EFFECTS OF THE ADDITION OF HYDROPOWER TO KAW DAM ON STRIPED BASS EGG ABUNDANCES IN THE ARKANSAS RIVER, OKLAHOMA

By

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Bachelor of Science

The Pennsylvania State University

University Park, Pennsylvania

1989

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 1992

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Thesis Approved:

Thesis Adviser

Jerry Wilhm

Anthony A. Echelle

Thomas C. Collins
Dean of the Graduate College

PREFACE

Chapters I and I of this thesis are manuscripts written in the format suitable for submission to <u>Transactions of the American Fisheries Society</u>. Each manuscript is complete without supporting materials. The order of arrangement is abstract, introduction, methods, results, discussion, references, tables, and figures.

I wish to thank my principal advisor, Dr. Alexander Zale, for giving me the opportunity to conduct this research and his valuable assistance throughout the project. I also thank Dr. Tony Echelle and Dr. Jerry Wilhm for serving on my graduate committee. Dr. P. Larry Claypool provided a great deal of assistance in analyzing the data. Brian Bohnsack deserves many thanks for showing me the ropes and for sharing his data with me. All the technicians and volunteers who spent many tedious hours collecting and sorting samples deserve special thanks. I also thank the Oklahoma Cooperative Fish and Wildlife Research Unit for supplying equipment and vehicles and for providing support to attend meetings to present this research. I am grateful to the Oklahoma Municipal Power Authority for funding this research.

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CHAPTER I

EFFECTS OF THE ADDITION OF HYDROPOWER TO KAW DAM ON STRIPED BASS EGG ABUNDANCES IN THE ARKANSAS RIVER, OKLAHOMA.

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Abstract.-Striped bass spawn in the Arkansas River between Kaw Dam and Keystone Reservoir. A hydropower generator was added to Kaw Dam in 1989. I sampled ichthyoplankton at five sites during the first 2 years of hydropower operations (1990 and 1991) and compared striped bass egg densities and abundances with data from 1987 and 1988. Spawning began during the second week of April and peaked within 1 week of 1 May each year. Spawning was protracted during hydropower years. Significant differences among years in daily egg density and daily abundance occurred only at Ponca City. The differences at Ponca City were likely not due to hydropower because 1987 levels were significantly greater than densities and abundances during the other 3 years. Daily densities and abundances in 1988, 1990, and 1991 were not significantly different. No significant difference in annual egg abundances at the five sites existed between the non-hydropower and hydropower years. Mean discharge at Kaw Dam from 1 March through June in 1987 was the highest since the completion of Kaw Dam in 1976. Conversely, March through June discharges during 1991 were the second lowest since 1976. Hydropower effects are greater at low discharges. Despite low discharges, the first two years of hydropower operations did not adversely affect striped bass spawning success.

The Oklahoma Department of Wildlife Conservation introduced striped bass (Morone saxatilis) into Keystone Reservoir from 1965 through 1969 to produce a trophy sport fishery and to control gizzard shad (Dorosoma cepedianum) (Combs 1979a). The striped bass is an anadromous species native to the eastern and Gulf coasts of North America. Reproduction of striped bass has occurred annually in the Arkansas River tributary of Keystone Reservoir since 1970 (Mensinger 1971; Hicks 1982; Bohnsack 1990), precluding the need for additional stocking. The Keystone population is one of only eight reproducing potadromous striped bass populations, although the species has been introduced into large reservoirs in at least 38 states (Gustaveson et al. 1984).

A popular striped bass fishery has developed in Keystone Reservoir as well as in its headwaters and tailwaters (Combs 1980; Hamilton et al. 1985; Jacks 1990). Individuals from this population disperse far downstream; striped bass tagged in the Keystone Dam tailwaters have been caught in Arkansas and in the Gulf of Mexico (Zale and Jacks 1988). Additionally, this population is one of the best sources of brood stock for state hatcheries, thereby supporting striped bass and striped bass x white bass (Morone chrysops) hybrid fisheries throughout Oklahoma (Hensley 1983).

Kaw Dam was constructed on the Arkansas River 150 km above Keystone Reservoir in 1976. The dam blocked striped bass spawning migrations which previously extended into Kansas. However, annual recruitment in Keystone Reservoir apparently increased possibly because Kaw Dam stablized the river discharge (Combs 1979a).

A hydroelectric generator was added to Kaw Dam in the autumn of 1989, resulting in a change in discharge regime. Power generation is inefficient at low discharges. If the daily allotment of water is inadequate to generate power efficiently the entire day, water is stored part of the day and released at a more efficient rate during peak demand hours. This practice is termed daily pooling. Generation and associated high discharges were estimated to occur for an annual average of 8 h/d (Hensley 1983). Discharge fluctuations due to hydropower generation vary by as much as 156 m^3/s, which is the capacity of the hydropower facility. Periodic discharges may adversely affect striped bass reproduction by causing unstable flow and temperature regimes in the spawning areas (Neal 1971; Crim 1982). A 3-day period of simulated hydropower releases in 1988 did not affect striped bass egg density or abundance, but spawning did shift downstream (Bohnsack 1990).

Successful reproduction of striped bass is dependent upon water velocity, temperature, and river discharge. Striped bass eggs are slightly heavier than water, and will suffocate if they settle to the substrate. They require sufficient current to suspend them in the water column. Eggs were concentrated near the bottom when the current velocity was less than 0.3 m/s in the San Joaquin River (Albrecht 1964). However, excessive water velocity will carry the eggs or young larvae into the slack waters of the downstream reservoir before sufficient development occurs. A minimum discharge is required to induce spawning migrations and, in some cases, allow access to optimum spawning sites (Fish and McCoy 1959). A 19-day period of steady discharge during the peak spawning period improved reproduction in the Roanoke (Staunton)

River, Virginia (Neal 1971). Recruitment was correlated with the number of days during the spawning period when discharges ranged between the historical 25% low-flow value and the 75% high-flow in the Roanoke River (Rulifson and Manooch 1990). Recruitment was strongly correlated with discharge in the San Joaquin River (Turner and Chadwick 1972).

Water temperature is one of the most important factors affecting the timing of striped bass spawning (Crance 1984). The temperature range for peak striped bass spawning is 14.5° C to 20.0° C (Kornegay and Humphries 1976). Egg survival and development are also related to temperature. Eggs develop and hatch at temperatures from 12° C to 23° C (Albrecht 1964; Shannon and Smith 1968; Morgan and Rasin 1973). Sudden and repeated temperature changes may disrupt or inhibit spawning behavior and physiology (Crim 1982).

Discharge fluctuations resulting from hydroelectric generation at Kaw Dam may adversely affect the major factors related to striped bass spawning. Low water velocity during periods of pooling may inhibit spawning and preclude egg suspension. Water temperatures in the river and stilling basin may increase during storage hours and decrease rapidly when generation begins.

My objective was to evaluate the effect of hydropower generation at Kaw Dam on densities and abundances of striped bass eggs in the Arkansas River. The null hypothesis was that no significant difference ($P \le 0.05$) existed in densities or abundances of striped bass eggs in the Arkansas River between Kaw Dam and Keystone Reservoir before and after initiation of hydropower generation at Kaw Dam.

Methods

Bohnsack (1990) studied striped bass spawning between Kaw Dam and Keystone Reservoir in 1987 and 1988. He supplied the non-hydropower data for 1987 and 1988. I replicated his methods during the first two spawning seasons of hydropower operations (1990 and 1991).

The study area encompassed the Arkansas River between Kaw Dam, near Ponca City, Oklahoma, and Keystone Reservoir, 32 km west of Tulsa, Oklahoma (Figure 1). The river is slow flowing (gradient = 0.5 m/km), shallow, and turbid, with extensive unstable sandbars and long pools (Hensley 1983). The 50-year mean discharge at Ralston, Oklahoma (Figure 1) was 137 m^3/s. Mean discharge has decreased slightly to 133 m^3/s since completion of Kaw Dam (U.S. Geological Survey 1986).

Ichthyoplankton was collected at least twice each week beginning in mid-March 2 years before (1987 and 1988, Bohnsack 1990) and 2 years after (1990 and 1991) the initiation of hydropower operations. This population was reported to begin spawning in early April (Combs 1979b). Sampling continued until striped bass ichthyoplankton was no longer present.

Sampling was conducted from an anchored boat 450 m below the dam, and at bridges 14 km (Ponca City), 78 km (Belford), 95 km (Ralston), and 119 km (Blackburn) downstream from Kaw Dam (Figure 1). Conical plankton nets 0.5 m in diameter and 2.5 m in length with 0.5-mm mesh and fitted with collecting buckets 10.2 cm in diameter and 30.5 cm long, with 0.5-mm mesh were used to sample ichthyoplankton. Three nets were fished concurrently in 1987 and 1988, and four nets were used during 1990 and

1991. Water volumes sampled were measured with General Oceanics model 2030 flow meters (General Oceanics, Miami, Florida) secured in the mouths of the nets at 0.33 of the diameter (Bowles et al. 1978). Nets were suspended just below the surface in the main current (Kornegay and Humphries 1975) for 1 hour in 1987 and for 15 minutes in 1988, 1990, and 1991. Nets occasionally clogged in the turbid water when fished for 1 hour.

Kaw Dam discharge data were supplied by the U.S. Army Corps of Engineers and Oklahoma Municipal Power Authority. The U.S. Geologic Survey operates a gauging station at Ralston, Oklahoma, and supplied the discharge data collected there. Discharge from Kaw Dam was used for Kaw Dam tailwaters and Ponca City. Discharge at the Ralston gauging station was used for the Belford, Ralston, and Blackburn sites.

Samples were preserved in 5% unbuffered formalin (Gates et al. 1987) and stored in plastic buckets immediately upon collection. Rose bengal, a protein stain, was used to facilitate sorting of ichthyoplankton from debris and other unwanted organisms (Mitterer and Pearson 1977). Striped bass ichthyoplankton was identified and enumerated using a binocular dissecting microscope with an ocular micrometer. Identification was based on published descriptions of eggs and larvae (Merriman 1941; Mansueti 1958; Bayless 1972; Combs 1979b).

Both egg densities and egg abundances were determined for each date that sampling occurred. Densities were calculated by dividing the number of eggs in each net by the volume of water sampled. I refer to the mean of all density estimates for a given date and site as the daily density (i.e., the mean of all nets). Estimated egg abundance, the number of eggs passing the site that day, was calculated by multiplying egg density by daily river discharge at the site. Daily abundance is the mean of all abundance estimates for a given date and site. Only data collected on and after 8 April of each year (the earliest date striped eggs were captured) were used in these analyses.

Daily densities and daily abundances were not normally distributed; zeros were frequent. Nonparametric techniques were therefore required to analyze these data. Each site was tested separately. One-way analysis of variance was performed on rank transformed data, a technique equivalent to the Kruskal-Wallis rank sums test (Conover and Iman 1981). Years were considered treatments and an orthogonal contrast (Steel and Torrie 1980) was used to test for a significant difference between the non-hydropower years and the hydropower years. If a significant difference among years existed Tukey's Studentized multiple range test was used to test all year combinations for significant differences. Tukey's test controls the experimentwise α-level (Steel and Torrie 1980).

The total number of eggs passing each site each year was estimated. I refer to these values as annual abundances. I estimated egg densities on dates that were not sampled by interpolating between densities on dates I did sample. Daily abundance was estimated by multiplying the interpolated densities by the volume of water discharged from Kaw Dam (Kaw Dam and Ponca City) or passing the Ralston gauging station (Belford, Ralston, and Blackburn) that day. Annual abundances were simply the sum of the daily abundance estimates.

