The Effects of Aeration on the Shoreline Fishes of a Eutrophic Florida Lake

by

Andrew J. Leslie, Jr., Larry E. Nall, and
Don C. Schmitz

Florida Department of Natural Resources
Bureau of Aquatic Plant Research and Control
3915 Commonwealth Boulevard
Tallahassee, Florida 32399

1986

Abstract--Highly eutrophic Lake Brooker (10.5 ha) in central Florida was aerated using ceramic microporous diffusers coupled to four one-half horsepower air pumps. The system was run continuously in the two year aeration period--three pumps operated flawlessly, one pump failed twice. Aeration was sufficient to turn over the lake volume every 7-11 days. The fish community was electrofished every two months for one year before and two years after the multiple-inversion aeration system was turned on. We found that total catch per hour electrofishing increased 50%, most of the increase was due to bluegill, redear sunfish, dollar sunfish, and threadfin shad. Catches of largemouth bass, bowfin, brook silverside, lake chubsucker, and yellow bullhead declined. Declines in catches of largemouth bass, lake chubsucker, and yellow bullhead may be related to oxygenation of previously anoxic offshore habitat. Significant decreases in condition factor (KTL) of larger fishes, indicative of increased numbers or crowding, occurred in the aeration years, but an increase in young largemouth bass occurred in aeration year two, with concomitant reductions in small bluegill. Although the population was still in a state of flux, it is likely that significant overcrowding will not occur if largemouth bass reproduce in similar magnitudes in subsequent years.

Introduction

Cultural eutrophication is one of the major problems affecting the water resources of Florida (Brezonik, 1969; Brezonik and Shannon, 1971). The semitropical-tropical climate and the generally shallow, clear-water nature of Florida lakes magnify the effects of enrichment. Problems associated with introduction of anthropogenic wastes in water bodies include: increased sedimentation rates, phytoplankton blooms (predominantly bluegreen algae), increased biomass of aquatic plants, and deterioration of water quality that can result in fish kills and human health hazards. Anaerobic conditions predominate throughout extensive areas of highly eutrophic lakes (Hutchinson, 1975). Such conditions reduce available habitat for fishes and invertebrates (Gebhart and Summerfelt, 1976) and are conducive to production of toxic gasses and mobilization of nutrients and heavy metals from the hydrosoil into the water column (Burns, 1972; Cole, 1975; Hutchinson, 1975; Wetzel, 1975). Aeration shows promise as a lake restoration technique to relieve many of the problems associated with hypolimnetic anoxia. Two strategies were delineated by Fast et al. (1973): 1) destratification--the entire lake is mixed, and 2) hypolimnetic aeration--stratification is maintained while oxygenating the hypolimnion. Maintenance of stratification avoids recirculation of hypolimnetic nutrients that may promote undesirable increases in algal production. Hooper et al. (1952) used destratification as an alternative to fertilization for increased fishery yields. They found that 52% of the available hypolimnetic phosphorus was transferred to the surface waters in the first three days of mixing, and that the carrying capacity of the lake was increased, possibly beyond that expected through the addition of agricultural fertilizers. Aeration has been used successfully to relieve low dissolved oxygen conditions and prevent winter-kill of fishes in northern lakes (McWilliams, 1981). This technique can restore oxygen to the hypolimnion and lower concentrations of reduced compounds that are toxic or repelling to fishes (Gebhart and Summerfelt, 1976; Carr and Martin, 1978). Although generally improving aquatic habitats, aeration can have detrimental effects. Increases in turbidity and nutrient concentrations in the water column can occur if the bottom sediments are disturbed (Carr and Martin, 1978). Under some circumstances, hypolimnetic mixing has resulted in oxygen depletion of overlying water layers causing fish kills (Haynes, 1973; Pastorok et al., 1980). Results in Florida have been rather positive to date. Improved dissolved oxygen conditions, decreases in the magnitude of algal blooms with a shift in species composition from bluegreen algae to green algae and diatoms, and although not quantified, a decrease in bottom muck was apparent to field personnel in Lake Weston (Bateman and Laing, 1977; Kaleel and Gabor, 1978). Similar effects on phytoplankton and water quality were observed in other parts of the world (Sirenko et al., 1972; Pastorok et al., 1980).

