ENTRAINMENT SUSCEPTIBILITIES OF FISHES INHABITING THE LOWER PORTION OF GRAND LAKE, OKLAHOMA

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Chapter I

INTRODUCTION

This thesis is comprised of one manuscript written for submission to the Transactions of the American Fisheries Society. Chapter I is an introduction to the rest of the thesis. The manuscript is complete as written and does not require additional support material. The manuscript is contained in Chapter II and is titled 'Entrainment susceptibilities of fishes inhabiting the lower portion of Grand Lake, Oklahoma.'

Chapter II

ENTRAINMENT SUSCEPTIBILITIES OF FISHES INHABITING THE LOWER PORTION OF GRAND LAKE, OKLAHOMA

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Abstract.-I documented the seasonal dynamics of juvenile and adult fish in the vicinity of the Pensacola Dam hydropower facility on Grand Lake, Oklahoma, to determine species-specific entrainment susceptibilities. Fishes in Grand Lake were sampled monthly from August 1988 to July 1989 using gill nets, trap nets, and electrofishing gear. Water quality profiles were recorded concurrently. I used techniques typically used to quantify foraging preferences of selective predators to estimate the entrainment susceptibilities of individual species to non-selective "predation" by hydropower intakes. Relative abundances of fishes in Grand Lake were compared to relative abundances of fishes entrained (obtained from a concurrent study estimating entrainment rates) using Strauss' electivity index to determine species-specific entrainment susceptibilities. Wilcoxon's signed-rank test was used to incorporate sampling error and test statistical significance. Fishes were not entrained at rates reflecting their relative abundance in the lake. Only 8 of the 25 species collected in Grand Lake were entrained. Entrainment of gizzard shad exceeded expectations based on their relative abundance in the reservoir and it was the only species significantly susceptible to entrainment. Susceptibility to entrainment of all other species was negative or proportional to relative abundance. High midwinter entrainment of gizzard shad resulted from their

habitation of deep water proximal to the turbine intakes and cold-induced torpor. Entrainment was size-selective being skewed to enhance the selection of small fish. Occasional entrainment of white crappie and channel catfish was probably a result of the predilection of these species for structural cover in deep water as afforded by the forebay of the intake structure. Hypolimnetic anoxia associated with summer stratification precluded entrainment of all species during summer.

Extensive research on the effects of hydropower on adult and juvenile fish has been conducted in coldwater systems. These studies addressed upstream and downstream passage associated with the completion of life cycles of anadromous salmon and shad in the Pacific Northwest and New England (e.g., Schoeneman et al. 1961; Raymond 1979; Bell and Kynard 1985). Fish passing through hydropower plants may be subject to both immediate and delayed mortality. Common forms of immediate mortality include decapitation and crushing; delayed forms include deaths resulting from internal injuries, sudden pressure changes, and predation (Cramer and Oligher 1964; Cada 1988). Of no less importance are the fishes merely displaced downstream from the dam, because they are lost from the reservoir fishery.

Entrainment in warm-water reservoirs has not been studied because of the absence of obligatory migrants in these systems. However, many warmwater reservoirs contain populations of once-anadromous, now land-locked species (e.g., striped bass, _Morone saxatilis_; Scruggs 1955) which range widely (Pflieger 1975) and are subject to entrainment. In addition, many reservoir fishes are pelagic and nomadic (Pflieger 1975), rendering them vulnerable to entrainment. Grand Lake O' the Cherokees (Grand Lake) is an 18,818-hectare multi-purpose hydropower impoundment completed by the Grand River Dam Authority (GRDA) in 1940 by inundation of the Grand (Neosho) River by the Pensacola Dam. Grand

Lake was authorized by Congress to provide flood control, recreation, and hydropower, and the hydroelectric generating plant was granted a 50-year operating license. The license expired in 1988 and required renewal for the GRDA to continue hydropower generation. Relicensing required the GRDA to prepare an environmental impact assessment of the hydropower project. This assessment provided an opportunity to examine the effects of entrainment by the hydropower plant on adult and juvenile fishes in a warm-water reservoir.

The only previous study on entrainment of adult and juvenile warm-water fish was on the Ohio River (Greenup Dam, Vanceburg, Kentucky). Seasonal spatial and temporal distributions of fishes remained unchanged throughout the nine month duration of the study. At least 80 percent of the fish detected hydroacoustically immediately upstream of the forebay trashracks were entrained into the turbine gallery. Of those entrained, 93 percent were gizzard shad (Dorosoma cepedianum) and freshwater drum (Aplodinotus grunniens). Sport fish were entrained at a lower rate than expected as judged by their relative abundances upstream from the dam. However, no work was done during the winter months when streamflows peaked and entrainment potentials probably were greatest (Olson et al. 1988).

Simply documenting the presence of fishes in areas of potentially high entrainment risk does not allow estimation of entrainment because the assumption of equal species-specific entrainment susceptibility is likely erroneous (Helvey 1985). Entrainment susceptibility is regulated by attraction to intake structures, taxis to current, and body length due to the relationship between swimming speed and body length (Jones et al. 1974). Behavioral activities of a species may enhance or diminish entrainment potential, but species-specific entrainment susceptibilities have only been inferred by investigating behaviors and life histories (Helvey 1985).

Estimates of entrainment susceptibility can be made by comparing relative abundances of fishes subject to entrainment to the relative abundances of fishes entrained. My goal was to assess the possible effects of hydropower generation on fish populations in the lower portion of Grand Lake. Accordingly, my objectives were to: determine if relative abundances of fishes in the lower portion of Grand Lake were reflected by species-specific entrainment rates; determine if seasonal distribution of fishes contributed to the entrainment susceptibilities of fishes in the lower portion of Grand Lake; and determine if temporal differences in water quality affected entrainment rates of fishes in the lower portion of Grand Lake.

STUDY SITE

Grand Lake is a monomictic reservoir in northeastern Oklahoma with a mean depth of 13 meters and a maximum depth of about 45 meters. It has a capacity of 1,672,000 acre-feet at the top of the power pool (elevation 745 feet MSL). It has a shoreline of of 998 km and is about 88 km long from the confluence of the Neosho and Spring rivers in the north to the dam in the south. It has an irregular shoreline with numerous bays and small coves and has a shoreline development index value of 43.1. The average discharge during 44 years of record (1939-1981) was 6809 cfs (Oklahoma Water Resources Board 1984). This equates to a flushing rate of about once every 100 days.

The hydropower intakes are housed in a structure about 20 meters off the face of the dam (Figure 1). Three 4.6-m diameter penstocks supply water to six-14,400-kw generators. Net generating head is about 120 ft. The top of the intake is at elevation 705 feet MSL and the bottom is at elevation 682 feet MSL. The intake structure is about 35 m long and distance between the upstream trashracks and the intakes is about 6 m.

METHODS

Field techniques

The fish assemblage inhabiting Grand Lake in the vicinity of Pensacola Dam was sampled at about monthly intervals from August 1988 to July 1989 using three gear types (gill nets, trap nets, and electrofishing). The study area encompassed the lower section of Grand Lake within about 3 km of the hydroelectric facility (Figure 2). The area was divided into 22 sampling blocks, each roughly 500-m square (Figure 2).

From August through December 1988, twelve monofilament-nylon experimental gill nets were set each month. The nets were 2.4 m deep, 91.4 m long, and included six 15.2-m panels with bar mesh sizes of 3.81, 5.08, 6.35, 7.62, 8.89, and 10.16 cm. A stratified-random sampling design was used to select net locations and depths, with emphasis placed on the four blocks in the vicinity of the hydropower intakes (blocks 1, 2, 5, and 6; Figure 2). Four nets were set at randomly selected locations in these blocks, and the remainder were set in randomly selected blocks throughout the study area. Four nets were set at the surface, four at mid-water, and four at the bottom. Nets were fished for 24 hours. All captured fish were removed, identified, weighed (g), measured (mm total length), and released. Each net set constituted one unit of effort. Effort was increased to 16 net sets per month from January through July 1989 by the addition of four nets in block 1.

Ten trap nets were set in the study area on each sampling date. Trap nets were set in coves in sampling blocks 1 (2 nets), 4 (4 nets), 8 (3 nets), and 13 (2 nets). The nets were constructed of tarred 1.3-cm nylon mesh stretched over two 1.8x0.9-m frames and four 0.76-m diameter hoops; a single 12.7-m lead extended perpendicularly from the mouth of each net. The trap nets were set perpendicular to shore with their leads extending towards shore and fished for 24 hours. All captured fish were removed, identified, weighed, measured, and released. Each net set constituted one unit of effort in the catch-rate analyses.

A commercially-produced 6.1-m aluminum electrofishing boat (Coffelt Manufacturing, Inc., Flagstaff, AZ) was used to complete 10 standardized electrofishing transects each month from August through December 1988. Pulsed direct current (300 volts, 6 to 8 amperes, 60% pulse width, 80 pulses per second) was applied in 500-m linear transects. Transects were completed at randomly selected stations stratified as follows: three along the east shoreline (blocks 4, 8, and 13), one along the west shoreline (blocks 1, 5, 9, 14, 19, 20, and 22), one along the face of the dam in block 1, one along the shoreline in block 1, and four in open-water blocks. Two of the open-water transects were in the vicinity of the hydropower intakes (blocks 1, 2, 5, and 6; Figure 1). All captured fish were identified, weighed, measured, and released. Total catches of each species in each transect will constitute catch-per-unit-effort rates (i.e., number per transect). Effort was increased to 12 electrofishing transects per month from January through July 1989 by the addition of two open water transects in block 1.