I tested for equality of variances of annual abundances between years and sites with Levene's test (Snedecor and Cochran 1967). Variance was significantly different among years (P = 0.0218) and sites (P = 0.0074). The abundances were transformed using the natural logarithm because the means were more correlated with the variance than the standard deviation (Kempthorne 1952). The transformed data had equal variances among years (P = 0.10), but not among sites (P = 0.0093). Analysis of variance was inappropriate because of the heteroscedasticity among sites. Therefore, I tested for a significant difference in the transformed estimated annual abundances between the non-hydropower and the hydropower years using analysis of covariance (Steel and Torrie 1980). The covariate, distance of the sites downstream from Kaw Dam, substituted for blocks because variance was unequal among sites and because egg abundance increased with distance downstream. All analysis of variance and analysis of covariance procedures were performed with PC SAS (SAS Institute Inc. 1988).

I also tested the annual abundances for significant differences among years with a nonparametric test that allowed blocking by sites. Friedman's test was selected because of the small sample size (Hollander and Wolfe 1973).

Results

Striped bass eggs were collected at all sites during each year, except in the Kaw Dam tailwater in 1988. Spawning began during the second week of April each year. Striped bass eggs were first collected on 13 April in 1987, 14 April in 1988, 10 April in 1990, and on 8 April in 1991. The last eggs were collected on 19 May in 1987 and 17 May in 1988. Sampling was extended to 9 June in 1990 and 12 June in 1991 because eggs were still present in some samples until these dates.

Spawning was characterized by sporadic abrupt periods of elevated egg densities and abundances (Figures 2-5). These peaks normally occurred within one week of 1 May (Figures 3-5), except at Kaw Dam where they were delayed (Figure 2).

Maximum density from a single net was 58.3 eggs/m^3 and the highest mean density for a given site and date was 22.2 eggs/m^3. Maximum daily abundance at each site was 1,781,930 at Kaw Dam on 8 June 1991, 8,128,060 at Ponca City on 7 May 1987, 180,122,956 at Belford on 27 April 1987, 162,110,130 at Ralston on 6 May 1988, and 504,839,062 at Blackburn on 27 April 1987.

There were no significant differences in mean daily densities or mean daily abundances among years at Kaw Dam, Belford, Ralston, or Blackburn (Table 1). Significant differences existed only at Ponca City (Table 1).

Mean daily density was significantly different among years at Ponca City ($P = 0.0109$; Table 2 and Figure 3), as was mean daily abundance ($P = 0.0107$; Table 3 and Figure 4). The difference between the non-hydropower and hydropower years was significant for both mean daily density ($P = 0.0334$) and mean daily abundance ($P = 0.0292$). Mean daily density and mean daily abundance during 1987 was significantly higher than the other years, but the other years were not significantly different from each other ($\alpha = 0.05$)(Table 4).

Annual abundance was variable at all sites (Figure 7). Abundance was lowest in 1990 at the downstream sites. No eggs were found at Kaw Dam in 1988. Eggs were only captured at Kaw Dam on one day in 1991, but in high enough density to make the annual abundance estimate much larger than the other years (Figure 2). Estimated annual egg abundances were not significantly different between non-hydropower and hydropower years ($P = 0.1674$, Table 5) nor among years ($P = 0.35$, Friedman's test).

Discussion

Annual egg abundances at all sites showed no significant difference following initiation of hydropower generation. Ponca City was the only site showing significant among year differences in mean daily densities and abundance. This was due to high egg numbers in 1987, and may not be related to hydropower operations. Egg numbers in 1988, a non-hydropower year, were nearly identical to those in the two hydropower years. The unusually high discharge in March and early April of 1987 may have encouraged more fish to migrate upstream past Ponca City.

The greatest impact of daily pooling would be expected at the Kaw Dam tailwaters. Discharge is near zero when the facility is not generating and increases to between 51 m^3/s and 156 m^3/s within 30 minutes. Nevertheless, no significant difference existed in mean densities or mean abundances at this site. No eggs were captured at Kaw Dam in 1988 (before hydropower) and the greatest abundance of eggs at this site was on 8 June 1991, after 3 days of daily pooling.

Spawning was protracted following the initiation of hydropower operations (Figures 5-6). Unstable hydropower discharge and temperature regimes may have caused fish to delay spawning as they waited for better conditions. Recruitment could benefit from a longer spawning season. Recruitment could fail if all eggs are spawned during a short period and any of the critical factors for survival (i.e., river velocity, temperature, or zooplankton abundance) are not suitable. Accordingly, a longer spawning period will increase the probability of all conditions being suitable at some point in the season. Conversely, a longer spawn reduces the likelihood of exceptionally strong year classes resulting from all reproductive activity coinciding with perfect conditions.

Some spawning peaks may have gone undetected. The longest period of time that an egg could have been in the study area was 3.5 days, based on a velocity of 0.5 m/s (minimum at downstream sites) and a transport rate (Neal 1971) of 80%. Sampling was ordinarily conducted only twice a week with three or four days between samples. The peaks I detected, with only one exception, were over by the next sampling period. Abundance was high at Belford on 1 and 4 May 1991, but no such event was detected 17 km downstream at Ralston. The peak may have been abrupt and passed Ralston between sampling periods.

Hydropower generation at Kaw Dam did not have a significant effect on striped bass spawning in the Arkansas River during 1990 and 1991. Egg abundances varied to such an extent between and within years and sites, that only major effects of hydropower discharges would have been detected.

Power generation is inefficient at discharges below 51.0 m^3/s, therefore pooling normally occurred on days with a mean discharge lower than this. Mean discharge from 1 March through 31 June was 44.9 m^3/s in 1991, second lowest for this period since 1977. Mean discharge for May 1990 was 54.3 m^3/s, fourth lowest since 1976. These low discharges necessitated frequent pooling. Accordingly, serendipitous climatic conditions provided an exceptionally rigorous test of the effects of hydropower on striped bass spawning. It is unlikely that hydropower will impair striped bass spawning in this reach of the Arkansas River in the future, based on the data collected during the low discharge years of 1990 and 1991.

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Table 1.-Probability values of analysis of variance testing whether differences exist among years in rank transformed daily densities and daily abundances of striped bass eggs at five sites on the Arkansas River, Oklahoma.

Site	Density	Abundance
Kaw Dam	0.1592	0.1592
Ponca City	0.0109	0.0107
Belford	0.4514	0.3215
Ralston	0.8137	0.6151
Blackburn	0.4107	0.3604

Table 2.-Analysis of variance of rank transformed daily densities of striped bass eggs at Ponca City. Orthogonal contrast of daily densities before and after initiation of hydropower (1987 and 1988 vs. 1990 and 1991).

Source of variation	df	Sum of squares	F value	P > F
Year	3	2040.838	4.04	0.0109
Error	63	10615.162		
Corrected Total	66	12656.000		
Contrast				
Before vs. After	1	797.015	4.73	0.0334

Table 3.-Analysis of variance of rank transformed daily abundances of striped bass eggs at Ponca City. Orthogonal contrast of daily densities before and after initiation of hydropower (1987 and 1988 vs. 1990 and 1991).

Source of variation	df	Sum of squares	F value	P > F
Year	3	2045.891	4.05	0.0107
Error	63	10610.109		
Corrected Total	66	12656.000		
Contrast				
Before vs. After	1	838.664	4.98	0.0292

Table 4.-Tukey's multiple comparisons of rank transformed daily densities and daily abundances of striped bass eggs at Ponca City, Oklahoma. Means with the same group letter are not significantly different (α =0.05).

Year	Density Mean rank	Density Group	Abundance Mean rank	Abundance Group
1987	44.267	A	44.267	A
1988	31.400	B	31.600	B
1990	31.056	B	31.056	B
1991	30.737	B	30.579	B

Table 5. Analysis of covariance testing whether differences existed in the total number of striped bass eggs passing all sites all 4 years. Egg numbers were natural logarithm transformed. Distance downstream from Kaw Dam represents the five sites.

Source of variation	df	Sum of squares	F value	P > F
Distance downstream	1	207.1109	17.36	0.0007
Discharge regime	1	24.9644	2.09	0.1674
Interaction of above	1	32.3010	2.71	0.1194
Error	16	438.9651		

Figure Captions

1.- Sampling sites along the Arkansas River between Kaw Dam and Keystone Reservoir in north-central Oklahoma.

2.- Daily egg abundances at Kaw Dam tailwater from 1 April through 12 June of 1987, 1988, 1990, and 1991. Note that the ordinate scale is larger on the 1991 graph. Open circles indicate zero.

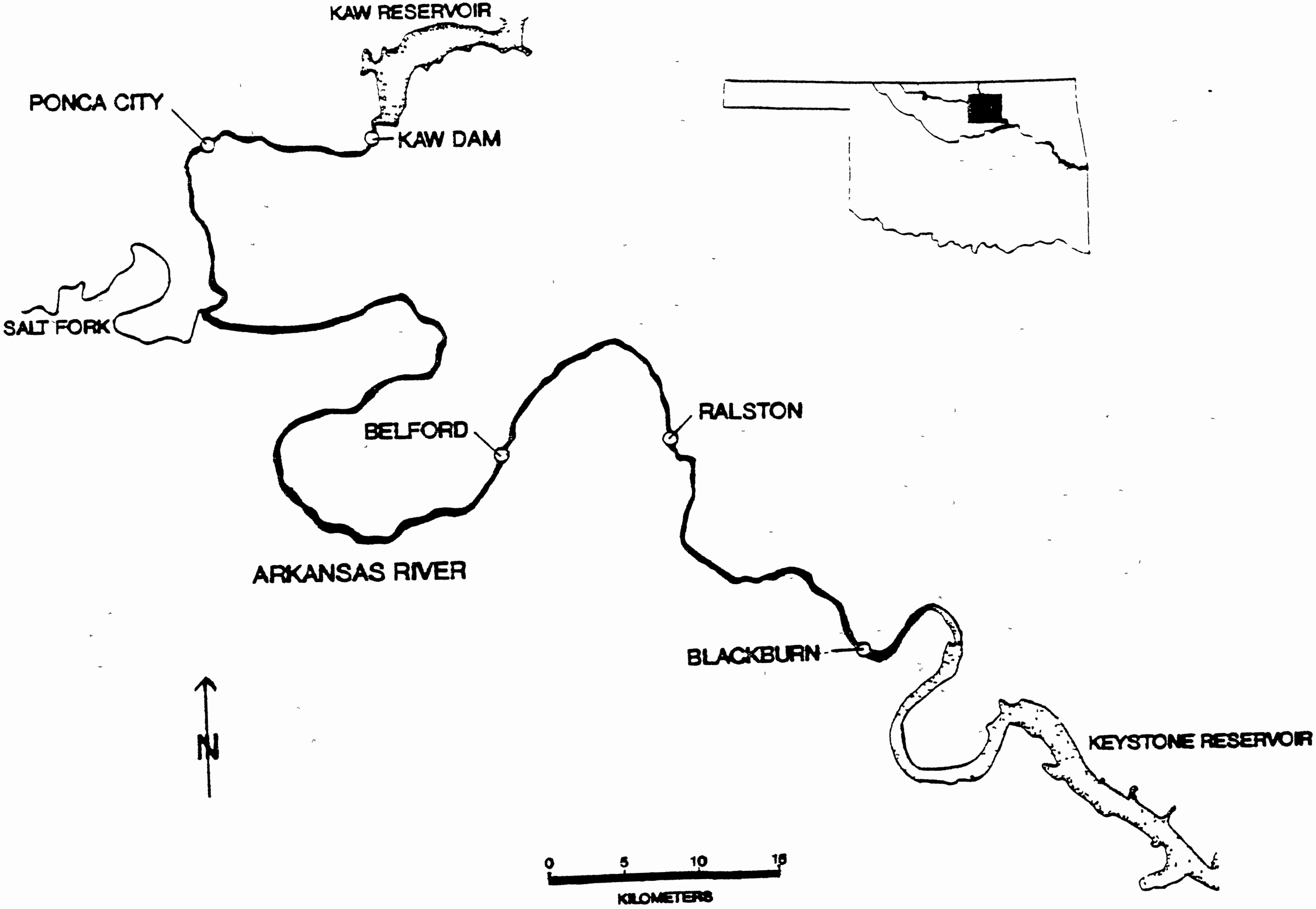
3.- Daily densities (eggs/m^3) at Ponca City from 1 April through 12 June in 1987, 1988, 1990, and 1991. Open circles indicate zero.