Laing (1979) reported that his multiple inversion aeration system is capable of moving 1.4 million liters of water from the lake bottom to the surface per hour per horsepower (HP). He reported 11 m^3 of water per minute rising to the surface in 1.8 m of water using 0.33 HP--the same unit moved 45 m^3 per minute at 3.6 m depth. This aeration system uses microporous ceramic diffusers that emit microscopic bubbles. It is important that oxygen is brought to the sediment-water interface. Multiple inversion equipment designed by Laing has this capability, and Carr and Martin (1978) reported that the aeration efficiency (weight of oxygen transferred per HP-hour) of diffusers supplied by Laing was two-fold greater than perforated pipe (2 kg O_2/HP-hour versus 1 kg O_2/HP-hour). Approximately 90% of the air bubbles emitted by the diffusers dissolve causing bottom water to float to the surface. The remaining 10% of the bubbles rise to the surface in a slender column. The smaller the diameters (and consequent larger cumulative surface area), the greater the quantity of water moved to the surface. This bottom water spreads out in a thin sheet at the surface, flows to the shoreline and then descends and moves towards the diffusers oxygenating the benthos (Laing, 1974).

This study was designed to evaluate the effects of aeration, using a multiple inversion system, on the shoreline fishes of a highly eutrophic lake that had been experiencing fish kills for more than 10 years.

Study Area--Lake Brooker is located in Section 2, T27S R18E of Hillsborough County near Lutz, Florida. A cypress (*Taxodium ascendens*) slough system drains wetlands northeast of the lake. This 10.5 ha lake is highly eutrophic, usually has dense phytoplankton (averaging 40 mg/m^3 chlorophyll a), and major fish kills occur periodically (Young, 1978; Cowell and Dawes, 1984). The primary nutrient source to the lake is a dairy feed-lot operation several hundred meters upstream in the cypress slough. The slough was ditched from the feed lot directly to the lake and was in operation from the late 1960's until 1978 when legal action by lake homeowners stopped direct drainage. However, sheet flow through the cypress wetland still occurs after heavy rains. The lake is 3.5 m deep near the center and the hydrosoil is composed of deep anaerobic muck (Young, 1978; Crisman et al., 1984). Secchi disc reading seldom exceed 0.6 m. The littoral zone contains primarily pond cypress, tupelo (*Nyssa sylvatica*), sweet bay (*Magnolia virginiana*), and some maidencane (*Panicum hemitomon*). There is no submersed vegetation.

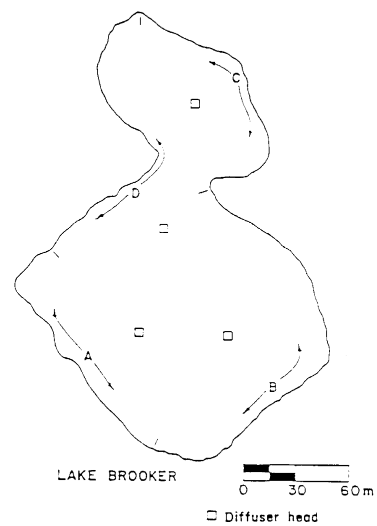

Figure 1. Electrofishing transects (A-D) and diffuser-head placement in Lake Brooker, Hillsborough County, Florida.

Methods

***Multiple - inversion apparatus*--**Clean-Flo Laboratories, 4342 Shady Oak Road, Hopkins, MN 55343, provided and installed the multiple-inversion apparatus. Four ceramic, microporous diffuser-heads were placed in the lake (Fig. 1) and coupled to four one-half HP air pumps. Diffusers were placed to achieve maximum effect over the entire lake area based on calculations by the manufacturer.

Displacement is sufficient to completely turn over the volume of Lake Brooker every 7 to 11 days. Aeration commenced in June 1981.

Fisheries appraisal--Fishes were collected by electrofishing four shoreline transects with a Smith-Root SR-16 electrofisher (Fig. 1) every two months starting July 1980. Samples were collected for one year before aeration (July 1980 - May 1981) and for two years after aeration began (July 1981 - May 1983). Catch per hour of each fish species was calculated for each bimonthly sampling period and averaged over the year. All fishes were measured (total and standard lengths, mm), weighed (to nearest gram) and released alive. Population size-structure and condition factor of bluegill (*Lepomis macrochirus*), redear (*L. microlophus*), black crappie (*Pomoxis nigromaculatus*) and largemouth bass (*Micropterus salmoides*) were compared over time using methods in Nielsen and Johnson (1983). Differences in means were tested by analysis of variance (PROC GLM, SAS Institute, 1982).

Results

Table 1. Average catch per hour electrofishing effort per bimonthly sample in Lake Brooker, Florida, from July 1980 to May 1983. Aeration commenced in June, 1981. Numbers in parentheses following annual means are % of total community catch. Ranges for sample means are in parentheses below annual mean. Annual means for a species followed by the same letter are not significantly different (Duncans Multiple Range Test, $\underline{a} \leq 0.05$).