Water quality profiles of the water column about 150 m directly upstream from the hydroelectric facility were recorded in association with fish sampling. Water temperature, dissolved oxygen concentration, pH, and conductivity were measured with a Hydrolab Surveyor II at 1-m intervals from the surface to a depth of 20 m; additional measurements were taken at 5-m intervals to the bottom.

Analyses

Mean catch-per-unit-effort (CPUE) rates (by gear) of all species in aggregate and of species composing >1% of total catch were plotted over time to assess seasonal trends in abundance at the study sites. A catch index value combining the two most effective gear types for each species was calculated for each sampling date to facilitate evaluation of seasonal trends in abundance of major species; the index incorporated the relative magnitude of gear-specific catch rates by date and treated both gears equally. Monthly gear-specific CPUE rates were divided by the highest CPUE of that gear type obtained over the study duration to calculate a relative CPUE value ranging from 0 to 1. The catch index value was the mean of the two relative CPUE rates. For example: Monthly index value = [(Gear 1 monthly CPUE/Gear 1 highest observed CPUE)+(Gear 2 monthly CPUE/Gear 2 highest observed CPUE)]/2. All three gear types were used to calculate the index value for all species in aggregate. The index values were used only to facilitate evaluation of seasonal trends; they were not used in the quantitative analyses.

Analysis of variance was used to test whether significant differences existed in mean CPUE rates of all species among sampling dates. Duncan's multiple comparison procedure was used to identify months during which CPUE rates were significantly different (alpha = 0.05). Length-frequency distributions of fishes collected in Grand Lake were constructed for comparison with fishes collected in the entrainment samples.

A concurrent study conducted by the Oklahoma Cooperative Fish and Wildlife Research Unit estimated monthly entrainment of fishes at the Pensacola Dam hydropower facility (Fisher and Zale 1990). Entrained fish were collected in modified fyke nets positioned in the draft tubes. The densities of entrained fish were multiplied by monthly discharges to estimate total monthly entrainment. A total of nine species were entrained (gizzard shad, white crappie (Pomoxis annularis), channel catfish (Ictalurus punctatus), bluegill (Lepomis macrochirus), blue catfish (Ictalurus furcatus), green sunfish (Lepomis cyanellus), freshwater drum, white bass (Morone chrysops), and bigmouth buffalo (Ictiobus cyprinellus); Appendix A). Most entrained individuals were small (<200 mm), with the exception of a few catchable-sized channel catfish and one large bigmouth buffalo.

These entrainment estimates were compared to relative abundances of fishes in monthly collections from Grand Lake to estimate entrainment susceptibilities of species present. I used techniques typically used to quantify foraging preferences of selective predators to quantify susceptibilities of individual species to non-selective 'predation' by the turbine intakes. The linear electivity index (Strauss 1979) was used to determine relative susceptibilities of individual species to entrainment; the index is defined as

$$L=r-p$$

where r and p are the relative abundances of a species in entrainment samples and Grand Lake, respectively. Strauss' index was used mainly because of its simplicity, but its linear property gives the advantage of having symmetrical deviation of the index for all values where r does not equal p (Lechowicz 1982). Relative abundances of each species in pooled monthly collections (all three gear types) and in pooled monthly turbine-net samples were compared. L ranges from -1 to +1, with positive values indicating enhanced susceptibility to entrainment and negative values indicating lower susceptibility to entrainment. The expected value for a species entrained in proportion to its relative abundance (i.e., random susceptibility) is zero. Wilcoxon's signed-rank test (Hollander and Wolfe 1973; Kohler and Ney 1982) was used to determine if susceptibilities were significantly different from random. Relative abundances of each species in pooled monthly collections and in individual turbine-net samples collected in a month were compared using this nonparametric paired test (Appendix B).

RESULTS

A total of 25 species composed of 3,726 individuals was collected in the lower Grand Lake study area with all three gear types from August 1988 to July 1989. Gizzard shad dominated the total catch (34.2%), followed by white crappie (14.3%), brook silverside (Labidesthes sicculus; 13.9%) and bluegill (13.8%); 10 species individually composed >1% of the total catch and 95.4% in aggregate (Figure 3).

The white bass was the most abundant (27.3%) of the 15 species in the gill net catch, followed by white crappie (23.8%), channel catfish (18.4%), and gizzard shad (10.2%). Ten species individually composed >1% of the gill-net catch and 97.6% in aggregate. White crappie (51.7%) and bluegill (37.5%) dominated the trap-net catch. Six of the 14 species collected with trap nets individually composed >1% of the catch and 98.2% in aggregate. The electrofishing catch was dominated by gizzard shad (51.6%). Brook silversides composed 22.3% of the electrofishing catch and 7 other species individually contributed at least 1%. In aggregate, these 9 species (out of 20) composed 97.7% of the electrofishing catch (Appendix C).

Gear-specific catch rates of all species in aggregate exhibited only modest seasonal fluctuations (Table 1). Catch rates of all species in aggregate for all gear types tended to be low and stable in autumn and winter and higher, yet variable, in spring and summer (Figure 4). Significant differences existed among monthly mean catch rates of all species in aggregate (Appendix D) only for trap nets (P=0.0012); no significant difference existed among monthly mean catch rates of all species in aggregate in gill nets (P=0.1320) or by electrofishing (P=0.1177).

Of the 11 major species present in lower Grand Lake (i.e., species that composed >1% of the total catch), significant differences existed among monthly mean catch rates of only three (bluegill, channel catfish, and gizzard shad) in the gear type most effective for each. Catch rates of bluegill in trap nets and channel catfish in gill nets were significantly elevated during July 1989 and June 1989, respectively. Catch rates of gizzard shad in electrofishing samples were significantly higher in November 1988 than during the remainder of the study period. Gill net catches of white bass peaked in April 1989, but the increased catch rate was not significant. Although elevated in summer, no significant differences existed among the monthly mean catch rates of the remaining abundant and entrained species in the gear type most effective for each (white crappie in trap nets, and green sunfish in electrofishing samples).

The length-frequency distribution of gizzard shad collected in lower Grand Lake was largely unimodal and primarily composed of adult sizes; the entrained gizzard shad consisted of mainly young-of-the-year individuals (Figure 5). The length frequency distribution of white crappie in Grand Lake consisted of unimodal adult-sized (>200 mm) individuals; entrained white crappie were represented by smaller (<200 mm) individuals. Channel catfish in Grand Lake were represented by wide size ranges of individuals including multiple age-classes and catchable-sized individuals. Entrained channel catfish were represented largely by sub-adult individuals, but catchable-sized fish were also collected.

Of 9 species entrained, 8 were collected in lower Grand Lake. A single bigmouth buffalo was taken in entrainment samples, but the species was absent in Grand Lake collections. Species that composed >1% of the Grand Lake assemblage but which were not entrained, included brook silversides, largemouth bass, smallmouth buffalo, and longear sunfish. Thirteen other species also collected in Grand Lake were absent from entrainment samples.

Susceptibility to entrainment of the 9 species entrained from August 1988 to July 1989 was positive (as judged by the linear electivity index) only for gizzard shad and bigmouth buffalo over the entire period (Table 2). However, susceptibility to entrainment was significantly positive only for gizzard shad over the entire August 1988 to July 1989 period; susceptibility was significantly negative for all other species (Table 2).

Entrainment susceptibilities of individual species varied among months as relative abundances in Grand Lake and in entrainment samples changed. However, significant positive susceptibility to entrainment was limited to gizzard shad and only from February through June 1989 (Figure 6). Entrainment of gizzard shad did not differ significantly from random during other months except during November 1988 when they were significantly negatively susceptible to entrainment. Monthly entrainment susceptibilities of all other species were either random or significantly negative over the entire period (Appendix B).

Seasonal trends in susceptibility to entrainment were evident only for gizzard shad, white crappie, and channel catfish. Entrainment susceptibilities of gizzard shad were depressed in autumn and enhanced in late winter, spring, and summer (Figure 6). The inverse, albeit less dramatic, was evident for white crappie and channel catfish (Figure 6). Entrainment susceptibilities of white bass, bluegill, blue catfish, green sunfish, and freshwater drum were typically random or slightly negative and showed no distinct seasonal trends.

Limnological characteristics of the water column in the immediate vicinity of Pensacola Dam (Figures 7 and 8) were largely dictated by seasonal reservoir stratification dynamics. Strong stratification was evident from August through October 1988 (Figure 7), but dissolved oxygen concentrations in 1988 were <2 mg/L over the entire range of depths encompassed by the intakes only during August (Figure 7). Stratification was absent from November 1988 through March 1989 (Figure 8), intermediate in May 1989 (Figure 8), and returned to patterns exhibited in October 1988 (Figure 7) and August 1988 (Figure 7) in June and July 1989, respectively. Dissolved oxygen concentrations were <2 mg/L over the entire range of depths encompassed by the intakes, similar to August 1988 profiles (Figure 7), again during July 1989. Only two fish were caught in gill nets set below the thermocline during periods when the reservoir was stratified; these may have become enmeshed during net retrieval.

DISCUSSION

The relative abundances of individual fish species in the hydropower intake area of Grand Lake did not accurately reflect relative entrainment rates. Both lake and entrainment samples were dominated by gizzard shad, but entrainment of this species often exceeded its relative abundance, suggesting it was more susceptible to entrainment than other fishes present in lower reaches of Grand Lake. The gizzard shad accounted for over 99% of the total abundance in entrainment samples (Fisher and Zale 1990), but it composed about 34% of the collections in Grand Lake. The gizzard shad was also the most frequently entrained species at Greenup Dam, Kentucky (Olson et al., 1988).