4.- Daily egg abundances at Ponca City from 1 April through 12 June in 1987, 1988, 1990, and 1991. Open circles indicate zero.

5.- Daily egg abundances at Belford from 1 April through 12 June in 1987, 1988, 1990, and 1991. Open circles indicate zero.

6.- Daily egg abundances at Blackburn from 1 April through 12 June in 1987, 1988, 1990, and 1991. Open circles indicate zero.

7.- Estimated annual egg abundances at all sites in 1987, 1988, 1990, and 1991.


KAW RESERVOIR
PONCA CITY
KAW DAM
SALT FORK
BELFORD
RALSTON
ARKANSAS RIVER
BLACKBURN
KEYSTONE RESERVOIR
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5
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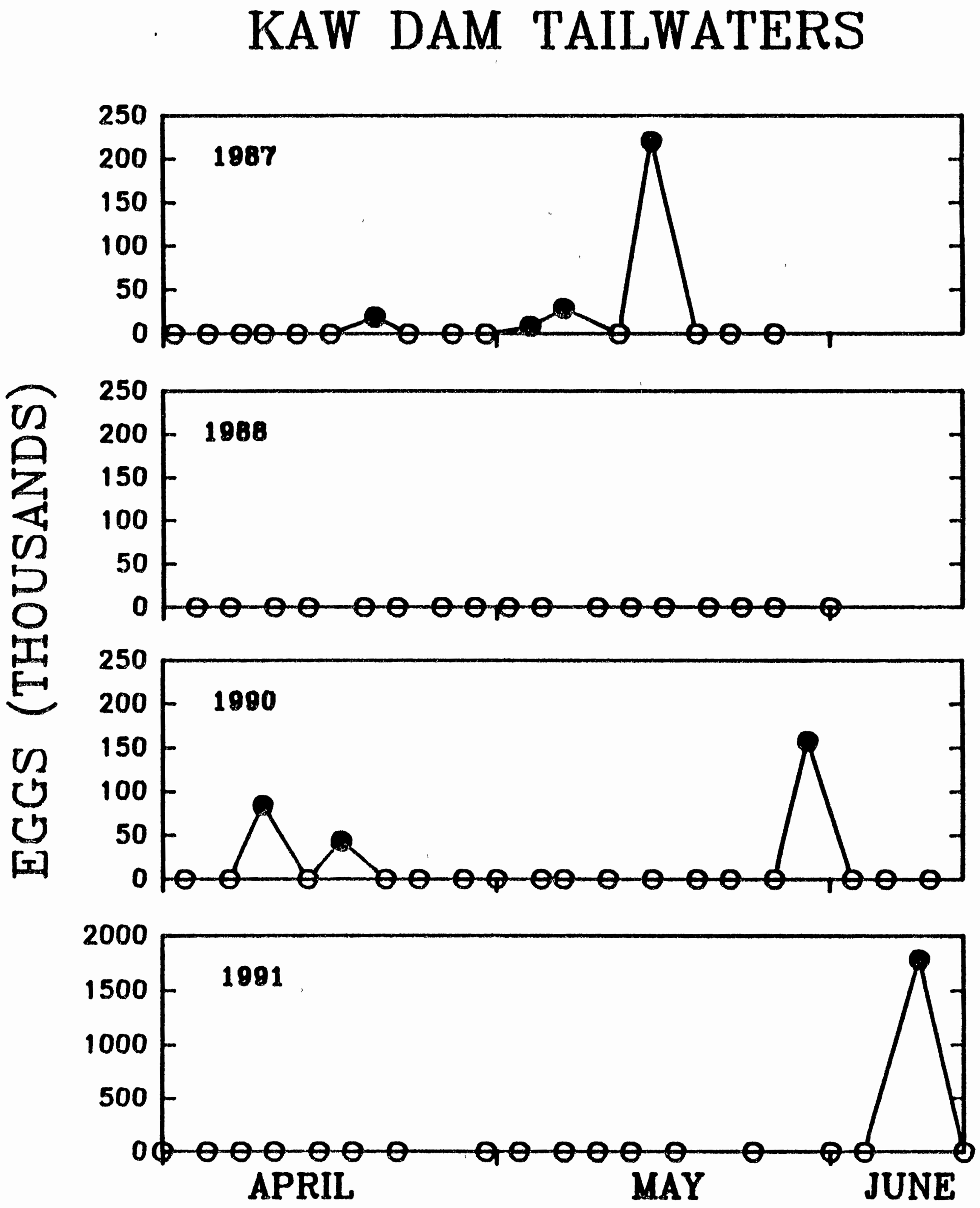
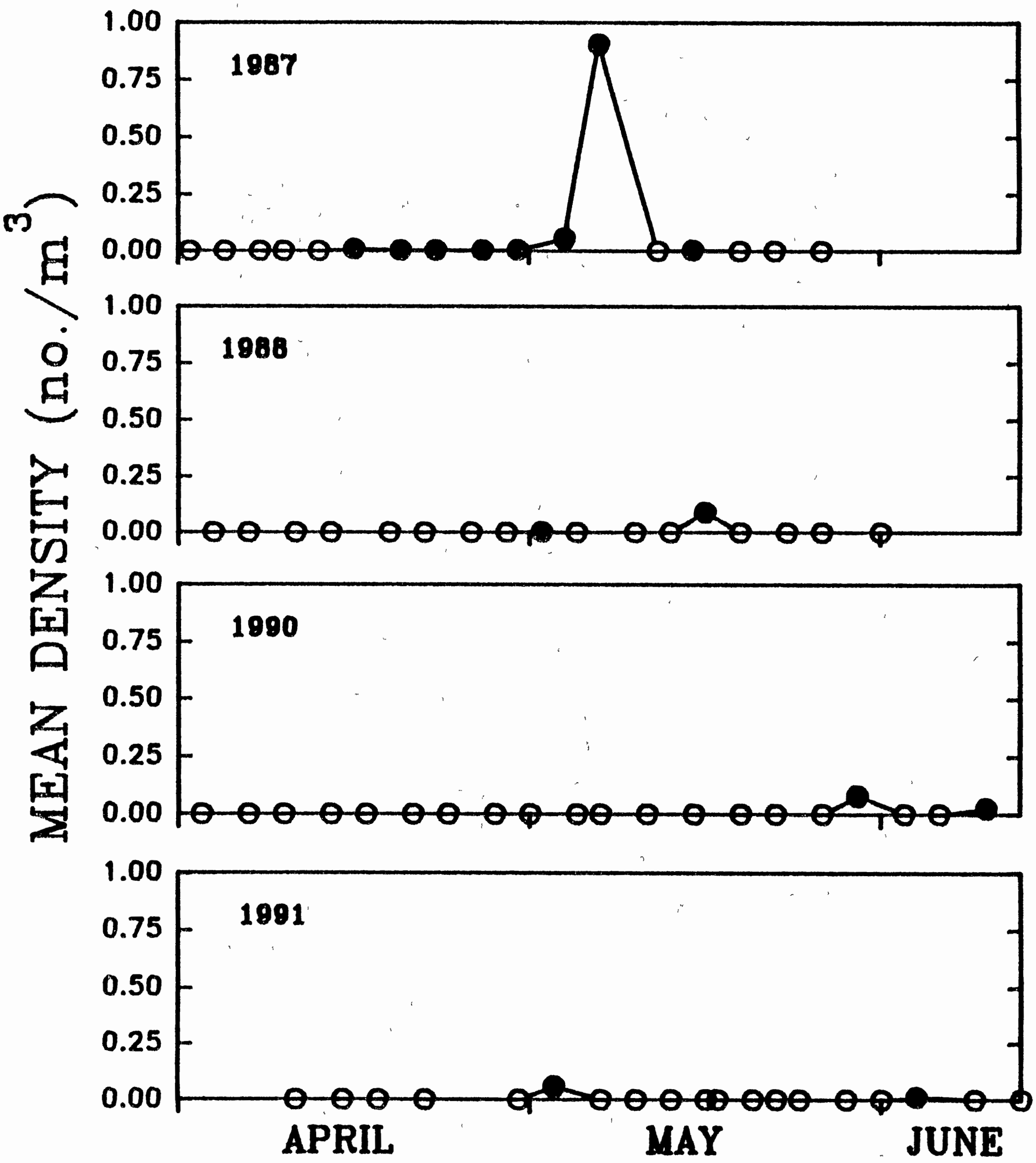
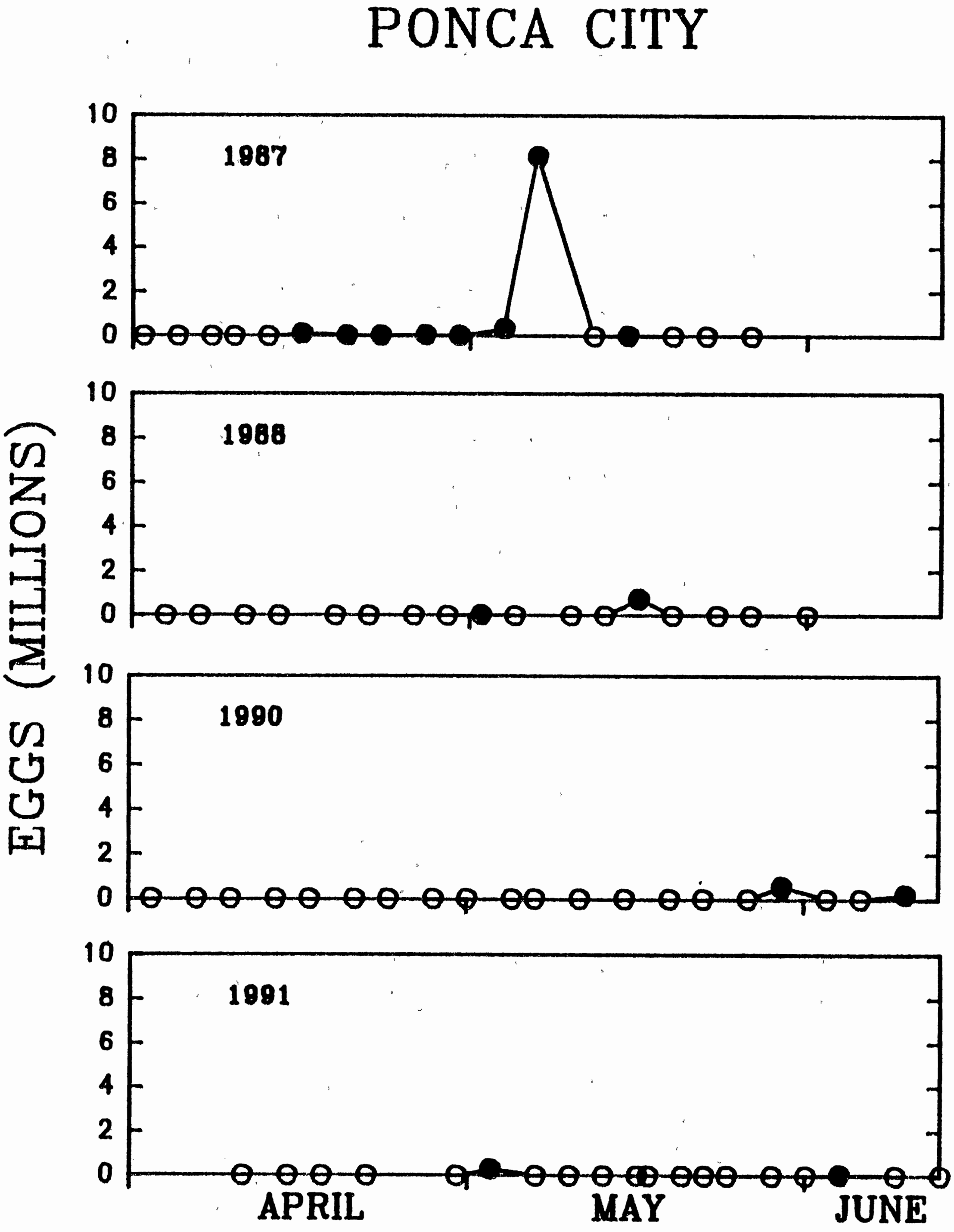
KILOMETERS