	Pre-aeration	-----------Aeration-----------	
Species	1980-81	1981-82	1982-83
Lepisosteus platyrhincus	0.8a (0.8%)	0.6a (0.4%)	0.4a (0.2%)
Florida gar	(0-2.3)	(0-1.3)	(0-1.5)
Amia calva	1.5a (1.4%)	0.1b (0.1%)	0.1b (0.1%)
bowfin	(0-3.3)	(0-0.5)	(0-0.6)
Dorosoma petenense	15.5a (15.0%)	10.9a (7.0%)	34.6b (21.3%)
threadfin shad	(0-91.7)	(0-17.6)	(0-83.5)
Notemigonus crysoleucas	10.7ab (10.3%)	8.0b (5.1%)	15.6a (9.6%)
golden shiner	(0.8-30.5)	(0.5-29.6)	(1.7-41.9)
Notropis maculatus	0a (0%)	0a (0%)	2.7b (1.7%)
taillight shiner	---	---	(0-16.1)
Erimyzon sucetta	0.9a (0.9%)	0.1b (0.1%)	0.2b (0.1%)
lake chubsucker	(0-3.8)	(0-0.4)	(0-0.6)
Ictalurus natalis	2.1a (2.0%)	0.6b (0.4%)	0b (0%)
yellow bullhead	(0-4.7)	(0-2.7)	---
Ictalurus nebulosus	0.8a (0.8%)	0.6a (0.4%)	0.6a (0.4%)
brown bullhead	(0-4.7)	(0-2.3)	(0-2.5)
Labidesthes sicculus	3.6a (3.5%)	0.4b (0.2%)	1.8b (1.1%)
brook silverside	(0-15.8)	(0-2.3)	(0-4.4)
Lepomis gulosus	1.3a (1.2%)	1.6a (1.0%)	0.6a (0.4%)
warmouth	(0-5.3)	(0-4.1)	(0-1.7)
Lepomis macrochirus	25.1a (24.3%)	85.5b (54.9%)	47.7c (29.4%)
bluegill	(8.8-64.8)	(40.3-152.3)	(28.4-88.9)
Lepomis marginatus	1.0a (1.0%)	2.2a (1.4%)	7.6b (4.7%)
dollar sunfish	(0-5.8)	(0-10.3)	(0-37.3)
Lepomis microlophus	6.9a (6.8%)	16.3b (10.5%)	25.7c (15.8%)
redear	(0.8-20.6)	(3.4-42.0)	(9.7-45.2)
Micropterus salmoides	30.4a (29.4%)	21.6b (13.9%)	21.5b (13.3%)
largemouth bass	(4.7-63.7)	(10.7-29.3)	(7.2-35.5)
Pomoxis nigromaculatus	2.8a (2.7%)	6.9b (4.4%)	2.6a (1.6%)
black crappie	(0-12.1)	(0.6-26.4)	(0.6-7.6)
Tilapia aurea	0a (0%)	0.3b (0.2%)	0.4b (0.2%)
blue tilapia	---	(0-1.3)	(0-1.5)
Total	103.4a	155.7b	162.1b
	(38.8-166.0)	(96.5-214.3)	(63.6-252.0)

Average electrical consumption to aerate this 10.5 ha lake was 1873 kilowatts per month (range 1232 to 2413). Costs averaged $136 per month (range $87 to $184). Three of the air pumps operated flawlessly over the 24 month treatment period; one pump failed twice.

Annual average catch per hour electrofishing for both treatment years was significantly higher than the pre-aeration year (Table 1). Largemouth bass were most abundant in the pre-aeration catch followed by bluegill, threadfin shad (*Dorosoma petenense*), golden shiner (*Notemigonus crysoleucas*), and redear sunfish. Catches during the two-year

Table 2. Average catch per hour electrofishing effort per bimonthly sample in Lake Brooker, Florida, for three species of centrarchids. Aeration commenced in June, 1981. Numbers in parentheses following annual means are % of total community catch. Ranges for sample means are in parentheses below annual mean. Annual means for a species followed by the same letter are not significantly different (Duncans Multiple Range Test, $a \leq 0.05$).