Gizzard shad tend to travel in large schools (Miller and Robison 1973; Pflieger 1975) which may predispose them to additional entrainment risk. At an offshore cooling intake off the Karachi coast of Pakistan, schooling fishes were generally more vulnerable to entrainment, as they were often sluggish, weak swimmers, and were generally of small size (Moazzam and Rizvi 1980). Schooling fishes were entrained at an offshore cooling intake off the California coast more often than resident reef fishes (Helvey 1985). Whereas gizzard shad are not a physically hardy species (Miller 1960), I do not believe them to be weak swimmers. However, schooling behavior may tend to magnify the consequence of an encounter with the hydropower intakes because entrainment is the fate of many individuals simultaneously.

Entrainment susceptibilities of other entrained species in Grand Lake (white crappie, channel catfish, bluegill, blue catfish, green sunfish, bigmouth buffalo, freshwater drum, and white bass) were negative and many species present in lower Grand Lake were absent in entrainment samples. These were often species that, due to their behavior and habitat preferences were not present in the deeper waters near the intake structures. For example, the brook silverside was numerically the third most abundant fish present in Grand Lake but was absent from entrainment samples. It spends most of its life within a few centimeters of the surface and never goes deeper than a few meters (Pflieger 1975). The largemouth bass (_Micropterus salmoides_) was not collected in entrainment sampled despite being the seventh most abundant fish collected in Grand Lake. Largemouth bass prefer weedy littoral areas and when in deeper water are found near bottom (Pflieger 1975).

Pelagic species other than gizzard shad (i.e., white bass, hybrid striped bass, and freshwater drum) did not appear to be susceptible to entrainment. Hybrid striped bass are stocked at locations far upstream of the intakes (Jim Smith, Oklahoma Department of Wildlife Conservation, pers. com.). Stocking them far upstream allows them time to grow before encountering the intakes and renders them less apt to be entrained. White bass migrate to tributary streams to spawn (Pflieger 1975), and by the time the young encounter the intakes, they too are likely large enough to effectively resist intake velocities. Freshwater drum were not abundant in the lower portion of Grand Lake and were entrained at rates proportional to, or less than, their monthly relative abundances.

White crappie and channel catfish were the only species other than gizzard shad often entrained. Although never significantly susceptible to entrainment, these were the only other species to frequently exhibit enhanced likelihood of entrainment as indicated by Strauss' index. Because lower Grand Lake is largely devoid of cover, the entrainment of these species may have resulted from their attraction to the cover afforded by the intake structure. Inasmuch as the intake structure offered cover, it also caused local vertical velocity gradients having an unknown effect on orientation and behavior (Hocutt and Edinger 1980).

Fishes may become entrained because of behaviors that bring them into direct contact with the intake water currents at times when their vision is impaired or when intake hydraulics disorient their position in the flow (Helvey 1985). Confusion caused by these factors may prevent fishes from vacating areas where intake velocities make entrainment imminent. In addition, the Pensacola plant is a load-control facility exhibiting frequent start-ups during peak electrical demand. This method of operation may have promoted entrainment of white crappie and channel catfish that were inhabiting the forebay during periods of non-generation.

Entrainment was size-selective and consisted primarily of small, young-of-the-year individuals. Although the hydroelectric facility's trash racks precluded entrainment of exceptionally large individuals, it is likely that size-selective entrainment was a function of the positive relationship between swimming speed and body length (Jones et al. 1974). Large individuals could attain swimming speeds required to escape intake velocities whereas smaller fish were unable to escape and were entrained. High entrainment rates of young-of-the-year gizzard shad during winter were likely a product of their size-mediated swimming ability, sensitivity to low temperatures (Miller 1960; Heidinger 1983), and propensity to 'hibernate' in deep water during winter (Velasquez 1939; Jester and Jensen 1972).

Seasonal changes in relative abundance were not reflected by similar entrainment rate changes. In fact, relative abundances in the lake were most often opposite those in the entrainment samples. Gizzard shad entrainment peaked during late winter and early spring coincident with their lowest CPUE rates and relative abundances in Grand Lake. Similarly, entrainment rates of other species (white crappie and channel catfish) were highest in late summer, autumn, and early winter, corresponding temporally with their lowest CPUE rates and relative abundances. The apparent high susceptibility of gizzard shad to entrainment during winter may have been due, in part, to sampling gear limitations. Gill nets were the only gear used to sample the profundal areas inhabited by the gizzard shad in the winter. Cold water renders passive gears less effective by reducing the activity of fish, ultimately leading to underrepresentation in the abundance estimates in the lake. The enhanced electivity index values (i.e., high susceptibility) may be an artifact of inadequate sampling gear performance, which artifically lowered the relative abundance estimates of gizzard shad in the winter samples of lower Grand Lake.

Seasonal stratification of Grand Lake influenced vertical fish distributions and entrainment rates. Fish were absent from the hypolimnion, but the thermocline was typically present at depths below the upper edge of the turbine intakes. Accordingly, stratification capable of inhibiting entrainment was present only during mid-summer. The two lowest estimates of monthly turbine entrainment were recorded in August 1988 and July 1989 when dissolved oxygen concentrations were <2 mg/L over the entire range of depths encompassed by the intakes. Gizzard shad, white crappie, and channel catfish avoid waters with dissolved oxygen concentrations less than 2 mg/L (Gebhart and Summerfelt 1978). However, low rates of entrainment during these months suggested that stratification was destabilized by hydropower generation in the forebay of the intake structure and allowed habitation of the forebay structure at the depth of the intakes by fish.

To minimize the effects of entrainment at hydropower facilities, methods to divert fish away from areas of high risk and practices to increase survival of entrained fish have been used. Operation of hydropower facilities at peak efficiency minimizes the probability of encounter of excess stress during turbine passage. Operation at low efficiency subjects entrained fish to increased cavitation, excess turbulence, and shear forces. However, no single operational or design approach decreases mortality rates to <10% on a consistent basis (Cada 1988). Where operational or design alterations are not feasible, appreciable decreases in mortality are best obtained through exclusion from areas of high entrainment risk. Due to the low entrainment rates of game fish and the seasonality of gizzard shad entrainment, implementation of entrainment deterrance devices would probably not lead to a significant improvement in the fishery of Grand Lake.

In summary, entrainment of recreationally and commercially important sport and food fishes by the Pensacola Dam hydroelectric facility was limited because these species were not abundant in the vicinity of the dam and their relative susceptibilities to entrainment were low. Gizzard shad, especially young-of-the-year, were seasonally susceptible to entrainment, but dominance of the reservoir's fish assemblage by this species suggested that effects of entrainment were minimal or inconsequential. Because gizzard shad are often considered over-abundant in impoundments (Miller 1960; Jenkins 1957), it seems unlikely that selective entrainment of this species is deleterious to the ichthyofauna of Grand Lake.

My research may be applicable to many morphologically similar southern reservoirs built primarily for hydropower generation. Application to smaller reservoirs, those not stratifying, or those with faster flushing rates (i.e., more riverine in nature) may be limited. Relevance to pumped-storage facilities would only be incurred during generation periods and not to pump phases of operation.

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Table 1. Total catches (N), mean catch-per-unit-effort (CPUE) values, and standard deviations (SD) of CPUE of all fish species in aggregate, by gear type, collected in Grand Lake, August 1988 to July 1989.

	Gill net			Trap net			Electrofishing		
Month	N	CPUE	SD	N	CPUE	SD	N	CPUE	SD
AUG 88	59	4.92	7.14	70	7.00	9.24	26	2.60	3.72
SEP 88	47	3.92	8.50	57	5.70	5.77	73	7.30	10.35
OCT 88	29	2.50	4.46	15	1.50	2.17	245	24.50	48.31
NOV 88	16	1.33	1.87	7	0.70	1.16	578	57.90	87.84
DEC 88	38	3.17	6.64	32	3.20	2.10	115	12.10	21.55
JAN 89	18	1.06	1.61	21	2.10	2.13	36	3.00	7.52
FEB 89	39	2.44	6.90	5	0.50	0.71	161	13.42	32.22
MAR 89	15	0.94	1.39	64	6.40	9.81	326	27.17	71.84
APR 89	88	5.50	6.95	124	12.40	13.47	207	17.25	20.94
MAY 89	169	7.22	9.98	52	5.20	5.29	165	13.75	19.97
JUN 89	142	8.88	16.49	100	10.00	13.22	87	7.25	9.19
JUL 89	47	2.94	7.70	146	14.60	14.49	307	25.58	33.63
	707	3.80	8.06	693	5.78	9.06	2326	17.40	40.03

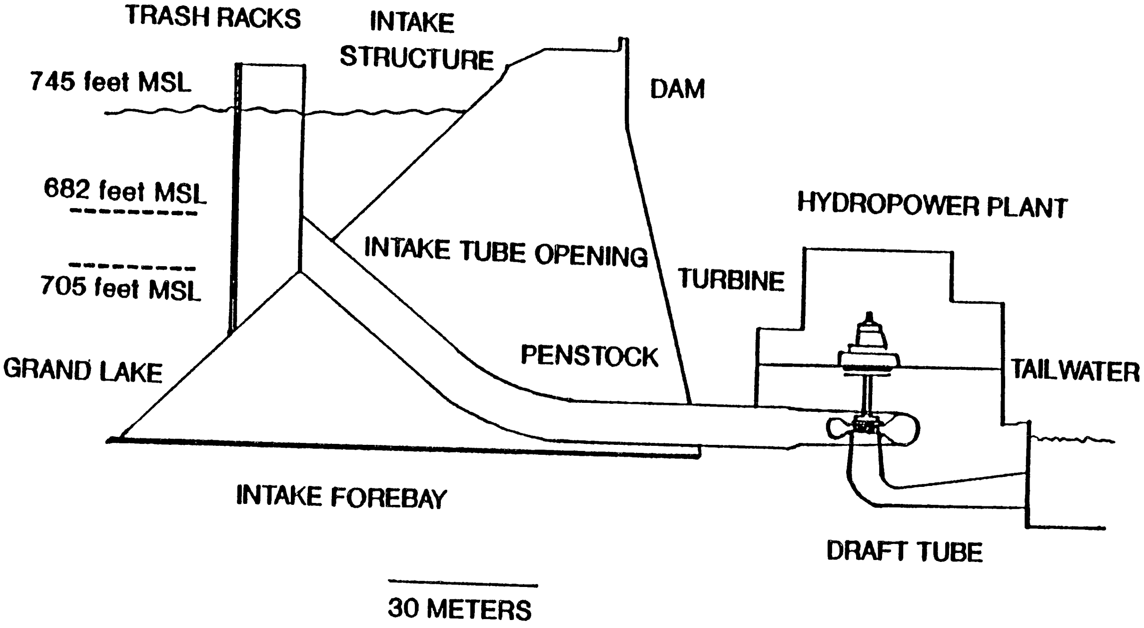
Table 2. Turbine-entrainment susceptibilities of fishes in Grand Lake, August 1988 to July 1989. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols + and - represent positive and negative susceptibility, respectively. Probability values are given in parentheses (Wilcoxon's signed rank test).