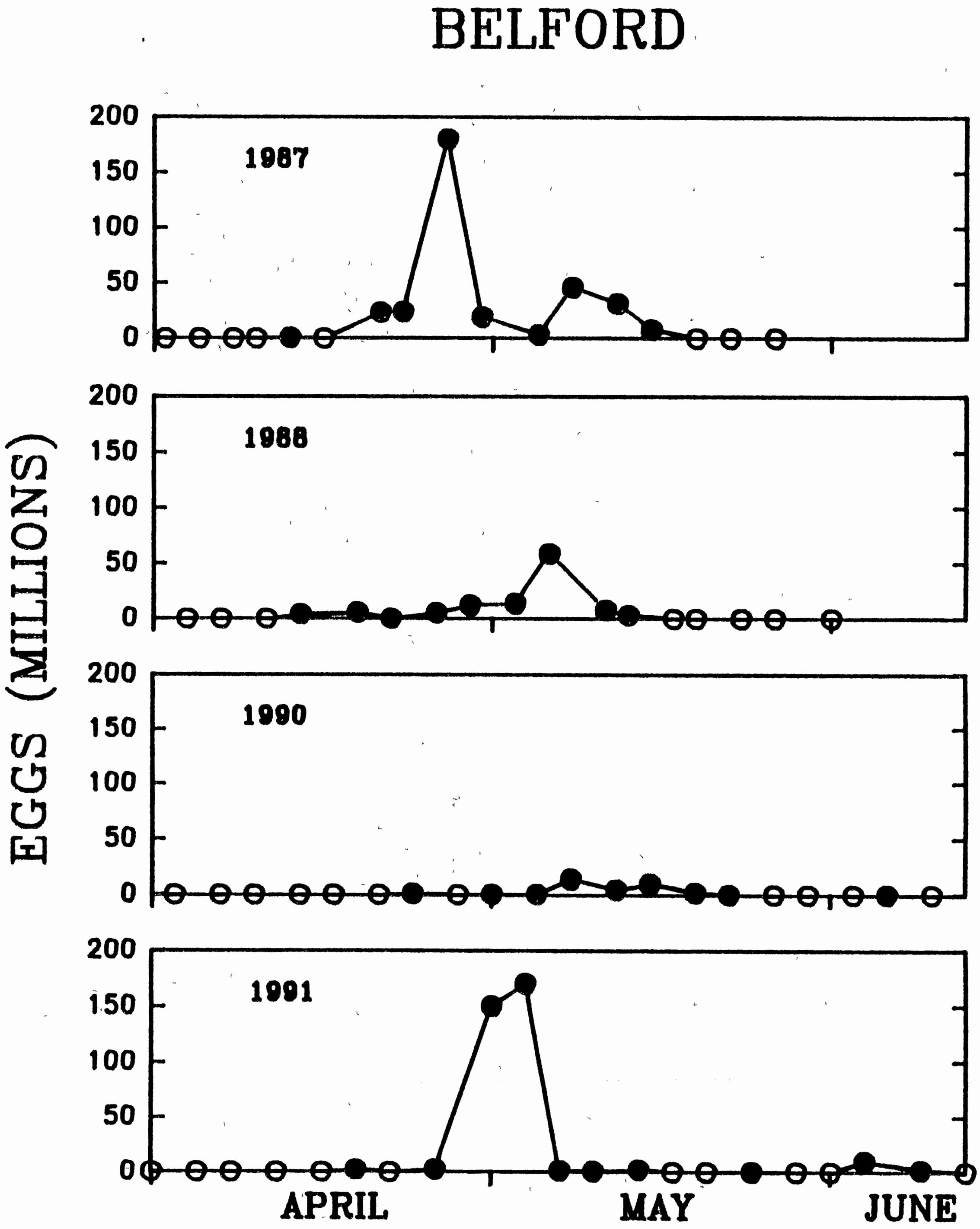


KAW DAM TAILWATERS

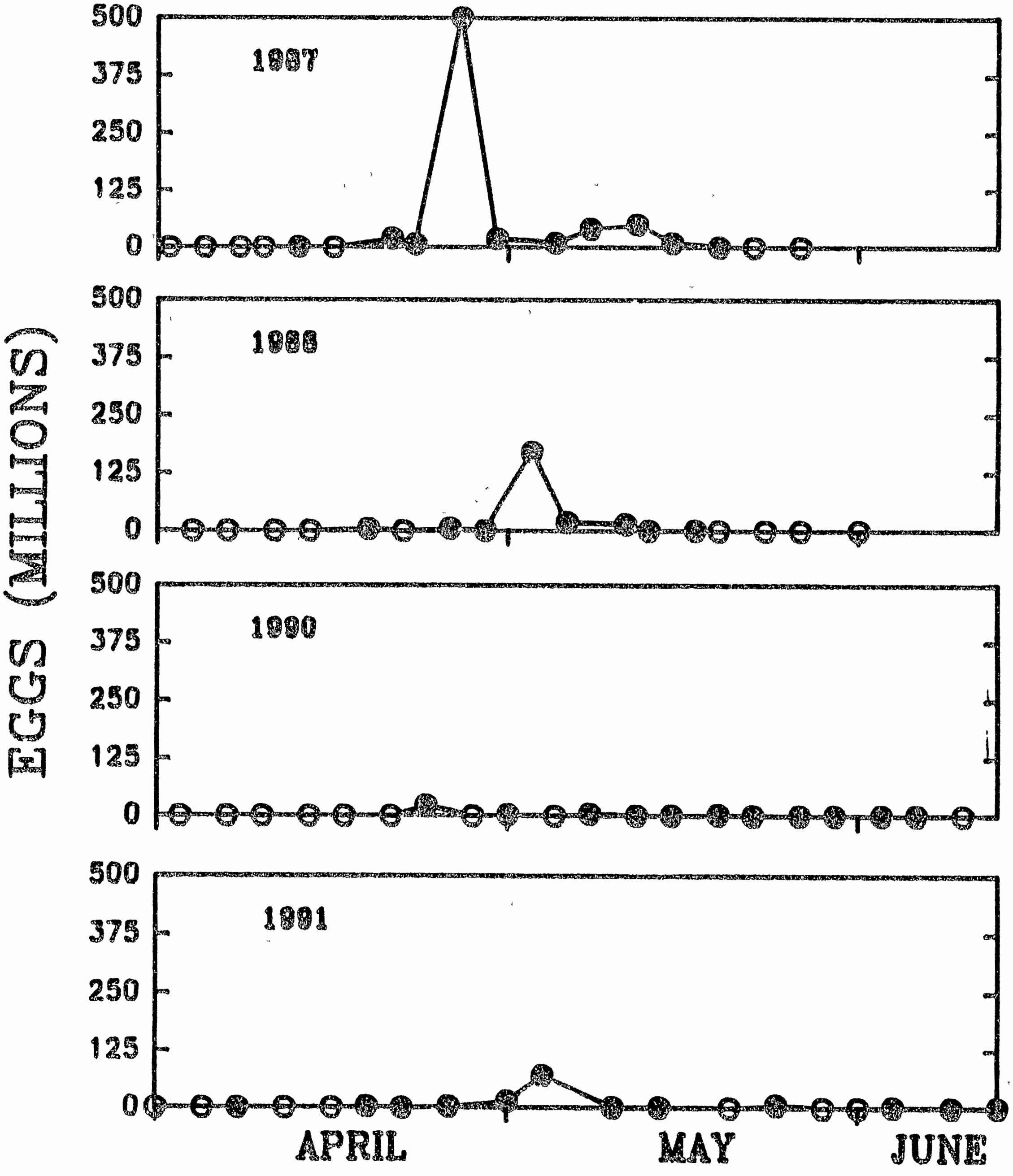
PONCA CITY

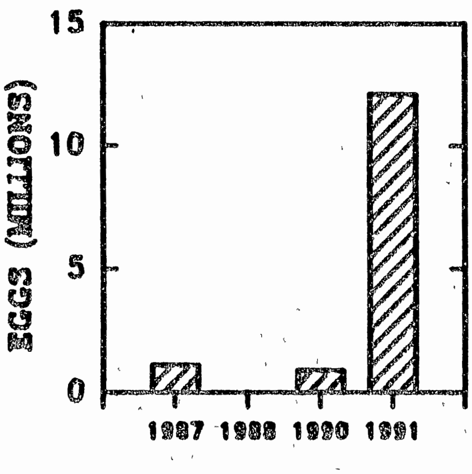

1987
1988
1990
1991
1.00
0.75
0.50
0.25
0.00
MEAN DENSITY (no./m³)
APRIL
MAY
JUNE


PONCA CITY
EGGS (MILLIONS)
10
8
6
4
2
0
1987
1988
1990
1991
APRIL
MAY
JUNE


BELFORD
EGGS (MILLIONS)
200
150
100
50
0
1987
1988
1990
1991
APRIL
MAY
JUNE

BLACKBURN


EGGS (MILLIONS)
500
375
250
125
0
1987
1988
1990
1991
APRIL
MAY
JUNE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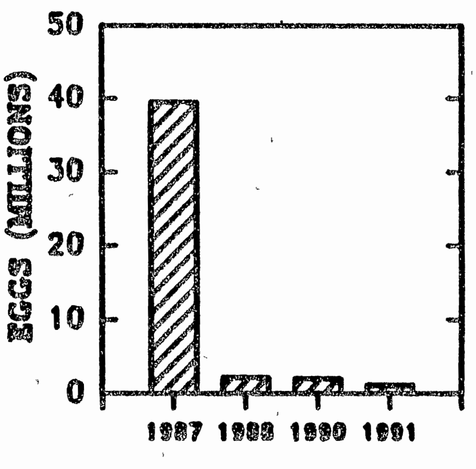
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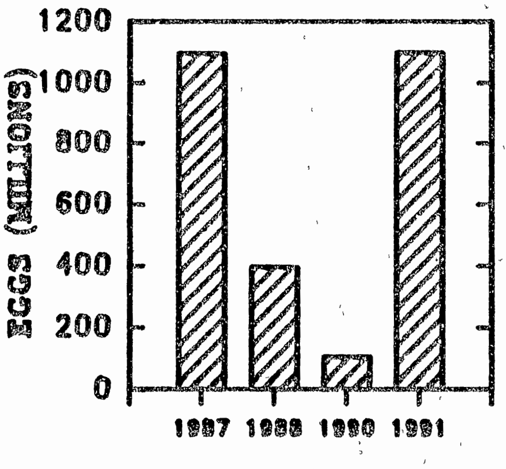
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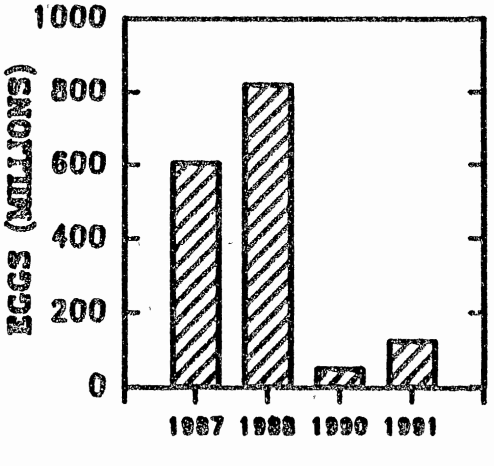
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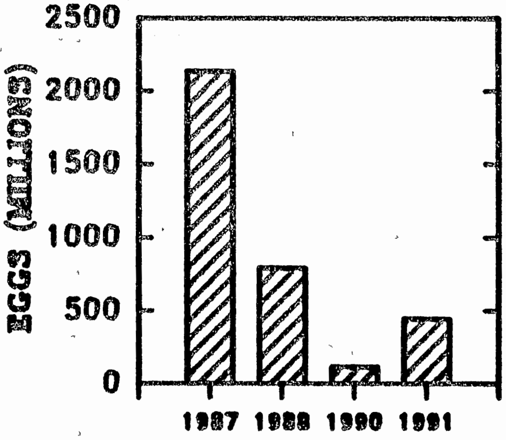
BLACKBURN

CHAPTER II

EFFECTS OF THE ADDITION OF HYDROPOWER TO KAW DAM ON ENVIRONMENTAL VARIABLES RELATED TO SPAWNING SUCCESS OF STRIPED BASS IN THE ARKANSAS RIVER, OKLAHOMA.