	Pre-aeration	------------Aeration------------	
Species	1980-81	1981-82	1982-83
Lepomis macrochirus			
≤ 100 mm TL	5.0a (4.8%)	22.2b (14.2%)	3.1a (1.9%)
	(0-13.9)	(0.6-99.8)	(0.4-12.0)
101-150 mm TL	4.0a (3.9%)	31.6b (20.3%)	16.4c (10.1%)
	(0-9.5)	(13.0-55.9)	(12.7-21.6)
151-200 mm TL	2.3a (2.2%)	14.1b (9.0%)	15.3b (9.4%)
	(0-6.3)	(6.8-32.1)	(9.7-24.1)
201-250 mm TL	10.3a (10.0%)	16.6b (10.7)	12.8ab (7.9%)
	(3.2-27.9)	(9.1-39.6)	(5.4-35.0)
251-300 mm TL	3.5a (3.4%)	1.0b (0.6%)	0.1b (0.1%)
	(0-9.0)	(0-2.9)	(0-0.5)
Lepomis microlophus			
≤ 100 mm TL	0.1a (0.1%)	3.4b (2.2%)	1.0a (0.6%)
	(0-0.9)	(0-15.7)	(0-4.2)
101-150 mm TL	2.7a (2.6%)	5.2b (3.3%)	12.9c (8.0%)
	(0-8.6)	(0-12.5)	(6.1-9.8)
151-200 mm TL	1.9a (1.8%)	2.4a (1.5%)	8.5b (5.2%)
	(0-7.4)	(0-3.7)	(3.0-15.8)
201-251 mm TL	1.7a (1.6%)	4.2a (2.7%)	3.0a (1.8%)
	(0-7.4)	(0-8.3)	(0-8.9)
251-300 mm TL	0.5a (0.5%)	1.1a (0.7%)	0.3a (0.2%)
	(0-1.6)	(0-3.4)	(0-1.1)
Micropterus salmoides			
≤ 100 mm TL	1.2a (1.2%)	2.2a (1.4%)	2.8a (1.7%)
	(0-5.3)	(0-7.5)	(0-6.4)
101-150 mm TL	9.3a (9.0%)	4.6b (3.0%)	8.6a (5.3%)
	(0-39.2)	(0-8.9)	(1.8-22.0)
151-200 mm TL	8.7a (8.4%)	2.6b (1.7%)	2.7b (1.7%)
	(0-37.4)	(0-4.6)	(0-10.3)
201-250 mm TL	1.5a (1.4%)	2.6a (1.7%)	0.6a (0.4%)
	(0-5.3)	(0.9-6.8)	(0-1.3)
251-300 mm TL	1.6a (1.5%)	2.4a (1.5%)	1.1a (0.7%)
	(0-7.9)	(0.7-4.2)	(0-3.4)
301-350 mm TL	0.9a (0.9%)	3.6b (2.3%)	1.5a (0.9%)
	(0-2.7)	(0.7-10.3)	(0.6-3.2)
351-400 mm TL	2.6a (2.5%)	1.3b (0.8%)	2.7a (1.7%)
	(1.0-5.3)	(0-2.9)	(0.6-8.6)
401-450 mm TL	3.1a (3.0%)	1.0b (0.6%)	0.8b (0.5%)
	(0-6.8)	(0-1.8)	(0-1.3)
> 450 mm TL	1.5a (1.4%)	1.3b (0.8%)	0.7b (0.4%)
	(0-3.2)	(0-2.7)	(0-1.0)

aeration period were predominated by bluegill, followed by threadfin shad, largemouth bass, redear sunfish, and golden shiner. Catch per hour of Florida gar (*Lepisosteus platyrhincus*), golden shiner, brown bullhead (*Ictalurus nebulosus*), and warmouth (*Lepomis gulosus*) were not significantly different from the pre-aeration year. Catches of bowfin (*Amia calva*), lake chubsucker (*Erimyzon sucetta*), yellow bullhead (*I. natalis*), brook silverside (*Labidesthes sicculus*), and largemouth bass declined significantly after the aerators were turned on. Catches of threadfin shad, dollar sunfish (*Lepomis marginatus*), bluegill, and redear sunfish increased during the aeration period. The catch of black crappie (*Pomoxis nigromaculatus*) increased in aeration year one but returned to baseline levels in aeration year two. Taillight shiner (*Notropis maculatus*) were collected for the first time in May of aeration year two and blue tilapia (*Tilapia aurea*) were collected only during aeration years.

Catches of all size classes of bluegill increased more than three-fold in the first aeration year compared to the pre-aeration year; catch of large bluegill (> 200 mm TL) doubled while catches of small and intermediate bluegill (< 200 mm TL) increased almost six-fold (Table 2). Catch of bluegill decreased in aeration year two versus aeration year one, but was still about two-fold higher than pre-aeration. The decrease resulted from reduced catch per effort of bluegill < 150 mm TL. Catch of redear sunfish more than doubled in aeration year one and increased an additional 50% by aeration year two (Table 1). Trends were similar in all size classes but were significantly higher only for redear $\leq$ 150 mm TL. Catch of largemouth bass was significantly lower in both aeration years versus the pre-aeration year (Table 1). This reduction was the result of lower catch of largemouth bass 151-200 mm TL size and large fish > 400 mm TL (Table 2).

Condition factor (KTL) of bluegill < 150 mm TL was similar before and during aeration (Table 3). Condition factor of bluegill 151-250 mm TL significantly declined during aeration treatment; however, there was no decline in condition factor of large bluegill (> 250 mm TL). Condition factor of all size classes of redear sunfish was statistically similar over time. Condition factors of largemouth bass < 150 mm TL was variable but generally higher in the aeration years, but condition factors of largemouth bass 250-450 mm TL declined after aeration commenced. Condition factors of largemouth bass 150-250 mm TL and larger fish (> 450 mm TL) during aeration years were not significantly different from the pre-aeration year.