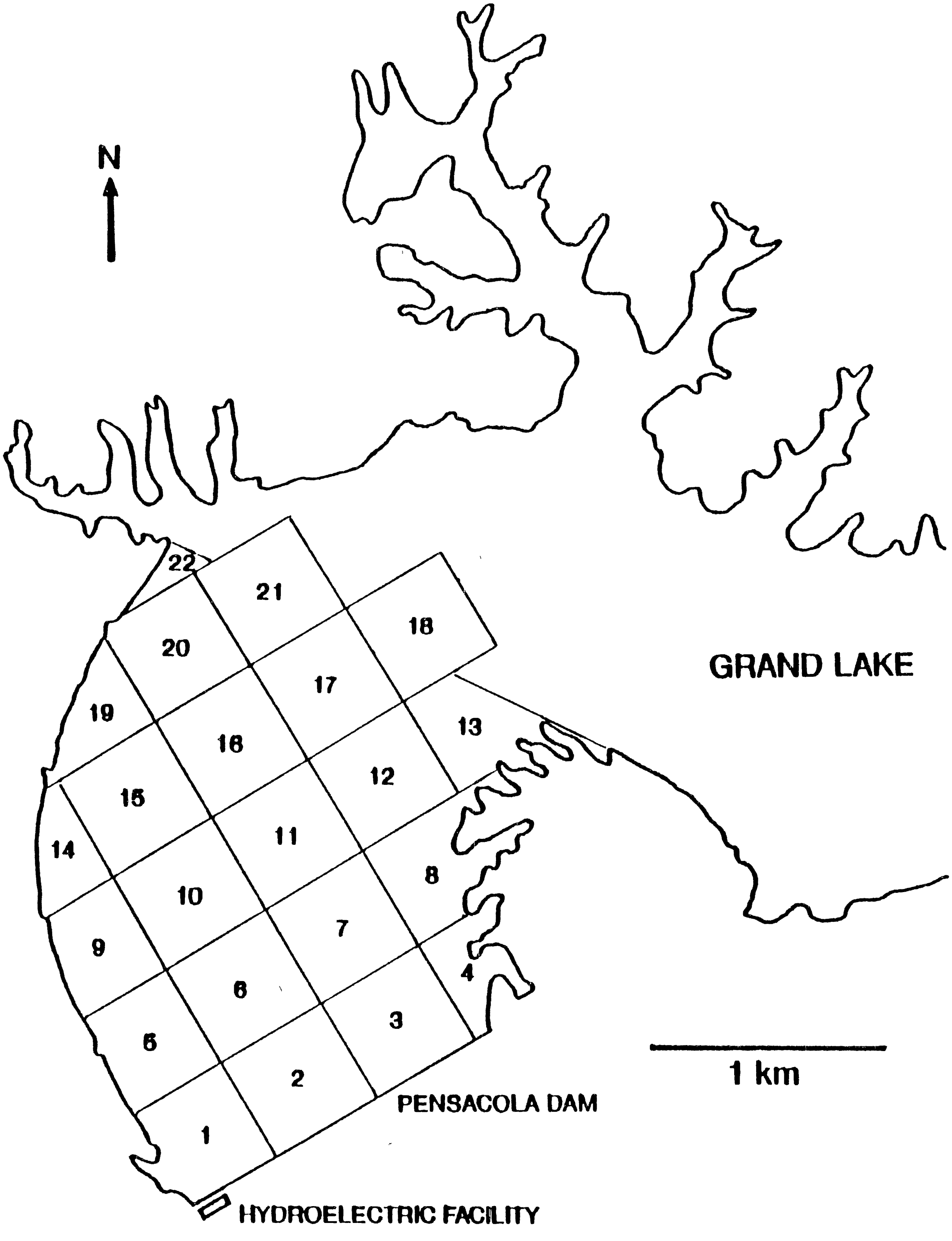
Species	r	p	L	Susceptibility
Gizzard shad	0.995	0.342	+0.653	+ (0.0008)
White crappie	0.002	0.143	-0.141	- (<0.0002)
Channel catfish	0.002	0.036	-0.034	- (<0.0002)
Bluegill	<0.001	0.135	-0.135	- (<0.0002)
Blue catfish	<0.001	0.003	-0.003	- (<0.0002)
Green sunfish	<0.001	0.017	-0.017	- (<0.0002)
Bigmouth buffalo	<0.001	0.000	+<0.001	- (<0.0002)
Freshwater drum	<0.001	0.007	-0.007	- (<0.0002)
White bass	<0.001	0.074	-0.074	- (<0.0002)