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Abstract.-A hydropower generator was added to Kaw Dam on the Arkansas River, Oklahoma in 1989. I determined the effects of hydropower operations on environmental variables important to striped bass spawning, between Kaw Dam and Keystone Reservoir during the first two spawning seasons with hydropower (1990 and 1991). I measured water temperature, pH, dissolved oxygen concentration, conductivity, and current velocity at five sites and compared them to data collected in 1987 and 1988. Daily discharge fluctuations were significantly greater during hydropower years ($P = 0.0001$) as far as 95 km downstream of Kaw Dam. Percent oxygen saturation was significantly lower during hydropower years than non-hydropower years ($P = 0.0001$) as far as 14 km downstream from Kaw Dam. After reservoir stratification, sluice gate discharges were required to maintain dissolved oxygen concentrations above 5 mg/l during hydropower generation in 1990 and 1991. Striped bass eggs require a current velocity of 0.3 m/s to remain suspended in the water column. Current velocities were often near zero in the tailwater and 0.3 m/s 14 km downstream during storage hours. Striped bass spawning was protracted during hydropower years; late spawned eggs were occasionally exposed to temperatures lethal to striped bass eggs. Hydropower discharge fluctuation was frequent in 1991 because of low discharge. Nevertheless, this section of river provided favorable conditions for striped bass spawning.

The Oklahoma Department of Wildlife Conservation introduced striped bass (Morone saxatilis) into Keystone Reservoir from 1965 through 1969 to produce a trophy sport fishery and to control gizzard shad (Dorosoma cepedianum) (Combs 1979). The striped bass is an anadromous species native to the eastern and Gulf coasts of North America. Reproduction of striped bass has occurred annually in the Arkansas River tributary of Keystone Reservoir since 1970 (Mensinger 1971; Hicks 1982; Bohnsack 1990) precluding the need for additional stocking. The Keystone population is one of only eight reproducing potadromous striped bass populations, although the species has been introduced into large reservoirs in at least 38 states (Gustaveson et al. 1984).

A popular striped bass fishery has developed in Keystone Reservoir as well as in its headwaters and tailwaters (Combs 1980; Hamilton et al. 1985; Jacks 1990). Individuals from this population disperse far downstream; striped bass tagged in the Keystone Dam tailwaters have been caught in Arkansas and in the Gulf of Mexico (Zale and Jacks 1988). Additionally, this population is one of the best sources of brood stock for state hatcheries, thereby supporting striped bass and striped bass x white bass (Morone chrysops) hybrid fisheries throughout Oklahoma (Hensley 1983).

Kaw Dam was constructed on the Arkansas River 150 km above Keystone Reservoir in 1976. The dam blocked striped bass spawning migrations which previously extended into Kansas. Annual recruitment estimates in Keystone Reservoir suggest that striped bass recruitment may have increased since completion of the dam because of moderation of floods and droughts (Combs 1979).

A hydroelectric generator was added to Kaw Dam in the autumn of 1989, resulting in a change in discharge regime. Power generation is inefficient at low discharges. Therefore, daily pooling is practiced. Daily allotments of water less than could efficiently generate power the entire day were stored for a time and released at a higher, more efficient rate for a shorter period of time than if discharge was constant the entire day. Generation and associated high discharges were estimated to occur for an average of 8 h/d (Hensley 1983). Discharge fluctuations due to hydropower generation vary as much as the capacity of the hydropower facility (156 m^3/s).

Successful reproduction of striped bass is dependent on many environmental factors. Some of the most important of these are current velocity, water temperature, and river discharge. The eggs of striped bass are slightly heavier than water and will suffocate if they settle to the substrate. Thus, they require sufficient current to suspend them in the water column. Eggs were concentrated near the bottom when the current velocity was less than 0.3 m/s in the San Joaquin River, California (Albrecht 1964). However, excessive water velocity will carry the eggs or young larvae into the slack waters of the downstream reservoir before sufficient development occurs. A minimum discharge is required to induce spawning migrations and, in some cases, allow access to optimum spawning sites (Fish and McCoy 1959). A 19-day period of steady discharge during the peak spawning period improved reproduction in the Roanoke (Staunton) River, Virginia (Neal 1971). Recruitment was correlated with the number of days during the spawning period when discharges ranged between the historical 25% low-flow and the 75% high-flow in the Roanoke River (Rulifson and Manooch 1990). Recruitment was strongly correlated with discharge in the San Joaquin River, (Turner and Chadwick 1972).

Water temperature is one of the most important factors affecting the timing of striped bass spawning (Crance 1984). The temperature range for peak spawning of striped bass is 14.5° C to 20.0° C (Kornegay and Humphries 1976). Egg survival and development are also related to temperature. Eggs can develop and hatch from 12° C to 23° C (Albrecht 1964; Shannon and Smith 1968; Morgan and Rasin 1973). Sudden and repeated temperature changes may disrupt or inhibit spawning behavior and physiology (Crim 1982).

Hydropower operations may affect environmental variables associated with striped bass spawning by drawing water from a different level of the reservoir or increasing the variability due to pooling (Neal 1971; Baxter 1977; Cada et al. 1983; Hensley 1983). Low current velocity during periods of pooling may inhibit spawning and preclude egg suspension. Water temperatures in the river and stilling basin may increase during storage hours and decrease rapidly when generation begins. Striped bass eggs require 5.0 mg/l of dissolved oxygen (Turner and Farley 1971). Hydropower releases are often low in dissolved oxygen (Cada et al. 1983).

The objective of this research was to evaluate the effect of hydropower generation at Kaw Dam on environmental variables important to striped bass reproductive success in the Arkansas River. The null hypotheses were that hydropower operation had no significant effect ($P \leq 0.05$) on means or variances of temperature, pH, dissolved oxygen, current velocity, or conductivity in the Arkansas River, Oklahoma.

Methods

The study area encompassed the Arkansas River between Kaw Dam, near Ponca City, Oklahoma, and Keystone Reservoir 32 km west of Tulsa, Oklahoma (Figure 1). The river is slow flowing (gradient = 0.5 m/km), shallow, and turbid, with extensive unstable sandbars and long pools (Hensley 1983). The 50-year mean discharge at Ralston, Oklahoma, (Figure 1) was 137 m^3/s. Mean discharge has decreased slightly to 133 m^3/s since completion of Kaw Dam (U.S. Geological Survey 1986). Sampling was conducted from an anchored boat 450 m below Kaw Dam (Kaw Dam), and at bridges 14 km (Ponca City), 78 km (Belford), 95 km (Ralston), and 119 km (Blackburn) downstream from Kaw Dam (Figure 1).

Bohnsack (1990) supplied water quality data measured between Kaw Dam and Keystone Reservoir in 1987 and 1988. I replicated his methods during the first two spawning seasons with hydropower (1990 and 1991). Sampling was conducted at least twice each week. Striped bass spawning was reported to begin in mid-April at this site (Combs 1979). Sampling began in mid-March and continued until spawning ceased (Chapter I).

Temperature, dissolved oxygen, pH, and conductivity were measured using a Hydrolab Surveyor II (Hydrolab Corporation, Austin, Texas). YSI meters (Yellow Springs Instrument Company, Yellow Springs, Ohio) were used to measure temperature, conductivity, and dissolved oxygen concentration when the Hydrolab was inoperable. Current velocity was measured with a Teledyne Gurley Model 622 current meter (Teledyne Gurley, Troy, New York).

All measurements were taken in the main current. However, when the water level at the Kaw Dam tailwater was too low to launch the boat, measurements were taken at the boat ramp. Velocity was assumed to be zero when discharge in the Kaw Dam tailwater was too low to launch a boat.

Kaw Dam mean hourly discharge data were supplied by the U.S. Army Corps of Engineers and Oklahoma Municipal Power Authority. The U.S. Geological Survey supplied the daily minimum, maximum, and mean discharge data from Ralston and monthly mean discharge data from Kaw Dam for 1976 through 1991. Daily discharge fluctuation was measured as a percentage of the mean. Daily fluctuation was equal to the discharge range divided by the mean discharge for the day multiplied by 100.

Dissolved oxygen concentration is confounded with temperature. Variance of dissolved oxygen concentration was affected by the slope of the seasonal temperature increase. Therefore, I converted dissolved oxygen to percent oxygen saturation using tables prepared by Green and Carritt (1967). I could then better test oxygenation as influenced by aeration, respiration, and photosynthesis among years independent of temperature regimes. Percent oxygen saturation also allowed me to test for variability of oxygenation due to pooling, independent of temperature.

I tested all variables (hourly discharge, daily discharge fluctuation, temperature, percent oxygen saturation, pH, conductivity, and current velocity) for homogeneity of variance among years at each site with Levene's test (Snedecor and Cochran 1967). Variance must be homogeneous to test means with analysis of variance. An orthogonal contrast tested for a significant difference in variance of the variables between non-hydropower and hydropower years (Steel and Torrie 1980). Tukey's Studentized range test (Steel and Torrie 1980) was used to elucidate differences between all year pairs if a significant difference among years existed. If variance was significantly different among years, natural logarithmic and square root transformed data were used in additional Levene's tests. If none of these transformations homogenized the variance among years, rank transformation was used.

Because temperature increased through the sampling season, variance of temperature was affected by the slope of the seasonal increase. Temperature data were not collected frequently enough to separate the effect of hydropower operations from that of seasonal warming. Therefore, I did not test for differences in variance of temperatures between non-hydropower and hydropower years.

Temperature and pH data were homoscedastic at all sites except Kaw Dam. Untransformed and rank transformed pH and temperature data for Kaw Dam resulted in identical conclusions in tests of means. Therefore, I used the untransformed data to test for differences in means at all sites for both of these parameters.

The natural logarithmic transformation (base e) homogenized variance of percent oxygen saturation data, and therefore was used in the tests of means for this parameter.

Variance of hourly discharge, daily fluctuation, velocity, and conductivity, were heteroscedastic. I could find no suitable transformation. Therefore, I used rank transformations in the analysis of variance for differences in means. This is equivalent to the nonparametric Kruskal-Wallis rank sums test (Conover and Iman 1981). This technique does not assume homogeneity of variance.