Discussion

Oxygen conditions during the pre-aeration year probably restricted use of much of the lake for non-pelagic fishes throughout the year. Based on bathymetric charts that we generated and seasonal oxygen profiles in Cowell and Dawes (1984), less than 40% of the benthic habitat had average oxygen conditions greater than 2 mg/l. Most species of fish do not tolerate oxygen concentrations less than 4 mg/l for prolonged periods, and much higher concentrations are considered necessary for activity, growth, and reproduction (Moss and Scott, 1961; Dahlberg et al., 1968; Warren et al., 1973; Gebhart and Summerfelt, 1976). In addition to low oxygen levels, there were near toxic concentrations of ammonia and hydrogen sulfide (Cowell and Dawes, 1984). Such conditions affect fish species interactions. Larger fishes which may usually forage relatively offshore remain in shallower habitats which could reduce food availability and increase predation upon young of the year and other fishes that normally find refuge here. The acute reduction of available habitat and the frequent fish kills in previous years undoubtedly were instrumental in the status of the pre-aeration fish community. We observed no fish kills in the pre-aeration year. It is likely that the recent curtailment of direct input of organics from a dairy operation could have ameliorated acute oxygen depletion to some degree by the time that this project began. In general, the bluegill population consisted of mostly large adults (> 200 mm TL) and fewer small and intermediate sizes (< 150 mm TL). Large and juvenile largemouth bass were well represented.

The most obvious effect of aeration was increased survival of smaller sunfishes and reduction in the largest individuals (> 250 mm TL). The more favorable oxygen conditions combined with fewer largemouth bass in the shoreline areas in the first aeration year may have contributed to this increase. Increased survival of young *Lepomis* spp. could lead to overcrowding and stunting (Swingle, 1950). There were some indications that this was occurring--condition factors for large bluegill, redear sunfish, and largemouth bass decreased significantly while smaller fishes in many cases showed a significant increase in condition. However, by aeration year two, it was evident that the trend of expansion of smaller bluegill had reversed, possibly as a result of the largemouth bass population cropping young bluegill. Dollar sunfish and young redear sunfish increased but were scarce relative to bluegill.

It is interesting that relatively few "rough fish" were collected during the study. An oxygen-poor environment with considerable shoreline structure (trees etc. in the water) would seem to be advantageous to gar and bowfin which are capable of utilizing atmospheric oxygen (Lagler et al., 1962). Also, few lake chubsucker were collected, but this benthic feeder had little habitat available before aeration (Carlander, 1970). Although chubsucker had not responded to the increased available habitat and

Table 3. Average annual condition factor (KTL) for three species of centrarchids captured by electrofishing in Lake Brooker, Florida. Aeration commenced in June, 1981. Numbers in parentheses following annual means are total number caught. Ranges for sample means are in parentheses below annual mean. Annual means within size classes followed by the same letter are not significantly different (Duncans Multiple Range Test, $\underline{a} \leq 0.05$).

	Pre-aeration	------------Aeration------------	
Species	1980-81	1981-82	1982-83
Lepomis macrochirus			
< 100 mm TL	1.71a (58)	1.62a (212)	1.76a (32)
	(1.65-2.01)	(1.40-2.38)	(1.52-1.81)
101-150 mm TL	1.69a (44)	1.63a (355)	1.71a (182)
	(1.40-1.85)	(1.52-1.83)	(1.57-1.78)
151-200 mm TL	1.89a (24)	1.77b (156)	1.69c (174)
	(1.65-2.13)	(1.69-1.96)	(1.61-1.81)
201-250 mm TL	2.33a (102)	2.04b (179)	1.97c (141)
	(2.06-2.52)	(1.91-2.26)	(1.95-1.99)
> 250 mm TL	2.19a (33)	1.95a (10)	2.22a (1)
	(1.92-2.42)	(1.88-2.18)	---
Lepomis microlophus			
< 100 mm TL	1.84a (2)	1.41a (42)	1.66a (12)
	---	(1.31-1.57)	(1.65-1.70)
101-150 mm TL	1.48a (25)	1.48a (60)	1.51a (145)
	(1.36-1.64)	(1.31-1.60)	(1.46-1.61)
151-200 mm TL	1.67a (21)	1.69a (27)	1.59a (96)
	(1.56-2.06)	(1.56-1.79)	(1.56-1.64)
201-250 mm TL	1.89a (18)	1.86a (46)	1.83a (33)
	(1.80-2.39)	(1.79-2.28)	(1.79-1.91)
> 250 mm TL	1.87a (5)	1.80a (11)	1.71a (3)
	(1.74-2.17)	(1.68-1.96)	(1.39-1.87)
Micropterus salmoides			
< 100 mm TL	1.06a (12)	1.50b (20)	1.15a (28)
	(0.93-1.30)	(0.93-1.73)	(0.80-1.33)
101-150 mm TL	0.94a (82)	1.04b (51)	1.03b (95)
	(0.92-1.08)	(0.88-1.13)	(0.97-1.26)
151-200 mm TL	1.06a (91)	1.05a (28)	1.09a (31)
	(0.98-1.12)	(0.99-1.08)	(1.00-1.18)
201-250 mm TL	1.19a (16)	1.22a (27)	1.18a (6)
	(1.07-1.37)	(1.03-1.36)	(1.04-1.41)
251-300 mm TL	1.28a (12)	1.30a (28)	1.16b (13)
	(1.27-1.40)	(1.17-1.41)	(1.11-1.22)
301-350 mm TL	1.64a (12)	1.33b (39)	1.28b (30)
	(1.36-2.26)	(1.19-1.55)	(1.18-1.51)
351-400 mm TL	1.52a (23)	1.52a (14)	1.32b (30)
	(1.33-1.65)	(1.41-1.79)	(1.26-1.61)
401-450 mm TL	1.56a (28)	1.48ab (11)	1.41b (10)
	(1.45-1.67)	(1.30-1.60)	(1.16-1.64)
451-500 mm TL	1.65a (12)	1.67a (11)	1.55a (2)
	(1.57-1.79)	(1.46-1.75)	(1.51-1.60)
> 500 mm TL	1.80a (3)	1.79a (6)	1.82a(6)
	(1.78-1.83)	(1.57-2.06)	(1.76-1.88)