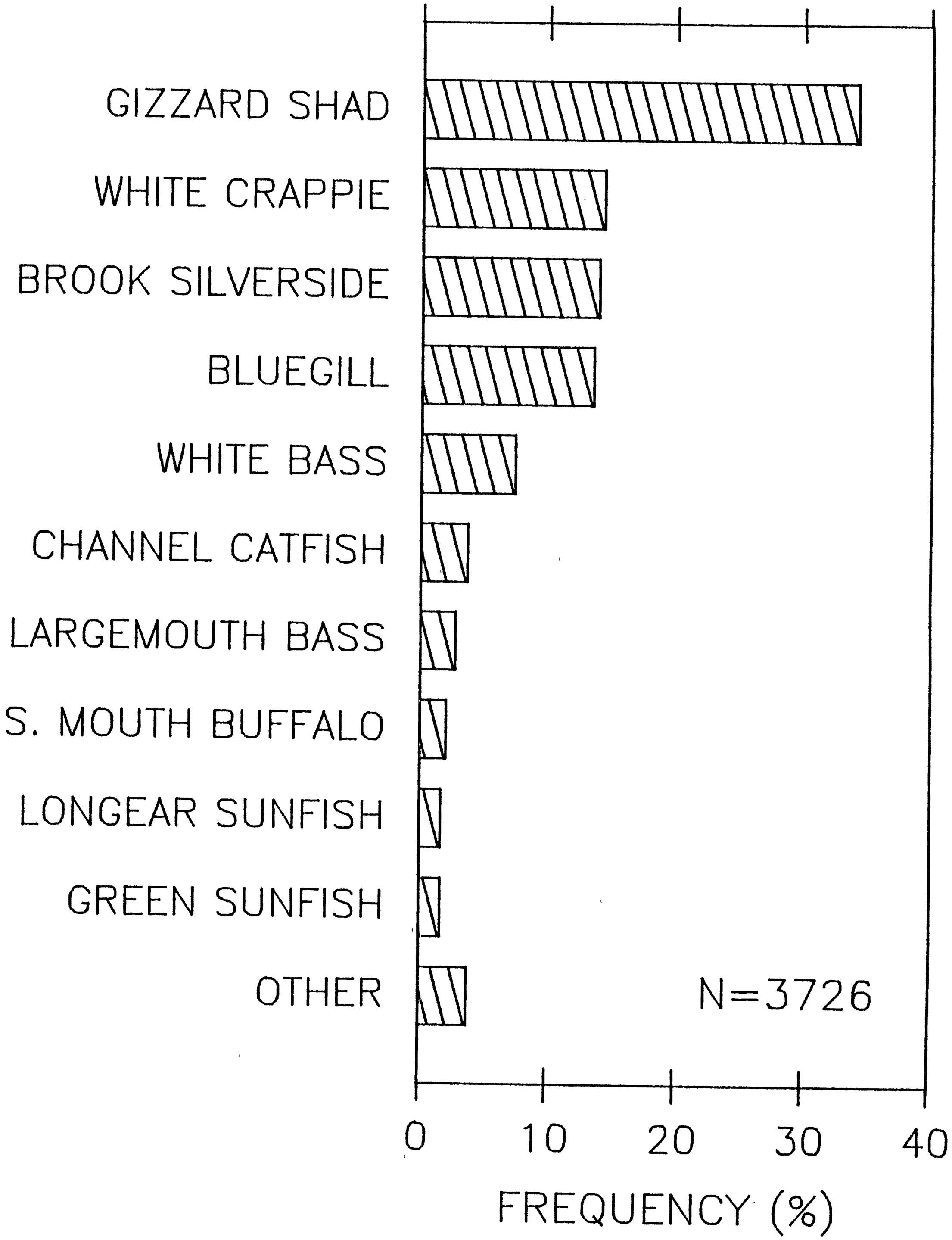
FIGURE CAPTIONS

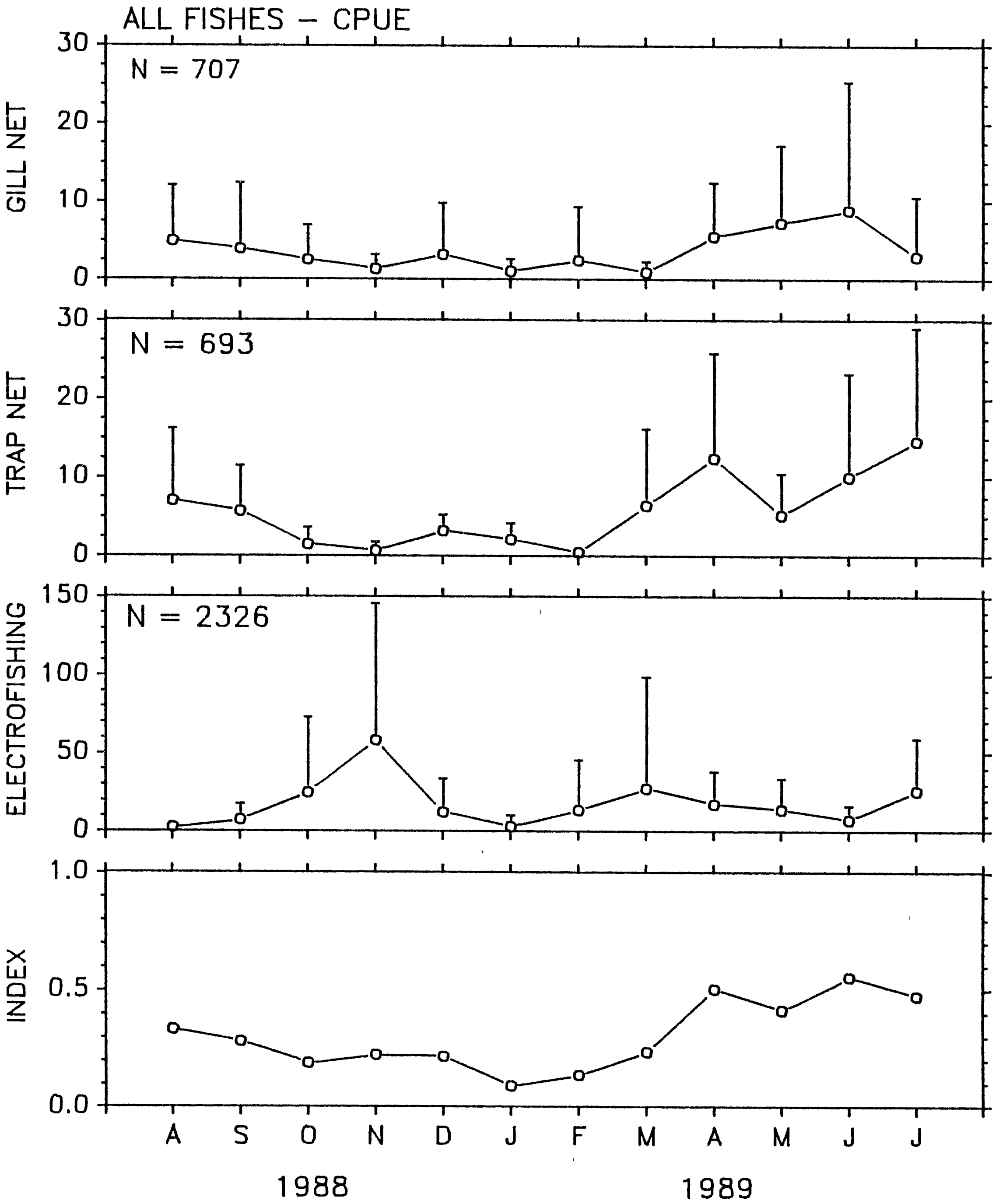
1. Diagrammatic Representation of Pensacola Dam Hydroelectric Facility Showing Structures Referred to in Text.
2. Fish Sampling Blocks in the Lower Grand Lake Study Area.
3. Relative Numeric Abundances (%) of Fishes Constituting >1% of the Total Catch Captured Using all Gear Types in Lower Grand Lake, August 1988 to July 1989.
4. Numeric Catch-Per-Unit-Effort Rates (+1 SD) by Gear and Combined-Gear Catch Index Values of all Fishes in Aggregate, Lower Grand Lake, August 1988 to July 1989.
5. Length-Frequency Distributions of Gizzard Shad Collected in Grand Lake Samples and Entrainment Samples August 1988 to July 1989.
6. Monthly Entrainment Susceptibility Trends for Gizzard Shad, White Crappie, and Channel Catfish Calculated as Electivity Indices from August 1988 to July 1989.

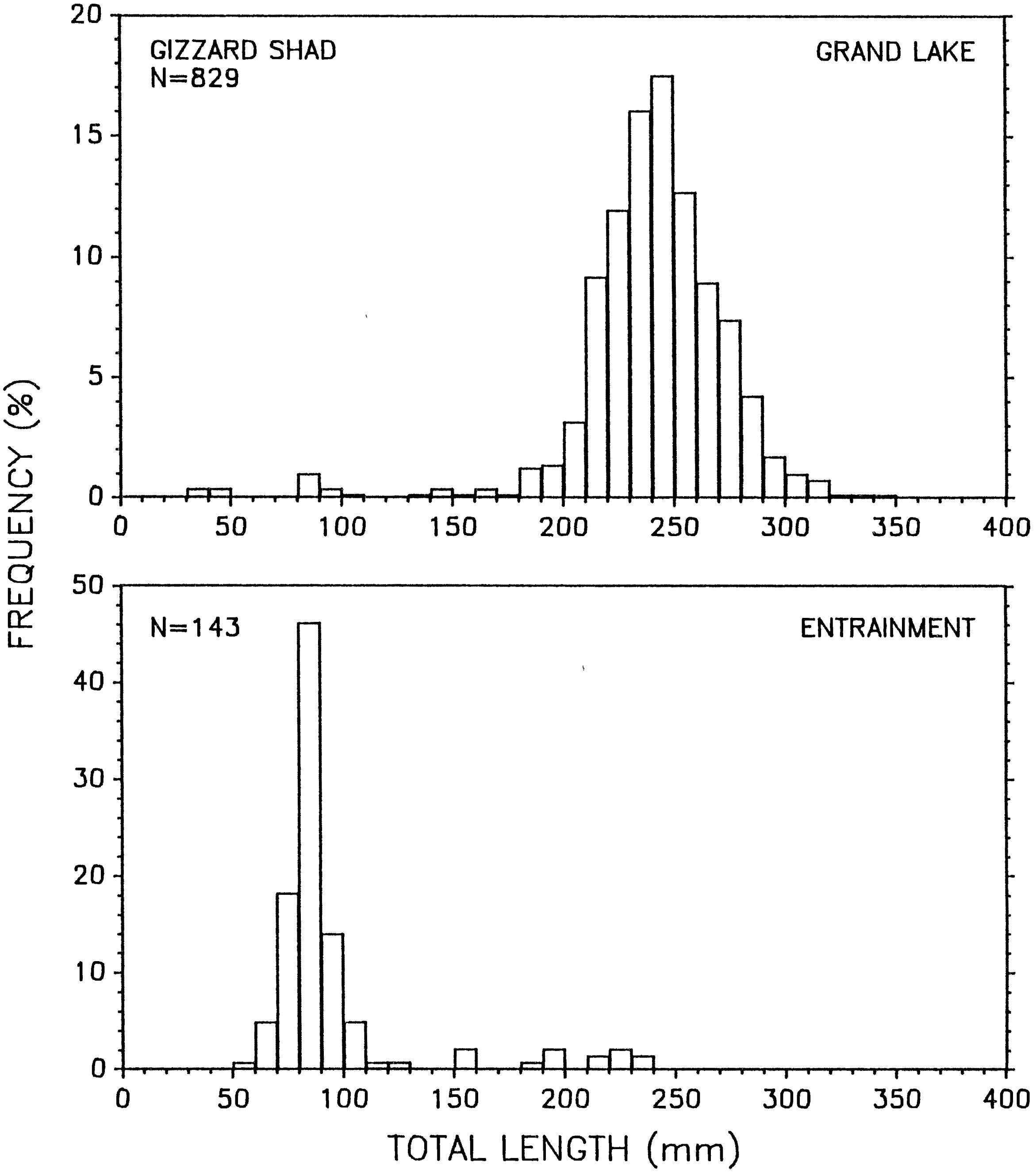
7. Water Temperature and Dissolved Oxygen Concentration Profiles Directly Upstream From the Pensacola Dam Hydroelectric Facility, August and October 1988. The bars along the right vertical axes indicate the depths of the turbine intakes.
8. Water Temperature and Dissolved Oxygen Concentration Profiles Directly Upstream From the Pensacola Dam Hydroelectric Facility, November 1988 and May 1989. The bars along the right vertical axes indicate the depths of the turbine intakes.


