificial habitat was higher than in any other area of the lake.

Possible explanations of the success of the artificial habitat in attracting the fishes are offered and recommendations for the design, construction, and placement of future artificial habitats are made. Other possible means for increasing fishery productivity are mentioned.

The utilization of properly constructed and placed artificial habitats is a realistic means of increasing the productivity of the lake fisheries of Nicaragua and similar bodies of water.

Resumen

Un pequeño habitat artificial, construido con llantas y bloques de concreto, fue colocado en la Laguna de Jiloá, una laguna cratérica nicaragüense, para determinar la posibilidad de mejorar el habitat para aumentar la productividad de una pesquería dulceacuícola tropical. Durante las 7 semanas de estudio, del 29 de Marzo al 19 de Mayo de 1974, doce de las 13 especies de peces conocidos de Jiloá aparecieron en el habitat artificial, incluyendo las 10 especies importantes como alimento. La densidad media de peces en dicho habitat fue 7 veces mayor que en áreas adyacentes carentes del habitat artificial, y se aproximó a niveles como en los mejores habitats de la laguna. También, la diversidad de especies fue mayor que en cualquier otra parte de la laguna.

Se ofrecen posibles explicaciones con respecto al éxito que tuvo el habitat artificial en atraer los peces, así como recomendaciones para el diseño, construcción y emplazamiento de habitats artificiales en el futuro. Se mencionan otras posibilidades para aumentar la productividad pesquera.

La utilización de habitats artificiales construidos y situados adecuadamente es un medio realista para aumentar la productividad pesquera en lagos nicaragüenses, y de otras partes.

Literature Cited

Barlow, G. W. 1973. Competition between color morphs of the polychromatic Midas cichlid *Cichlasoma citrinellum*. Science 179:806–807.

Barlow, G. W. 1974. Contrasts in social behavior between Central American cichlid fishes and coral reef surgeon fishes. Amer. Zool. 14:9–34.

Barlow, G. W. 1976. The Midas cichlid in Nicaragua. *In:* Investigations of the Ichthyofanua of Nicaraguan Lakes. T. B. Thorson, ed. School of Life Sciences, Univ. Nebr.–Lincoln.

Barlow, G. W., J. R. Baylis and D. A. Roberts, 1976. Chemical analyses of some crater lakes in relation to adjacent Lake Nicaragua. *Ibid.*

Baylis, J. R. 1973. Informe preliminar de la expedición de campo Barlow-Baylis-McKaye. INFONAC, Boletín Informativa de Pesca 5(1):14–22.

Buchanan, C. C. 1973. Effects of an artificial habitat on the marine sport fishery and economy of Murrells Inlet, South Carolina. Mar. Fish. Rev. 35(9):15–22.

Carlisle, J. G., C. H. Turner and E. E. Ebert. 1964. Artificial habitat in the marine environment. Cal. Dept. Fish and Game, Fish .Bull. 124.

INFONAC. 1971. Las pesquerías y los recursos pesqueros del Gran Lago de Nicaragua. Informe preliminar sobre las pesquerías del Lago de Nicaragua. Boletín Informativo de Pesca 3(1):1–13. Instituto de Fomento Nacional, División de Pesca, Managua.

INFONAC. 1974. Informe sobre los resultados del programa de investigación de los recursos pesqueros del Lago de Nicaragua. Instituto de Fomento Nacional, División de Pesca, Managua.

Lin, S. Y. 1961. Informe al gobierno de Nicaragua sobre desarrollo de un proyecto de pesquerías continentales en dicho país. Informe FAO 1347:1–21.

McKaye, K. R. and L. Hallacher. 1973. The Midas cichlid of Nicaragua. Pacific Discovery 26(5):1–8.

Randall, J. E. 1963. An analysis of the fish populations of artificial and natural reefs in the Virgin Islands. Carr. J. .Sci. 3(1):31–47.

Riedel, D. R. 1964. Informe al gobierno de Nicaragua sobre mejoramiento de las técnicas de pesca en el Lago de Managua y otras aguas continentales, 1961–1962. Informe FAO 1885:1–46.

Rounsefell, G. A. and W. H. Everhart. 1953. Fishery Science: Its Methods and Applications. John Wiley & Sons, Inc. New York.

Simberloff, D. S. and E. O. Wilson. 1970. Experimental zoogeography of islands. A two-year record of colonization. Ecology 51(5):934–937.

Stone, R. B. 1972. Artificial reefs of waste material for habitat improvement. Mar. Pollut. Bull. 3(2):27–28.

Stone, R. B. 1973. Artificial reefs and coastal fishery rescources. *In*: Proc. 10th Space Congress, Canaveral Council of Tech. Soc.

Stone, R. B., C. C. Buchanan and F. W. Steimle. 1974. Scrap tires as artificial reefs. U.S. Env. Prot. Agency Summary Report SW–119.

Turner, C. H., E. E. Ebert and R. R. Given. 1969. Man-made reef ecology. Cal. Dept. Fish and Game, Fish Bull. 146.

Villa, J. 1968. Una teoría sobre el origen de los peces de Xiloá. Rev. Univ. Centro Amer. 1:202–214.

Zaret, T. M. and R. T. Paine. 1973. Species introduction in a tropical lake. Science 182:449–455.