the additional access to benthic macroinvertebrates (Cowell and Dawes, 1984), increases were seen for redear sunfish and dollar sunfish which are insectivorous and/or capable of utilizing benthic macroinvertebrates (McLane, 1955; Wilbur, 1969). With the possible exception of brook silverside, planktivorous fishes have not reflected the decline in crustacean zooplankton reported by Cowell and Dawes (1984). Although freshwater fishes have clear degrees of specializations in feeding morphology, behavior, habitat, and actual food consumed (Keast and Webb, 1966), many are quite opportunistic, their choice of food resources are dependent on availability (Larkin, 1956). For example, Ingram and Ziebell (1983) demonstrated that the primarily planktivorous threadfin shad can shift to feeding on benthic chironomids by search and suction if the reward rate is greater. Keast (1977) found that bluegill tend to move from one resource to another depending on peaks in prey abundance. Cowell and Dawes (1984) have shown that benthic macroinvertebrate numbers in Lake Brooker have not decreased but did increase in diversity.

Other researchers have demonstrated an expansion of the vertical distribution of fishes after aeration. Gebhart and Summerfelt (1976) noted increased depth distributions after total available habitat (as defined by the 2 mg/l isopleth) increased from 53% to 99% as a result of aeration of Lake Arbuckle, Oklahoma. Fast (1968) and Shapiro and Pfannkuch (1973) also noted habitat expansion by fishes after aeration.

In our study, available habitat increased from less than 40% to virtually 100% of lake benthic area, and coincided with declines in largemouth bass and large bluegill. The declines were modest, and may be in part due to the larger fishes taking advantage of the deepwater habitat now available. Other authors have noted that largemouth bass and other species segregate into nearshore and offshore populations as water temperatures increase (Parker and Hasler, 1959; Gerking, 1962; Lewis and Flickinger, 1967). Van Den Avyle (1976) noted that non-random movements and territoriality can affect catchability. It is possible that the decline in catch per hour of largemouth bass, yellow bullhead, and lake chubsucker reflect a portion of the population moving offshore and thus reducing their vulnerability to electrofishing.

Although total numbers of largemouth bass > 400 mm TL declined and numbers of small bluegill increased in aeration year one versus the pre-aeration year, the fact that capture rates of largemouth bass did not further decline in aeration year two is noteworthy because a significant reduction in small bluegill also occurred. The reduction in small bluegill was important because largemouth bass have little hope of successfully defending their nest against the large numbers of small sunfish that typically occur in stunted sunfish populations (Heidinger, 1975). Apparently, it is not unusual for relatively low numbers of young largemouth bass to be produced following years with high or abnormally high production of young bass (Swingle and Swingle, 1967). Swingle (1956) believes that largemouth bass respond to environmental changes more slowly than bluegill.

Condition factors for largemouth bass and bluegill were higher than those reported by Colle and Shireman (1980) for macrophyte-infested Florida lakes for all size classes except the two smallest size classes of largemouth bass. Redear sunfish condition factors were similar to those reported by Colle and Shireman (1980).