TRASH RACKS
INTAKE STRUCTURE
745 feet MSL
DAM
682 feet MSL
HYDROPOWER PLANT
INTAKE TUBE OPENING
705 feet MSL
TURBINE
PENSTOCK
GRAND LAKE
TAILWATER
INTAKE FOREBAY
DRAFT TUBE
30 METERS

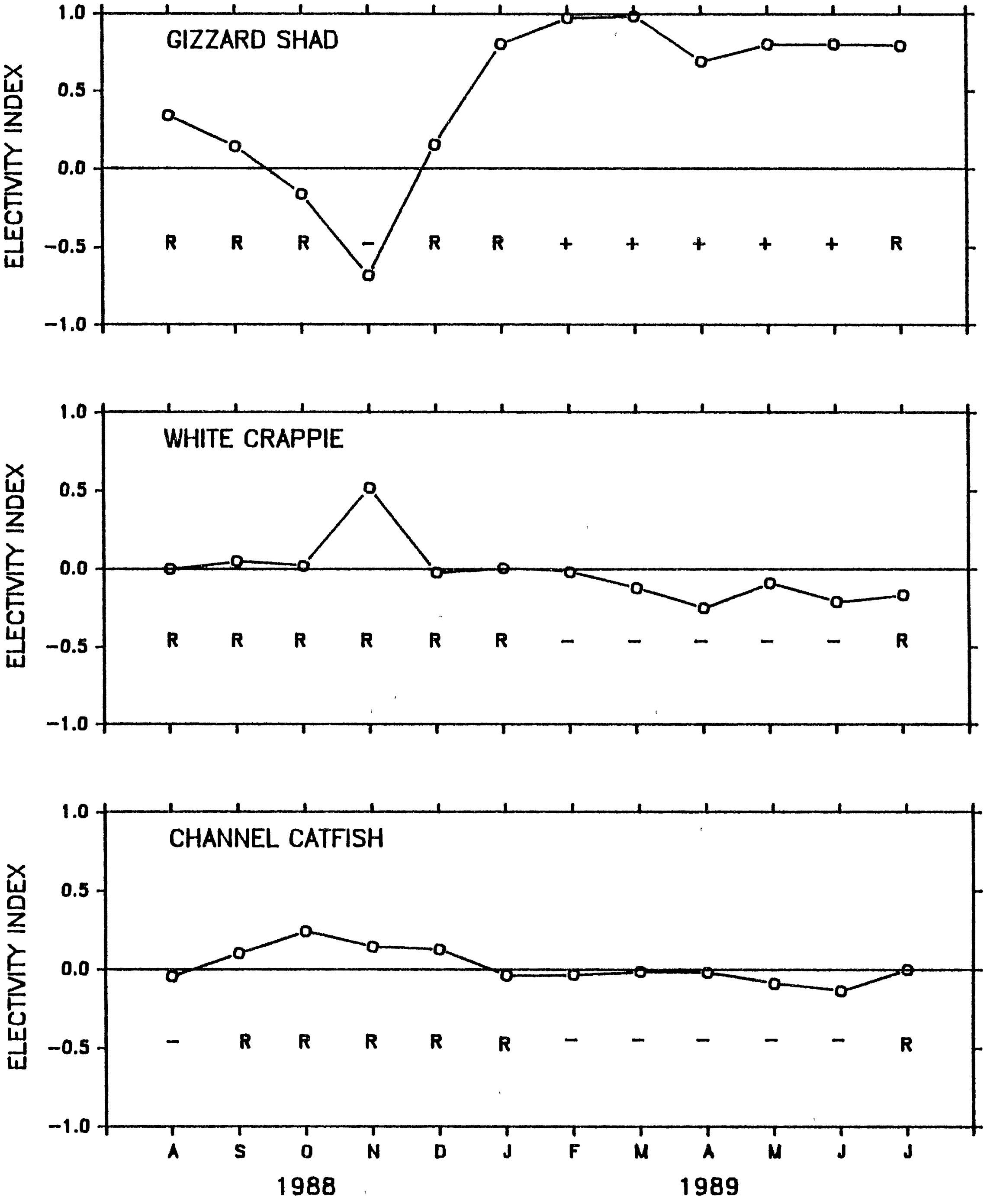

N
GRAND LAKE
22
21
20
18
19
17
16
13
15
12
11
14
10
8
9
7
6
4
5
3
2
1
1 km
PENSACOLA DAM
HYDROELECTRIC FACILITY

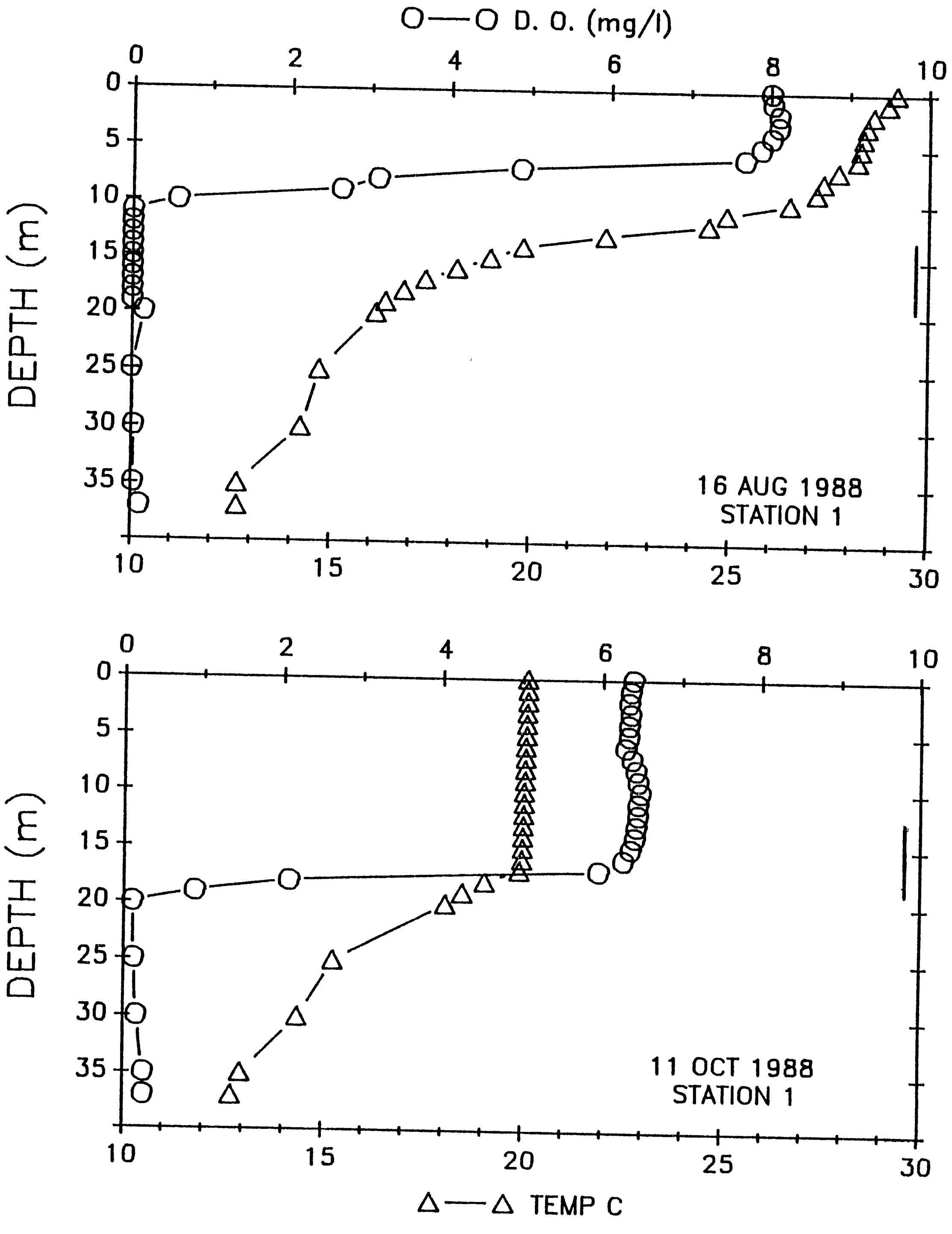

GIZZARD SHAD
WHITE CRAPPIE
BROOK SILVERSIDE
BLUEGILL
WHITE BASS
CHANNEL CATFISH
LARGEMOUTH BASS
S. MOUTH BUFFALO
LONGEAR SUNFISH
GREEN SUNFISH
OTHER
N=3726
0
10
20
30
40
FREQUENCY (%)