Each parameter was tested for a significant difference in means among years at each site with analysis of variance. Transformed data were used for some variables as described above. An orthogonal contrast was used to test for a significant difference in means between the non-hydropower and hydropower years. If a significant difference among years was detected, Tukey's Studentized range test was used to elucidate the specific differences between years (Steel and Torrie 1980). All statistical tests were performed with PC SAS (SAS Institute 1988).

Results

Discharge from Kaw Dam varied each year of this study (Figure 2). The mean discharge from 1 March through June 1987 was 264 m^3/s, the highest in the 15 years since the dam was built. Conversely, the March through June discharge in 1991 of 45 m^3/s was the second lowest recorded. Discharge for this period in 1988 was 116 m^3/s (sixth lowest) and 120 m^3/s in 1990 (eighth lowest). The 15-year mean discharge during this period was 126 m^3/s. Mean hourly discharge from Kaw Dam was significantly different ($P < 0.0001$) among years. Mean hourly discharge of each year was significantly different from each of the other three years ($\alpha = 0.05$).

Significant differences in daily discharge fluctuation (Figure 3) existed between non-hydropower and hydropower years at both Kaw Dam ($P = 0.0001$) and Ralston ($P = 0.0001$). Daily discharge fluctuation was significantly greater during 1990 and 1991 than during 1987 and 1988 ($\alpha = 0.5$). Variance of daily fluctuation was significantly different between non-hydropower and hydropower years at both Kaw Dam ($P = 0.0001$) and Ralston ($P = 0.0120$). At both sites, variance of daily fluctuation was greater during hydropower years than non-hydropower years ($\alpha = 0.05$).

Water temperature at Kaw Dam tailwater on the first sampling date was 9.30° C in 1987, 5.48° C in 1988, 10.89° C in 1990, and 7.03° C in 1991. Temperatures increased sharply throughout the sampling period each year at all sites (Figure 4). After mid-May, temperatures at the downstream sites generally exceeded the acceptable level for striped bass eggs (23° C; Morgan and Rasin 1973; Crance 1984). Significant differences existed in mean temperatures between non-hydropower and hydropower years at Ponca City ($P = 0.0123$). However, temperature was not significantly different between non-hydropower and hydropower years at Kaw Dam tailwaters ($P = 0.2447$), Belford ($P = 0.0515$), Ralston ($P = 0.1325$), or Blackburn ($P = 0.2850$; Table 1 and Figure 5). Temperatures were elevated during 1991 at all sites ($\alpha = 0.05$).

Percent oxygen saturation was significantly different between non-hydropower and hydropower years at both Kaw Dam ($P = 0.0001$) and Ponca City ($P = 0.0001$; Table 1 and Figure 6). At these sites, percent saturation was higher during non-hydropower years. Percent oxygen saturation was not significantly different between non-hydropower and hydropower years at Belford (P = 0.1748), Ralston (P = 0.9009), or Blackburn (P = 0.0648). Variance of percent oxygen saturation was not significantly different between non-hydropower and hydropower years at any site (Table 1).

The lowest current velocity measured was 0.19 m/s at Kaw Dam on 20 March 1990. Velocity was assumed to be 0.0 m/s in the at Kaw Dam during storage periods. Significant differences in current velocity existed between non-hydropower years and hydropower years at Kaw Dam (P = 0.0001), Ponca City (P = 0.0059), and Belford (P = 0.0104), mean current velocitiy being greater at these sites before the initiation of hydropower generation (Table 1). No significant difference in current velocity existed between the non-hydropower and hydropower years at Ralston (P = 0.5776) or Blackburn (P = 0.9582). Significant differences in variance of current velocities existed between non-hydropower and hydropower years at Kaw Dam (P = 0.0146) and Blackburn (P = 0.0284). Current velocity was more variable during hydropower years at Kaw Dam and less variable at Blackburn. Variance of current velocity was not significantly different between non-hydropower and hydropower years at Ponca City (P = 0.0846), Belford (P = 0.1051), or Ralston (P = 0.7433).

Conductivities ranged from 207 μmhos on 4 April 1988 to 4070 μmhos on 12 April 1991, both at Ralston. Conductivities were typically higher at the downstream sites (below the confluence of the Salt Fork). Conductivity was significantly different between the non-hydropower and hydropower years at all sites (Table 1). Conductivity was high at all sites in 1991. Variance in conductivity was significantly different between non-hydropower and hydropower years at Kaw Dam (P = 0.0001), Ponca City (P = 0.0001), Ralston (P = 0.0036), and Blackburn (P = 0.0105). Variance in conductivity in 1987 and 1988 was greater than 1990 and 1991 at both Kaw Dam and Ponca City. At the downstream sites, variance in conductivity was highest in 1991. No significant difference in variance in conductivity existed at Belford (P = 0.2566).

Minimum and maximum pH values were 6.80 at Ponca City on 17 April 1990 and 9.07 at Ralston on 12 April 1991. No significant differences in pH existed between non-hydropower and hydropower years at Kaw Dam (P = 0.7554), Ponca City (P = 0.9596), Belford (P = 0.2873), Ralston (P = 0.6686) or Blackburn (P = 0.8535). Variance of pH was significantly greater after initiation of hydropower at Kaw Dam (P = 0.0103). Variance of pH was greater at No significant differences existed in variance of pH values between non-hydropower and hydropower years at Ponca City (P = 0.2618), Belford (P = 0.4044), Ralston (P = 0.2469), or Blackburn (P = 0.9386).

Discussion

Large differences existed in discharge among years (Figure 2). The differences were due to rainfall, not hydropower operations. High and low discharge both have been correlated with poor striped bass recruitment in the Roanoke (Staunton) and San Joaquin rivers (Turner and Chadwick 1972; Rulifson and Manooch 1990). Nevertheless, striped bass spawned successfully in the Arkansas River during 1987 when mean discharge was 209% of the 15-year mean and also in 1991 when mean discharge was only 36% of the 15-year mean (Chapter I). The large differences in mean discharge among years had obvious effects on water quality parameters, such as temperature, velocity, and conductivity.

Hydropower operations affected daily discharge regimes throughout the spawning area. Daily discharge fluctuation was significantly greater at both Kaw Dam and Ralston. The effects of hydropower operations were much smaller at Ralston than at Kaw Dam, but the mean daily fluctuations in 1990 and 1991 were double that of 1987 and 1988. These regular fluctuations in discharge rates may have been responsible for the decrease in striped bass egg abundances and extension of the spawing season (Chapter I). Fish may have delayed spawning, waiting for more stable flows. Neal (1971) reported that spawning was improved in the Roanoke (Staunton) River by holding discharge constant for 2 weeks (Neal 1971).

Temperatures were higher at all sites in 1991 (Figure 5). The higher water temperatures in 1991 were due to low discharge. The higher temperatures at Kaw Dam may have been due to the low reservoir elevation and the warm inflows. The difference in temperatures between 1991 and the other years was greatest at Belford. Water temperatures apparently reached ambient air temperatures before reaching Belford in 1991. Otherwise, water temperature would have increased at Ralston and Blackburn, as it did during the first three years. Thus, I believe high water temperatures in 1991 probably were due to low discharge (thermal inertia) and not higher air temperatures. Hydropower operations often decrease downstream temperatures because penstocks typically withdraw deep water (Baxter 1977). Temperatures were not lower after the initiation of hydropower at this site because discharges before hydropower were usually concurrent with sluice and tainter gate discharges. The penstock draws water from a depth intermediate of the sluice and tainter gates.

The initiation of spawning and the period of peak spawning have been associated with specific water temperatures and photoperiod (Kornegay and Humphries 1976; Crance 1984). Occurrence of eggs suspended in the water indicated that striped bass egg abundance was correlated more closely with photoperiod than with temperature during 1987 and 1988 at my study sites (Bohnsack 1990). The optimal spawning temperature of 18.0° C (Crance 1984) was reached 21 days earlier in 1991 than in any of the other 3 years. Nevertheless, the first eggs were collected in 1991 only 6 days earlier than in 1988, the year spawning began latest (Chapter I). Photoperiod likely cues the initiation of spawning. Peak abundance of eggs occurred within 1 week of 1 May each year at the downstream sites. Peak egg abundances were generally delayed at the upstream sites, suggesting an effect of temperature. Apparently, both temperature and photoperiod are important temporal cues for striped bass spawning in the Arkansas River.

Temperatures above 23° C are lethal to striped bass eggs (Morgan and Rasin 1973). Eggs were captured at temperatures up to 28.9° C, but eggs were captured at temperatures greater than 23° C on only a few days each year. Spawning was protracted nearly a month longer during hydropower years than during non-hydropower years (Chapter I). Late-spawned eggs may have a lower probability of survival because water temperatures often exceeded tolerable levels after mid-May at the downstream sites.

Dissolved oxygen concentration is dependent primarily on temperature, aeration, photosynthesis, and biochemical oxygen demand. I removed the confounding effect of temperature by assessing percent oxygen saturation rather than dissolved oxygen concentration. Hydropower operations depressed oxygen levels in the tailwater and as far downstream as Ponca City (Figure 6). Hydropower limited aeration because the discharge was released below the surface of the water in the stilling basin. Both tainter and sluice gates produced highly aerated discharges. Energy deflectors at sluice openings spayed the discharged water into the air. Tainter gate discharges form thin sheets of water which fall into the tailwater. Oxygen levels were also depressed because the hydropower penstock draws relatively deep water. Oxygen levels decreased through the spring as the reservoir stratified and the hypolimnion became anoxic. Much of the penstock is below the typical thermocline at Kaw Reservoir. Because the river below the dam is slow-flowing with sand substrate, the lack of turbulent flows and riffles limits aeration, keeping the dissolved oxygen depressed as far downstream as Ponca City; however, it reaches saturation before Belford.

Dissolved oxygen concentration in the tailwater was rarely below 5 mg/l, the critical level for striped bass eggs (Turner and Farley 1971; Crance 1984). Corrective action was taken by the hydrpopower operators when dissolved oxygen in the tailrace was less than 6 mg/l for more than 6 hours, or if it dropped below 5 mg/l. Corrective action involved halting hydropower discharges, releasing water via the sluice gates, or a combination of both.

Current velocity is a critical factor for successful striped bass reproduction. If velocity is less than 0.3 m/s, the eggs will settle to the substrate and die (Albrecht 1964). As a result of pooling, current velocity was near zero at Kaw Dam and near the critical limit at Ponca City. Low velocities at Kaw Dam were more common than these data indicate because sampling at Kaw Dam was biased toward generation periods. Velocities below 0.3 m/s were uncommon before hydropower operation. Velocity lower than 0.3 m/s was only measured on one occasion at the downstream sites (22 May 1987 at Ralston). Frequent low velocities in the first 14 km downstream from Kaw Dam would likely impair striped bass reproduction in this reach. However, most striped bass spawning occurs downstream from Ponca City (Bohnsack 1990).

Conductivity is directly related to ion concentration. The river flows through mineral deposits, picking up ions. These ions become dilute at high discharges and concentrate at low discharges. Therefore, conductivity was closely related to river discharge. Low discharge in 1991 resulted in high conductivities and high discharges in 1987 resulted in lower conductivities. Conductivity probably was not affected by hydropower operations. Striped bass eggs can tolerate all conductivites I measured in this river reach (Crance 1984).

All pH measurements were within the tolerance range of striped bass eggs and most fell within the optimum range of pH 7.5 - 8.5 (Crance 1984). Differences in pH values among years at Kaw Dam were not due to hydropower operations. Kaw Reservoir stratified earlier in 1987 and 1991, the years of higher pH. Temperatures were high in April 1991 and May 1987. High temperatures caused algal blooms and earlier stratification. The pH also increased, possibly due to increased photosynthesis from the algal bloom (Wetzel 1975). Dissolved oxygen concentration in Kaw Reservoir decreased rapidly in late May 1991, leading to unstable and decreasing pH values; this is consistent with the suggestion that the earlier high pH values observed in April were due to high levels of photosynthesis. Another possible reason for high pH in 1991 was high conductivity. Anions contributing to high conductivity could also absorb hydrogen ions (Wetzel 1975). The maximum pH value (9.07) coincided with the maximum conductivity (4070 μmhos). High pH values in 1987 could not be attributed to this because conductivity was low during this year.