The multiple-inversion apparatus proved reliable over the two year aeration period--a single pump failed twice. Capital outlay for a similar aeration device, installed, is approximately $11,000 or about $300 per month financed for four years at current interest rates. Cost for operation of the four one-half HP aerators averaged $136 per month. Combining the electrical costs and financed capital outlay and dividing equally among the ten homeowners yields $43.60 per month per homeowner (plus maintenance). This seems a nominal investment considering the dramatic improvement in the lake environment and the effects on the fish community.

To summarize, we found that total catch per hour electrofishing increased 50% during the two year aeration period. Most of the increase was due to bluegill, redear sunfish, dollar sunfish, and threadfin shad. Slight decreases in condition of larger fishes, indicative of increased numbers or crowding occurred, but the largemouth bass population remained relatively stable and a reduction in small bluegill occurred in aeration year two. Although the fish community is still in a state of flux, it is likely that largemouth bass are capable of preventing significant overproduction of small bluegill.

Literature Cited

Bateman, J.M. and R.L. Laing. 1977. Restoration of water quality in Lake Weston, Orlando, Florida. Journal of Aquatic Plant Management 15:69-73.

Brezonik, P.L. 1969. Eutrophication: The process and its modeling potential. Pages 68-110 in Proceedings of a workshop on modeling the eutrophication process. University of Florida, Gainesville, USA.

Brezonik, P.L. and E.E. Shannon. 1971. Trophic state of lakes in north-central Florida. Water Resources Research Center, Publication Number 13, University of Florida, Gainesville, USA.

Brynildson, O.M. and S.L. Serns. 1977. Effects of destratification and aeration of a lake on the distribution of planktonic Crustacea, yellow perch and trout. Technical Bulletin 99. Wisconsin Department of Natural Resources, USA.

Burns, N.M. 1972. Oxygen-nutrient relationships within the central basin of Lake Erie. In H.E. Allen and J.R. Kramer, Editors. Nutrients in natural waters. John Wiley and Sons, New York, New York, USA.

Carlander, K.D. 1970. Handbook of freshwater fishery biology. Volume one. Iowa State University Press, Ames, Iowa, USA.

Carr, J.E. and D.F. Martin. 1978. Aeration efficiency as a means of comparing devices for lake restoration. Journal of Environmental Science and Health A 13:73-85.

Cole, G.A. 1975. Textbook of Limnology. C.V. Mosby, Saint Louis, Missouri, USA.

Colle, D.E. and J.V. Shireman. 1980. Coefficient of condition for largemouth bass, bluegill, and redear sunfish in hydrilla-infested lakes. Transactions of the American Fisheries Society 109:521-531.

Cowell, B.C. and C. J. Dawes. 1984. Algal studies of eutrophic Florida lakes: The influence of aeration on the limnology of a central Florida lake and its potential as a lake restoration technique. Final Report Florida Department of Natural Resources, Tallahassee, USA.

Crisman, T.L., P.R. Scheuerman, A. Keller, U.A.M. Crisman, D.J. Medina, J.S. Bays, J.S. Beaver, and M.W. Binford. 1984. Algal management through lake aeration. Final Report Florida Department of Natural Resources, Tallahassee, USA.

Dahlberg, M.L., D.L. Shumway, and P. Doudoroff. 1968. Influence of dissolved oxygen and carbon dioxide on swimming performance of largemouth bass and coho salmon. Journal of the Fisheries Research Board of Canada 25:49-70.

Fast, A.W. 1968. Artificial destratification of El Capitan Reservoir by aeration. Part 1: Effects on chemical and physical parameters. Fisheries Bulletin 141. California State Department of Fish and Game, USA.

Fast, A.W., B. Moss, and R.G. Wetzel. 1973. Effects of artificial aeration on the chemistry and algae of two Michigan lakes. Water Resources Research 9:624-647.

Gebhart, G.E. and R.C. Summerfelt. 1976. Effects of destratification on depth distribution of fish. Journal of the Environmental Division of the American Society of Civil Engineers 102:1215-1228.

Gerking, S.D. 1962. Production and food utilization in a population of bluegill sunfish. Ecological Monographs 32:31-78.

Hall, D.J., W.E. Cooper, and E.E. Werner. 1970. An experimental approach to the production dynamics and structure of freshwater animal communities. Limnology and Oceanography 15:839-928.

Haynes, R.C. 1973. Some ecological effects of artificial circulation on a small eutrophic lake with particular emphasis on phytoplankton 1. Kezar Lake experiment, 1968. Hydrobiologia 43:463-504.

Heidinger, R.C. 1975. Life history and biology of the largemouth bass. Pages 11-20 in H. Clepper, editor. Black bass biology and management. Sport Fishing Institute, Washington, District of Columbia, USA.

Hooper, F.F., R.C. Ball, and H.A. Tanner. 1952. An experiment in the artificial circulation of a small Michigan lake. Transactions of the American Fisheries Society 82:222-241.

Hutchinson, G.E. 1975. A treatise on Limnology. Volume 1, Part 2. Chemistry of lakes. John Wiley and Sons, New York, New York, USA.