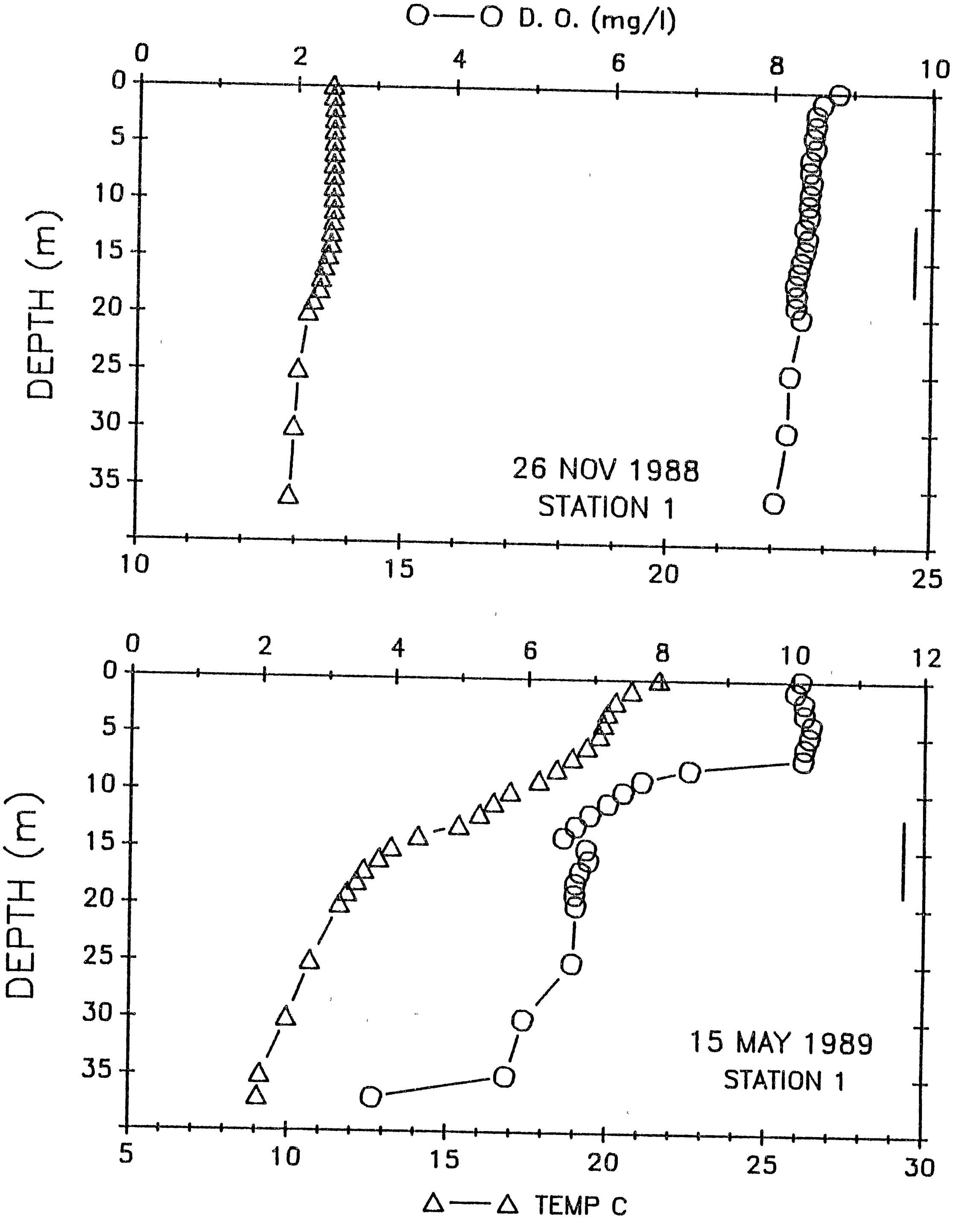

ALL FISHES – CPUE
N = 707
GILL NET
0
10
20
30
N = 693
TRAP NET
0
10
20
30
N = 2326
ELECTROFISHING
0
50
100
150
INDEX
0.0
0.5
1.0
A
S
O
N
D
J
F
M
A
M
J
J
1988
1989



GIZZARD SHAD
N=829
GRAND LAKE
N=143
ENTRAINMENT
FREQUENCY (%)
TOTAL LENGTH (mm)
0
5
10
15
20
0
10
20
30
40
50
0
50
100
150
200
250
300
350
400


GIZZARD SHAD
WHITE CRAPPIE
CHANNEL CATFISH
ELECTIVITY INDEX
1.0
0.5
0.0
-0.5
-1.0
R R R – R R + + + + + R
R R R R R R – – – – – R
– R R R R R – – – – – R
A
S
O
N
D
J
F
M
A
M
J
J
1988
1989


O—O D. O. (mg/l)
0
2
4
6
8
10
DEPTH (m)
0
5
10
15
20
25
30
35
16 AUG 1988
STATION 1
10
15
20
25
30
0
2
4
6
8
10
DEPTH (m)
0
5
10
15
20
25
30
35
11 OCT 1988
STATION 1
10
15
20
25
30
△—△ TEMP C



O—O D. O. (mg/l)
0
2
4
6
8
10
DEPTH (m)
0
5
10
15
20
25
30
35
26 NOV 1988
STATION 1
10
15
20
25
0
2
4
6
8
10
12
15 MAY 1989
STATION 1
5
10
15
20
25
30
Δ—Δ TEMP C

APPENDIX A

MONTHLY ENTRAINMENT RATES

Table A.1. Monthly entrainment rates of all fishes entrained at Pensacola Dam hydroelectric facility, August 1988 to July 1989 (Fisher and Zale 1990).

Month	Total	Gizzard shad	White crappie	Channel catfish	Blue-gill	Blue cat-fish	Green sun-fish	Big-mouth buffalo	Fresh-water drum	White bass	Uniden-tified
Aug 88	9150	4488	4026	0	0	0	0	0	636	0	0
Sep 88	14706	6491	2047	1834	2744	722	0	0	0	816	0
Oct 88	16272	7852	1035	3984	0	913	0	0	0	0	2488
Nov 88	21563	4474	11454	3227	0	0	0	0	0	0	0
Dec 88	55144	37708	4104	9640	0	0	2408	0	0	0	0
Jan 89	21500	17307	4193	0	0	0	0	2314	1377	0	0
Feb 89	8949493	8949493	0	0	0	0	0	0	0	0	0
Mar 89	4270989	4266504	0	4449	0	0	0	0	0	0	0
Apr 89	925433	920816	4623	0	0	0	0	0	0	0	0
May 89	998264	992382	0	1850	2190	1850	0	0	0	0	0
Jun 89	44319	44319	0	0	0	0	0	0	0	0	0
Jul 89	5950	5950	0	0	0	0	0	0	0	0	0
Total		15257784	31482	2498	493	3535	2408	2314	2013	816	2488
Percent		99.5	0.21	0.16	0.03	0.02	0.01	0.01	0.01	<0.01	0.02

APPENDIX B

SUSCEPTIBILITY VALUES

Table B.1. Turbine-entrainment susceptibilities of fishes in Grand Lake, August 1988. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility	
Gizzard shad	0.490	0.148	+0.342	R	(0.9680)
White crappie	0.440	0.439	+0.001	R	(0.6892)
Channel catfish	0	0.045	-0.045	-	(0.0434)
Bluegill	0	0.084	-0.084	-	(0.0434)
Blue catfish	0	0.006	-0.006	-	(0.0434)
Green sunfish	0	0.026	-0.026	-	(0.0434)
Bigmouth buffalo	0	0	--		--
Freshwater drum	0.070	0.026	+0.044	R	(0.5028)
White bass	0	0.084	-0.084	-	(0.0434)

Table B.32. Turbine-entrainment susceptibilities of fishes in Grand Lake, September 1988. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility	
Gizzard shad	0.441	0.299	+0.142	R	(0.9602)
White crappie	0.139	0.090	+0.049	R	(0.0075)
Channel catfish	0.125	0.023	+0.102	R	(0.3844)
Bluegill	0.187	0.395	-0.208	R	(0.3844)
Blue catfish	0.052	0	+0.052	R	(0.3174)
Green sunfish	0	0.034	-0.034	-	(0.0052)
Bigmouth buffalo	0	0	--		--
Freshwater drum	0	0	--		--
White bass	0.055	0.028	+0.027	R	(0.0750)

Table B.3. Turbine-entrainment susceptibilities of fishes in Grand Lake, October 1988. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility
Gizzard shad	0.482	0.644	-0.162	R (0.2628)
White crappie	0.064	0.045	+0.019	R (0.1616)
Channel catfis	0.245	0.003	+0.242	R (0.6744)
Bluegill	0	0.080	-0.080	- (0.0118)
Blue catfish	0.056	0.010	+0.046	R (0.1616)
Green sunfish	0	0.017	-0.017	- (0.0118)
Bigmouth buffalo	0	0	--	--
Freshwater drum	0	0.017	-0.017	- (0.0118)
White bass	0	0.017	-0.017	- (0.0118)

Table B.4. Turbine-entrainment susceptibilities of fishes in Grand Lake, November 1988. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility
Gizzard shad	0.207	0.890	-0.683	- (0.0434)
White crappie	0.531	0.012	+0.519	R (0.0802)
Channel catfish	0.150	0.007	+0.143	R (0.5028)
Bluegill	0	0.030	-0.030	- (0.0434)
Blue catfish	0	0.002	-0.002	- (0.0434)
Green sunfish	0.112	0.005	+0.107	R (0.5028)
Bigmouth buffalo	0	0	--	--
Freshwater drum	0	0.002	-0.002	- (0.0434)
White bass	0	0.008	-0.008	- (0.0434)

Table B.5. Turbine-entrainment susceptibilities of fishes in Grand Lake, December 1988. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility
Gizzard shad	0.684	0.530	+0.154	R (0.6600)
White crappie	0.074	0.097	-0.023	R (0.2846)
Channel catfish	0.175	0.049	+0.126	R (0.0512)
Bluegill	0	0.108	-0.108	- (0.0034)
Blue catfish	0	0	--	--
Green sunfish	0	0.016	-0.016	- (0.0034)
Bigmouth buffalo	0.042	0	+0.042	R (0.3174)
Freshwater drum	0.025	0	+0.025	R (0.3174)
White bass	0	0.070	-0.070	- (0.0034)

Table B.6. Turbine-entrainment susceptibilities of fishes in Grand Lake, January 1989. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility
Gizzard shad	0.805	0	+0.805	R (1.0000)
White crappie	0.195	0.200	+0.005	R (1.0000)
Channel catfish	0	0.040	-0.040	R (0.1096)
Bluegill	0	0.120	-0.120	R (0.1096)
Blue catfish	0	0.013	-0.013	R (0.1096)
Green sunfish	0	0	--	--
Bigmouth buffalo	0	0	--	--
Freshwater drum	0	0.013	-0.013	R (0.1096)
White bass	0	0.147	-0.147	R (0.1096)

Table B.7. Turbine-entrainment susceptibilities of fishes in Grand Lake, February 1989. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility
Gizzard shad	1.000	0.029	+0.971	+ (<0.0002)
White crappie	0	0.020	-0.020	- (<0.0002)
Channel catfish	0	0.034	-0.034	- (<0.0002)
Bluegill	0	0.005	-0.005	- (<0.0002)
Blue catfish	0	0.005	-0.005	- (<0.0002)
Green sunfish	0	0.005	-0.005	- (<0.0002)
Bigmouth buffalo	0	0	--	--
Freshwater drum	0	0	--	--
White bass	0	0.117	-0.117	- (<0.0002)