Hydropower operations had some deleterious effects on environmental factors important for successful striped bass reproduction. Current velocities lower than required to suspend striped bass eggs (Albrecht 1964) were common during hydropower years from Kaw Dam downstream to Ponca City. Little spawning occurred in this reach before hydropower operation began (Bohnsack 1990). Therefore, low velocities in this reach are not a major concern. Mean daily discharge fluctuations were 10 times greater at Kaw Dam and 2 times greater at Ralston during hydropower years. Discharge fluctuations are impediments to successful spawning (Neal 1971). Despite these conditions, spawning did occur at all sites during 1990 and 1991.

Because of the low discharge in 1991, daily pooling occurred on more days than will typically occur. Additionally, discharges will typically be of longer durations than in 1991. Because successful striped bass spawning occurred at all sites under these extreme conditions, it is unlikely that hydropower operations will have detrimental effects on striped bass reproduction in the future.

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Table 1.-Probability values testing whether differences existed between water quality characteristics before and after initiation of hydropower and among years. Tests of means were based on rank transformed data, except temperature and pH were untransformed and oxygen saturation was natural logarithmically transformed. Variances were tested with Levene's test.

	Before vs. After		Among Years	
	mean	variance	mean	variance
Temperature				
Kaw Dam	0.2447	0.0183	0.0884	0.0118
Ponca City	0.0123	0.2611	0.0001	0.3847
Belford	0.0515	0.7012	0.0008	0.9656
Ralston	0.1325	0.9006	0.0099	0.9985
Blackburn	0.2850	0.8089	0.0408	0.7631
Oxygen saturation				
Kaw Dam	0.0001	0.2161	0.0001	0.0257
Ponca City	0.0001	0.8496	0.0001	0.9980
Belford	0.1748	0.0679	0.0341	0.0011
Ralston	0.9009	0.4604	0.0347	0.0030
Blackburn	0.3272	0.8766	0.0648	0.0770
Velocity				
Kaw Dam	0.0001	0.0146	0.0001	0.0093
Ponca City	0.0059	0.0846	0.0001	0.0014
Belford	0.0104	0.1051	0.0176	0.0007
Ralston	0.5776	0.7433	0.7573	0.0192
Blackburn	0.9582	0.0284	0.0001	0.1190
pH				
Kaw Dam	0.7554	0.0103	0.0001	0.0450
Ponca City	0.9596	0.2618	0.0001	0.2243
Belford	0.2873	0.4044	0.0001	0.4000
Ralston	0.6686	0.2469	0.0148	0.2479
Blackburn	0.8535	0.9386	0.0002	0.5874
Conductivity				
Kaw Dam	0.0001	0.0001	0.0001	0.0001
Ponca City	0.0001	0.0001	0.0001	0.0001
Belford	0.0001	0.2566	0.0001	0.0017
Ralston	0.0053	0.0036	0.0001	0.0001
Blackburn	0.0001	0.0105	0.0001	0.0101
Daily discharge fluctuation				
Kaw Dam	0.0001	0.0001	0.0001	0.0001
Ralston	0.0001	0.0120	0.0001	0.0230

Figure Captions

1.-Sampling sites on the Arkansas River between Kaw Dam and Keystone Reservoir in north-central Oklahoma.

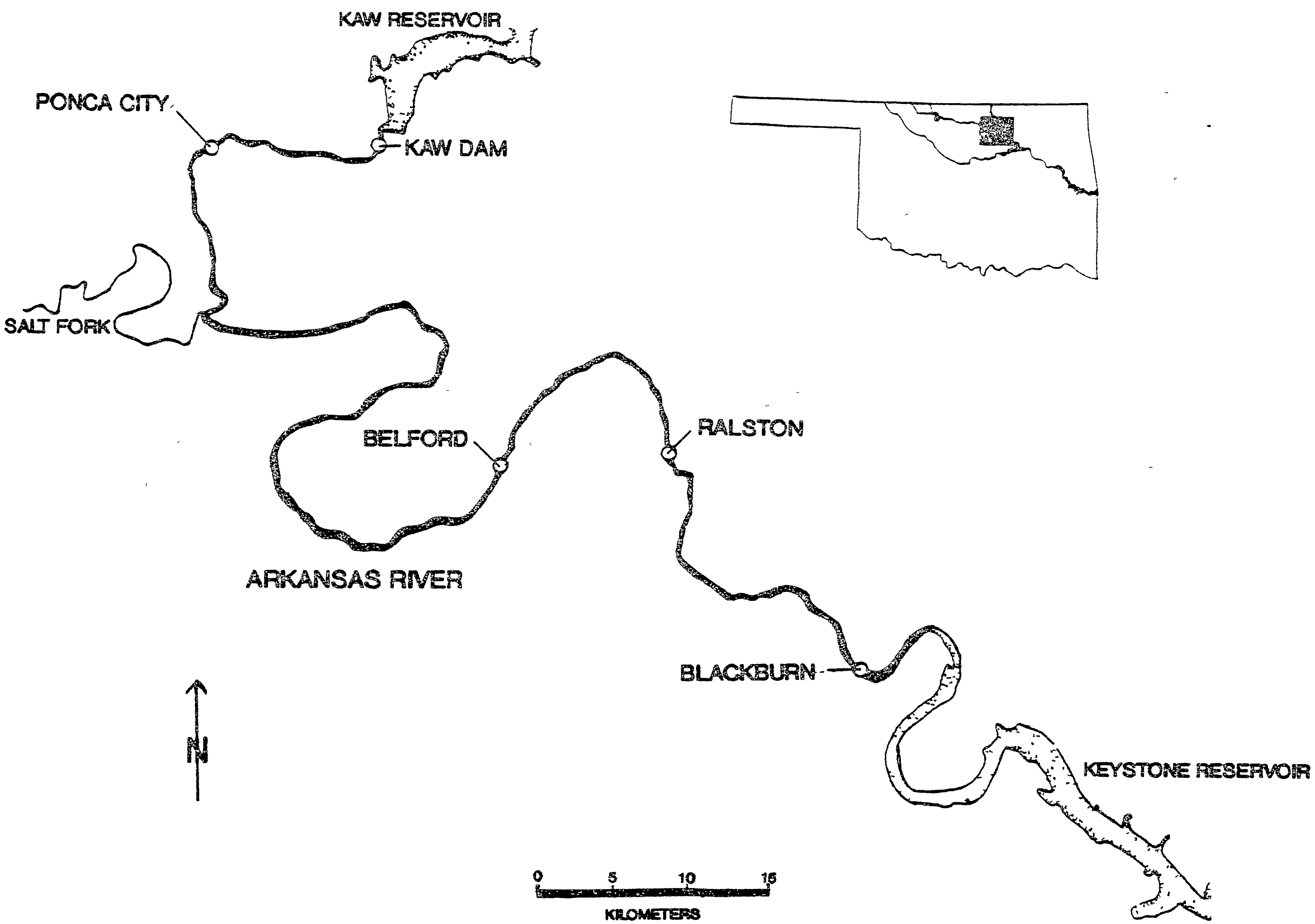
2.-Mean daily discharge from Kaw Dam for the period March through June in 1987, 1988, 1990, and 1991.

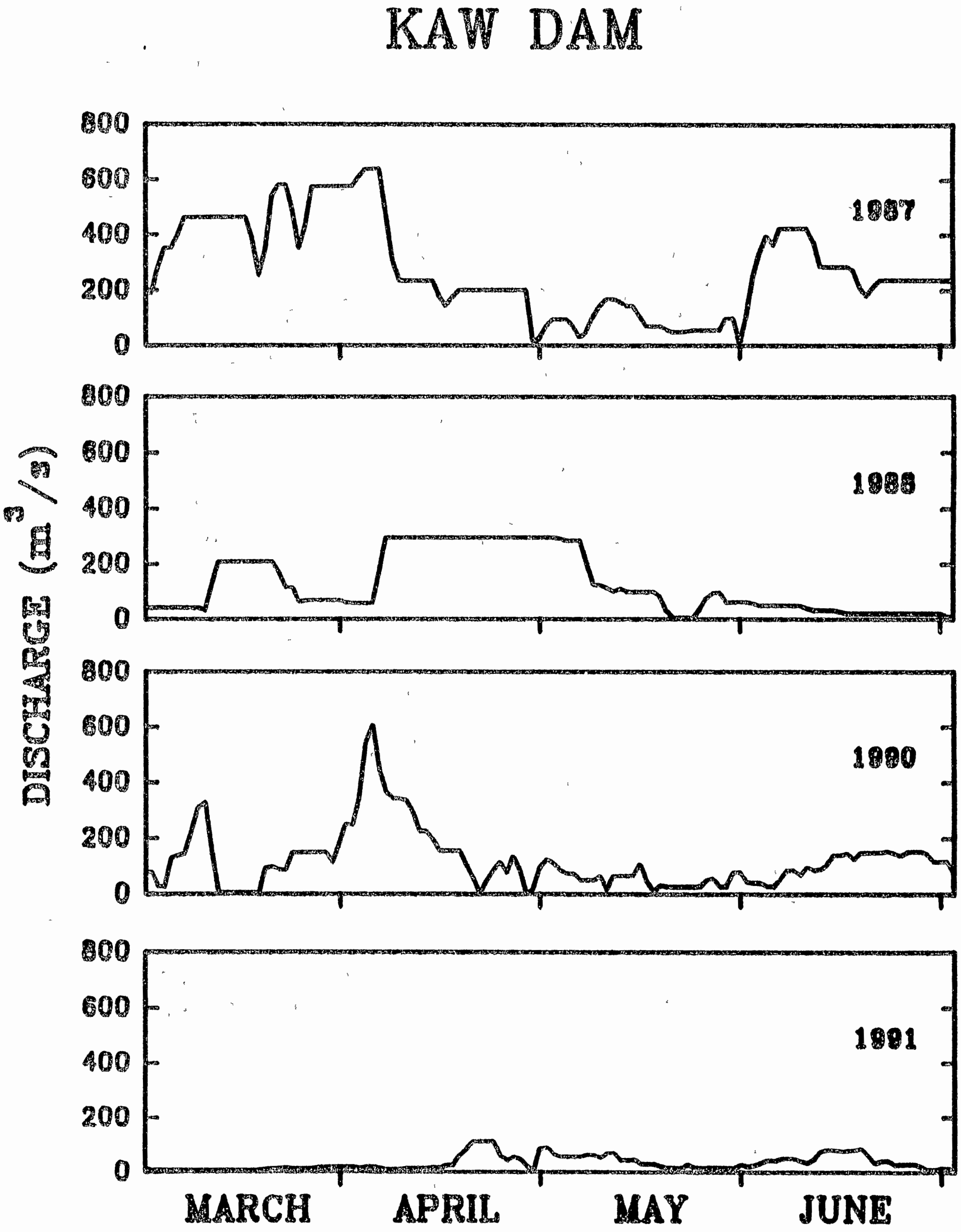
3.-Mean daily discharge fluctuation as a percent of the mean at Kaw Dam and Ralston for 1987, 1988, 1990, and 1991. A hydropower generator was installed in 1989. Error bars represent one standard deviation.