Ingram, W. and C.D. Ziebell. 1983. Diet shifts to benthic feeding by threadfin shad. Transactions of the American Fisheries Society 112:554-556.

Kaleel, R.T. and A.E. Gabor. 1978. Lake Weston restorative evaluation. Final Report Orange County Pollution Control Department, Orlando, Florida, USA.

Keast, A. 1977. Mechanisms expanding niche width and minimizing intraspecific competition in two centrarchid fishes. Evolutionary Biology 10:333-395.

Keast,A. and D. Webb. 1966. Mouth and body form relative to feeding ecology in the fish fauna of a small lake, Lake Opinicon, Ontario. Journal of the Fisheries Research Board of Canada 23:1845-1874.

Lagler, K.F., J.E. Bardach, and R.R. Miller. 1962. Ichthyology. John Wiley and Sons, New York, New York, USA.

Laing, R.L. 1974. A non-toxic lake management program. Hyacinth Control Journal 12:41-43.

Laing, R.L. 1979. The use of multiple inversion and Clean-Flo lake cleanser in controlling aquatic plants. Journal of Aquatic Plant Management 17:33-38.

Larkin, P.A. 1956. Interspecific competition and population control in freshwater fish. Journal of the Fisheries Research Board of Canada 13:327-342.

Lewis, W.M. and S. Flickinger. 1967. Home range tendency of the largemouth bass (*Micropterus salmoides*). Ecology 48:1020-1023.

McLane, W.M. 1955. The fishes of the St. Johns River system. Doctoral Dissertation University of Florida, Gainesville, USA.

McWilliams, D. 1981. Aeration of winterkill lakes. Completion Report, Study 104. Fisheries Section, Iowa Conservation Commission, USA.

Moss, D.D. and D.C. Scott. 1961. Dissolved-oxygen requirements of three species of fish. Transactions of the American Fisheries Society 90:377-393.

Neves, R.J. 1975. Zooplankton recolonization of a lake cove treated with rotenone. Transactions of the American Fisheries Society 104:390-393.

O'Brien, W.J. 1979. The predator-prey interaction of planktivorous fish and zooplankton. American Scientist 67:572-581.

Parker, R.A. and A.D. Hasler. 1959. Movements of some displaced centrarchids. Copeia 1959:11-18.

Pastorok, R.A., T.C. Ginn, and M.W. Lorenzen. 1980. Review of aeration/circulation for lake management. Pages 124-133 in Restoration of lakes and inland waters. United States Environmental Protection Agency USEPA 440/5-81-010.

Shapiro, J., V. Lamarra, and M. Lynch. 1975. Biomanipulation: An ecosystem approach to lake restoration. Pages 85-95 in P.L. Brezonik and J.L. Fox, editors. Proceedings of a symposium on water quality management through biological control. University of Florida and the United States Environmental Protection Agency, Gainesville, Florida, USA.

Shapiro, J. and J.O. Pfannkuch. 1973. The Minneapolis chain of lakes. A study of urban drainage and its effects. Interim Report 9. Limnological Research Center, University of Minnesota, USA.

Sirenko, L.A., N.V. Avil'tseva, and V.M. Chernousova. 1972. Effect of artificial aeration of pond water on the algal flora. Hydrobiological Journal 8:52-58.

Swingle, H.S. 1950. Relationships and dynamics of balanced and unbalanced fish populations. Alabama Polytechnic Institute, Agricultural Experiment Station Bulletin 254, USA.

Swingle, H.S. 1956. Appraisal of methods of fish population study- Part IV Determination of balance in farmponds. Transactions of the Twenty-first North American Wildlife Conference. Pages 298-318.

Swingle, H.S. and W.E. Swingle. 1967. Problems in dynamics of fish populations in reservoirs. Pages 229-243 in C.E. Lane, Jr., Chairman. Reservoir Fishery Resources Symposium, University of Georgia, Athens, USA.

Van Den Avyle, M.J. 1976. Analysis of seasonal distribution patterns of young largemouth bass (*Micropterus salmoides*) by use of frequency-of-capture data. Journal of the Fisheries Research Board of Canada 33:2427-2432.

Warren, C.E., P. Doudoroff, and D.L. Shumway. 1973. Development of dissolved oxygen criteria for freshwater fish. United States Environmental Protection Agency Ecological Research Series EPA-R3-73-019.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Company, Philadelphia, Pennsylvania, USA.

Wilbur, R.L. 1969. The redear sunfish in Florida. Florida Game and Freshwater Fish Commission Fishery Bulletin 5, Tallahassee, USA.

Young, S.N. 1978. Relationship between abundance of crustacean zooplankton and trophic state in fourteen central Florida lakes. Masters Thesis, University of South Florida, Tampa, USA.