Table B.8. Turbine-entrainment susceptibilities of fishes in Grand Lake, March 1989. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility
Gizzard shad	0.999	0.017	+0.982	+ (<0.0002)
White crappie	0	0.123	-0.123	- (<0.0002)
Channel catfish	0.001	0.015	-0.014	- (<0.0002)
Bluegill	0	0.049	-0.049	- (<0.0002)
Blue catfish	0	0	--	--
Green sunfish	0	0	--	--
Bigmouth buffalo	0	0	--	--
Freshwater drum	0	0	--	--
White bass	0	0.017	-0.017	- (<0.0002)

Table B.9. Turbine-entrainment susceptibilities of fishes in Grand Lake, April 1989. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility
Gizzard shad	0.995	0.303	+0.692	+ (<0.0002)
White crappie	0.005	0.255	-0.250	- (<0.0010)
Channel catfish	0	0.021	-0.021	- (<0.0002)
Bluegill	0	0.131	-0.131	- (<0.0002)
Blue catfish	0	0	--	--
Green sunfish	0	0.021	-0.021	- (<0.0002)
Bigmouth buffalo	0	0	--	--
Freshwater drum	0	0.005	-0.005	- (<0.0002)
White bass	0	0.122	-0.122	- (<0.0002)

Table B.10. Turbine-entrainment susceptibilities of fishes in Grand Lake, May 1989. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility
Gizzard shad	0.994	0.189	+0.805	+ (<0.0002)
White crappie	0	0.212	-0.212	- (<0.0002)
Channel catfish	0.002	0.093	-0.091	- (<0.0002)
Bluegill	0.002	0.111	-0.109	- (0.0010)
Blue catfish	0.002	0.010	-0.008	- (<0.0002)
Green sunfish	0	0.036	-0.036	- (<0.0002)
Bigmouth buffalo	0	0	--	--
Freshwater drum	0	0.008	-0.008	- (<0.0002)
White bass	0	0.150	-0.150	- (<0.0002)

Table B.11. Turbine-entrainment susceptibilities of fishes in Grand Lake, June 1989. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility
Gizzard shad	1.000	0.195	+0.805	+ (0.0434)
White crappie	0	0.210	-0.210	- (0.0434)
Channel catfish	0	0.137	-0.137	- (0.0434)
Bluegill	0	0.222	-0.222	- (0.0434)
Blue catfish	0	0	--	--
Green sunfish	0	0.021	-0.021	- (0.0434)
Bigmouth buffalo	0	0	--	--
Freshwater drum	0	0	--	--
White bass	0	0.018	-0.018	- (0.0434)

Table B.12. Turbine-entrainment susceptibilities of fishes in Grand Lake, July 1989. The relative abundances of fishes in entrainment and Grand Lake samples are denoted r and p, respectively. L is Strauss' linear electivity index. The symbols +, R, and - represent positive, random, and negative susceptibility, respectively. Probability values are given in parentheses. Probability values >0.05 were judged as indicating random susceptibility (Wilcoxon's signed rank test).

Species	r	p	L	Susceptibility
Gizzard shad	1.000	0.206	+0.794	R (0.6528)
White crappie	0	0.166	-0.166	R (0.1802)
Channel catfish	0	0.001	-0.001	R (0.1802)
Bluegill	0	0.316	-0.316	R (0.1802)
Blue catfish	0	0	--	--
Green sunfish	0	0.020	-0.020	R (0.1802)
Bigmouth buffalo	0	0	--	--
Freshwater drum	0	0.014	-0.014	R (0.1802)
White bass	0	0.154	-0.154	R (0.1802)

APPENDIX C

TOTAL CATCHES AND RELATIVE ABUNDANCE BY GEAR

Table C.1. Total catches (N) and relative abundances (%) of fishes captured with gill nets, trap nets, and by electrofishing in Grand Lake, August 1988 to July 1989.

	Gill net		Trap net		Electrofishing		Combined	
Species	N	%	N	%	N	%	N	%
Blue catfish Ictalurus furcatus	11	1.6	0	0.0	0	0.0	11	0.3
Bluegill Lepomis macrochirus	0	0.0	260	37.5	243	10.4	514	13.8
Brook silverside Labidesthes sicculus	0	0.0	0	0.0	518	22.3	518	27.7
Channel catfish Ictalurus punctatus	130	18.4	2	0.3	4	0.2	136	3.7
Common carp Cyprinus carpio	11	1.6	1	0.1	11	0.5	23	0.6
Freshwater drum Aplodinotus grunniens	13	1.8	3	0.4	10	0.4	26	0.7
Flathead catfish Polyodictus olivaris	2	0.3	0	0.0	0	0.0	2	0.1
Green sunfish Lepomis cyanellus	0	0.0	18	2.6	44	1.9	62	1.7
Gizzard shad Dorosoma cepedianum	72	10.2	1	0.1	1202	51.7	1275	34.2
Hybrid striped bass Morone saxatilis x M. chrysops	34	4.8	0	0.0	0	0.0	34	0.9
Hybrid sunfish Lepomis sp.	0	0.0	3	0.4	1	<0.1	4	0.1
Longear sunfish Lepomis megalotis	0	0.0	17	2.5	46	2.0	63	1.7
Logperch Percina caprodes	0	0.0	0	0.0	8	0.3	8	0.2
Largemouth bass Micropterus salmoides	5	0.7	19	2.7	81	3.5	105	2.8
Longnose gar Lepisosteus osseus	0	0.0	0	0.0	2	0.1	2	0.1
Paddlefish Polyodon spathula	7	1.0	0	0.0	0	0.0	7	0.2
Rainbow trout Oncorhynchus mykiss	2	0.3	0	0.0	1	<0.1	3	0.1
River carpsucker Carpiodes carpio	5	0.7	0	0.0	6	0.3	11	0.3
Redear sunfish Lepomis microlophus	0	0.0	1	0.1	0	0.0	1	<0.1
Smallmouth buffalo Ictiobus bubalus	52	7.4	1	0.1	27	1.2	80	2.1
Slender madtom Noturus exilis	0	0.0	0	0.0	1	<0.1	1	<0.1
Spotted bass Micropterus punctulatus	3	0.4	2	0.3	30	1.3	35	0.9
White bass Morone chrysops	192	27.2	0	0.0	83	3.6	275	7.4
White crappie Pomoxis annularis	168	23.8	358	51.7	6	0.3	532	14.3
Warmouth Lepomis gulosis	0	0.0	7	1.0	2	0.1	9	0.2
TOTAL	707		693		2326		3726	

APPENDIX D

ANOVA OF MONTHLY MEAN CPUE

Table D.1. Sums of squares (SS), F, and probability values (P) of analyses of variance testing whether differences existed among monthly mean numeric catch-per-unit-effort rates, by gear, of fishes collected in Grand Lake, August 1988 to July 1989. Asterisks denote significant differences (alpha = 0.05).

Species	Gill net			Trap net			Electrofishing		
	SS	F	P	SS	F	P	SS	F	P
Blue catfish	1.34	1.15	0.3280	--	--	--	--	--	--
Bluegill	--	--	--	845.07	3.10	0.0012*	320.90	1.64	0.0956
Brook silverside	--	--	--	--	--	--	7642.59	1.30	0.2329
Channel catfish	108.61	1.85	0.0505	0.17	0.91	0.5344	0.40	0.80	0.6363
Common carp	0.59	0.73	0.7079	0.09	1.00	0.4513	1.08	0.80	0.6418
Freshwater drum	2.44	1.55	0.1186	0.27	0.73	0.7102	1.27	1.41	0.1761
Flathead catfish	0.23	1.88	0.0449*	--	--	--	--	--	--
Green sunfish	--	--	--	2.30	1.19	0.3036	10.05	0.53	0.8783
Gizzard shad	85.73	1.75	0.0665	0.09	1.00	0.4513	24836.80	3.30	0.0005*
Hybrid striped bass	11.64	1.22	0.2755	--	--	--	--	--	--
Hybrid sunfish	--	--	--	0.43	0.93	0.5173	0.09	1.14	0.3363
Longear sunfish	--	--	--	7.49	0.84	0.5964	15.37	1.25	0.2642
Logperch	--	--	--	--	--	--	2.11	0.92	0.5247
Largemouth bass	0.42	0.94	0.5014	6.49	2.50	0.0077*	37.55	1.20	0.2927
Longnose gar	--	--	--	--	--	--	0.14	0.83	0.6127
Paddlefish	0.37	1.11	0.3594	--	--	--	--	--	--
Rainbow trout	0.06	0.88	0.5617	--	--	--	0.07	0.92	0.5255
River carpsucker	0.58	0.83	0.6134	--	--	--	0.41	0.87	0.5762
Redear sunfish	--	--	--	0.09	1.00	0.4513	--	--	--
Smallmouth buffalo	24.09	1.30	0.2282	0.09	1.00	0.4513	15.99	2.55	0.0062*
Slender madtom	--	--	--	--	--	--	0.07	0.92	0.5255
Spotted bass	0.51	1.67	0.0814	0.17	0.91	0.5344	8.05	1.37	0.1961
White bass	138.14	1.58	0.1081	--	--	--	420.59	0.93	0.5169
White crappie	135.96	1.80	0.0572	795.57	1.80	0.0622	0.96	0.84	0.6025
Warmouth	--	--	--	0.05	0.94	0.5017	0.30	0.92	0.5255
TOTAL	1045.76	1.51	0.1320	2338.43	3.09	0.0012*	26340.49	1.56	0.1177

VITA

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Master of Science

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