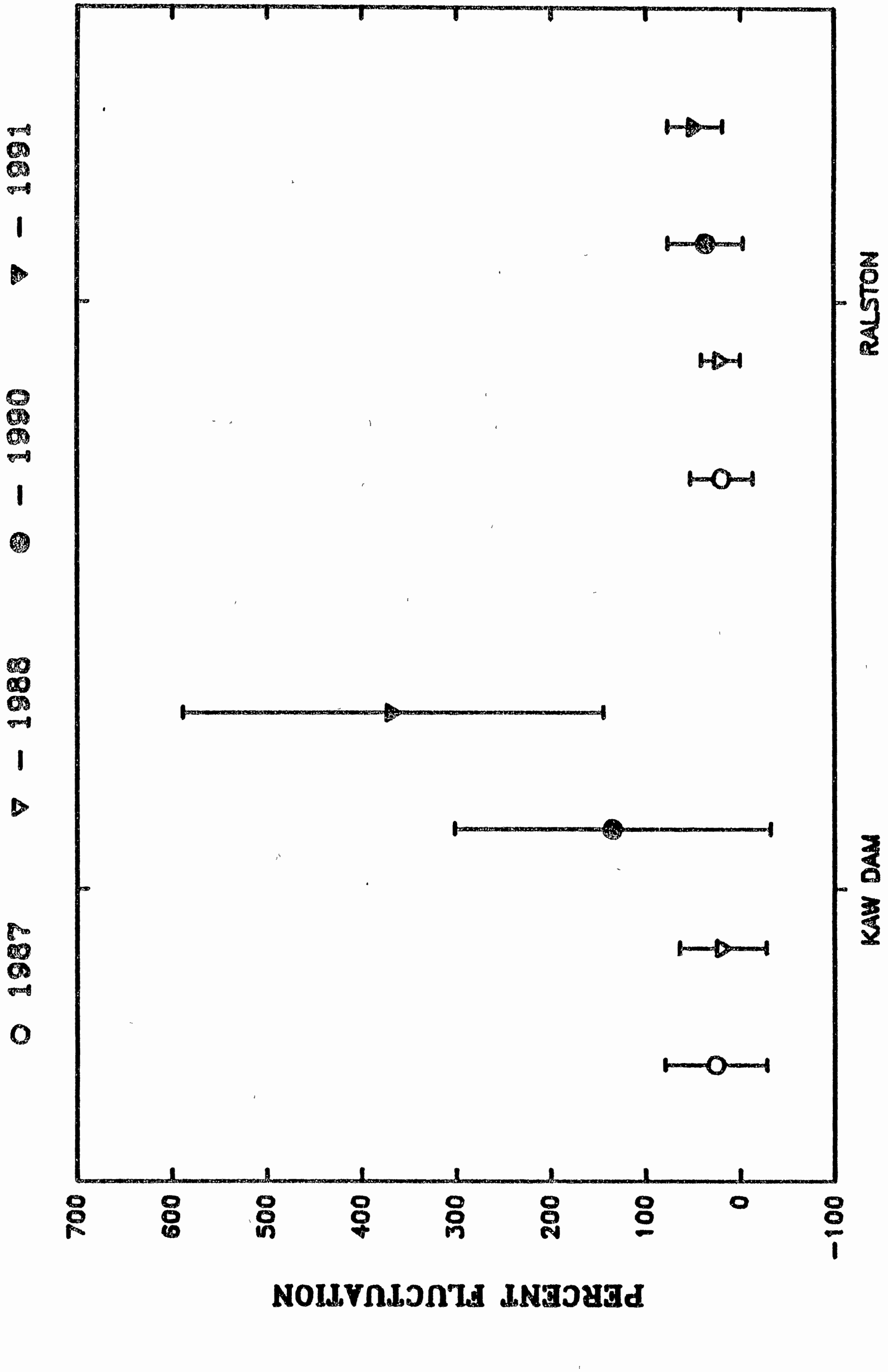
4.-Temperatures at Belford from mid-March through mid-June for 1987, 1988, 1990, and 1991.

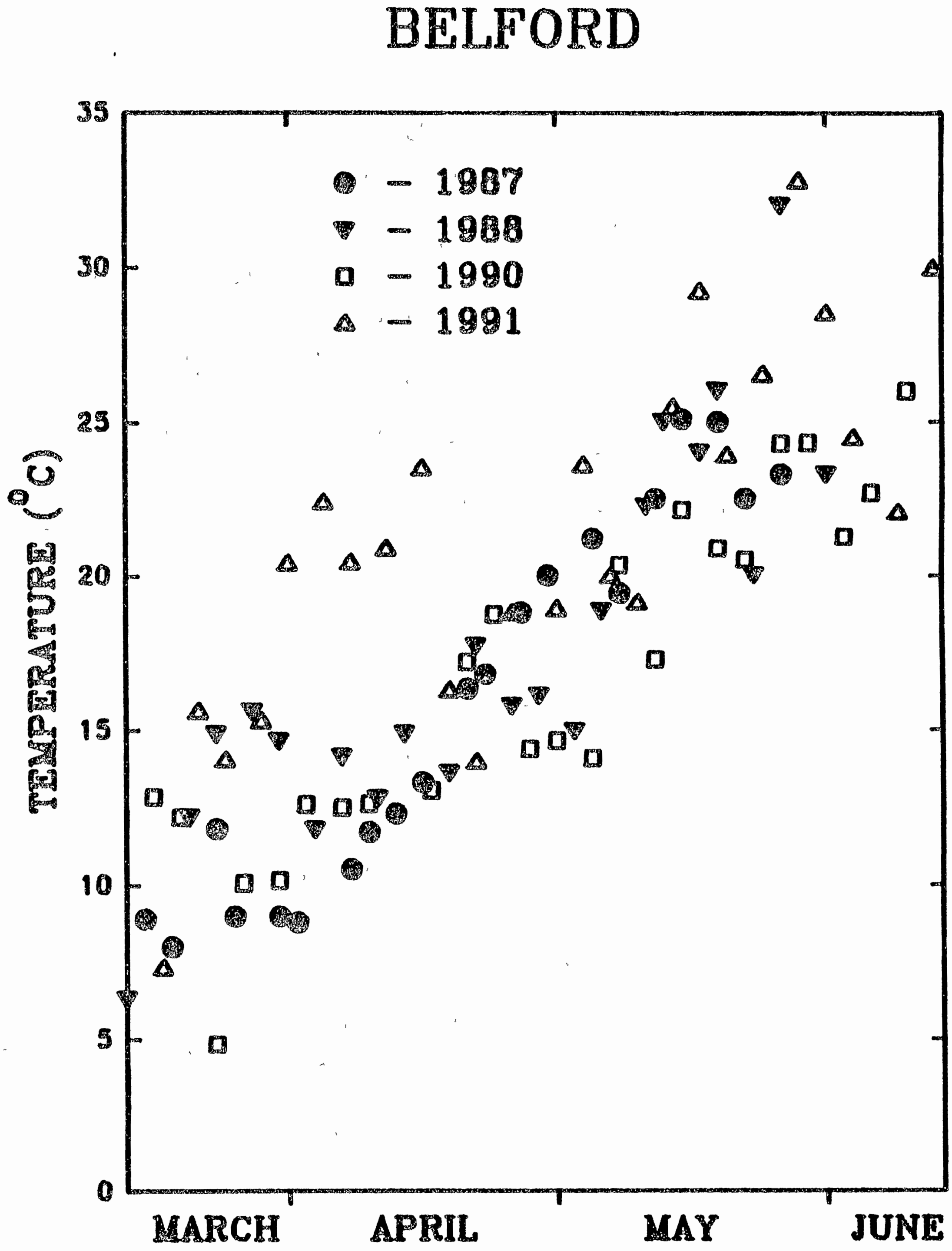
5.-Mean temperatures at Kaw Dam, Ponca City, Belford, Ralston, and Blackburn in 1987, 1988, 1990, and 1991. Error bars represent one standard deviation.

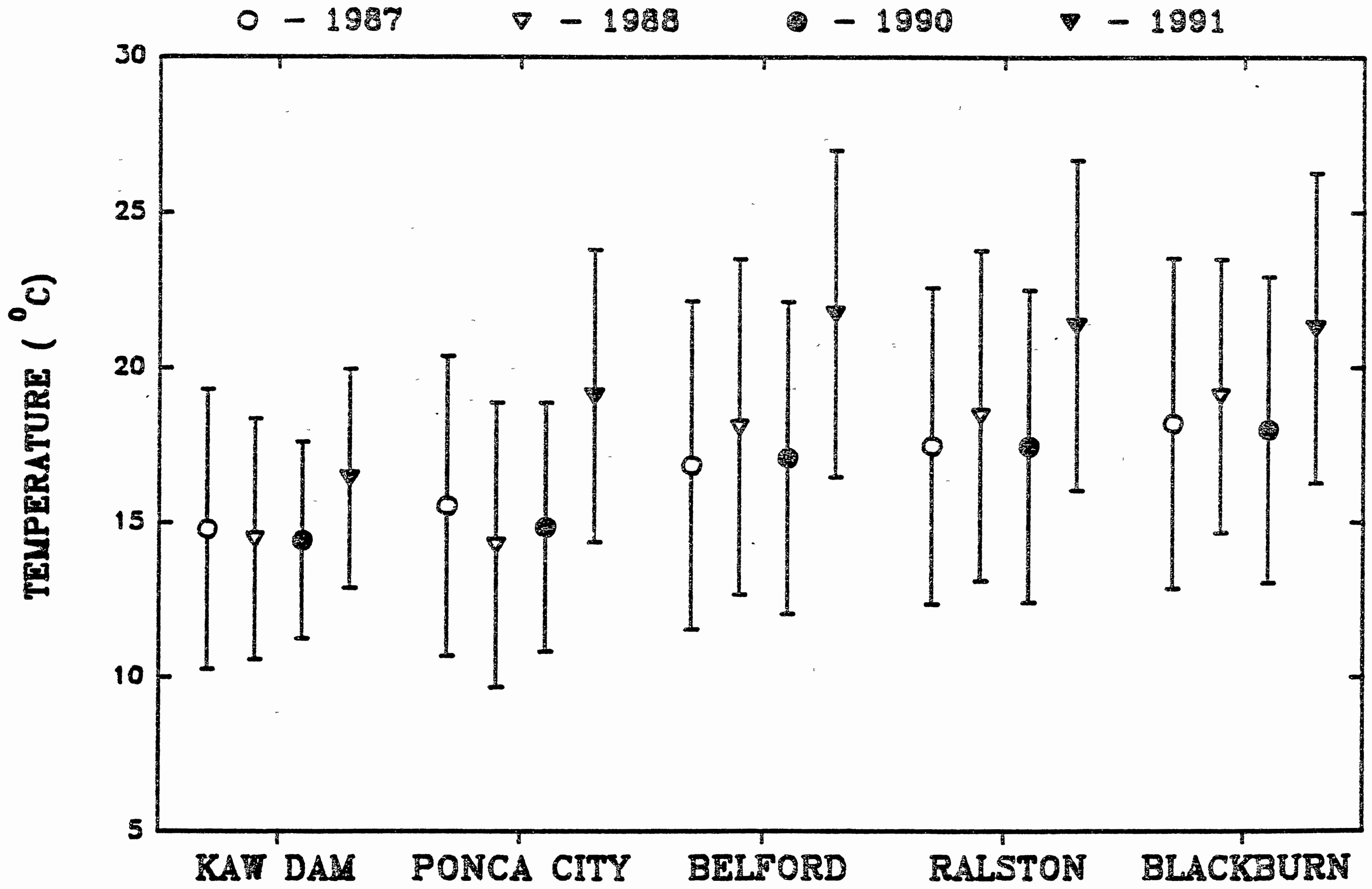
6.-Mean percent oxygen saturation at Kaw Dam, Ponca City, Belford, Ralston, and Blackburn in 1987, 1988, 1990, and 1991. A hydropower generator was installed in 1989. Error bars represent one standard deviation.

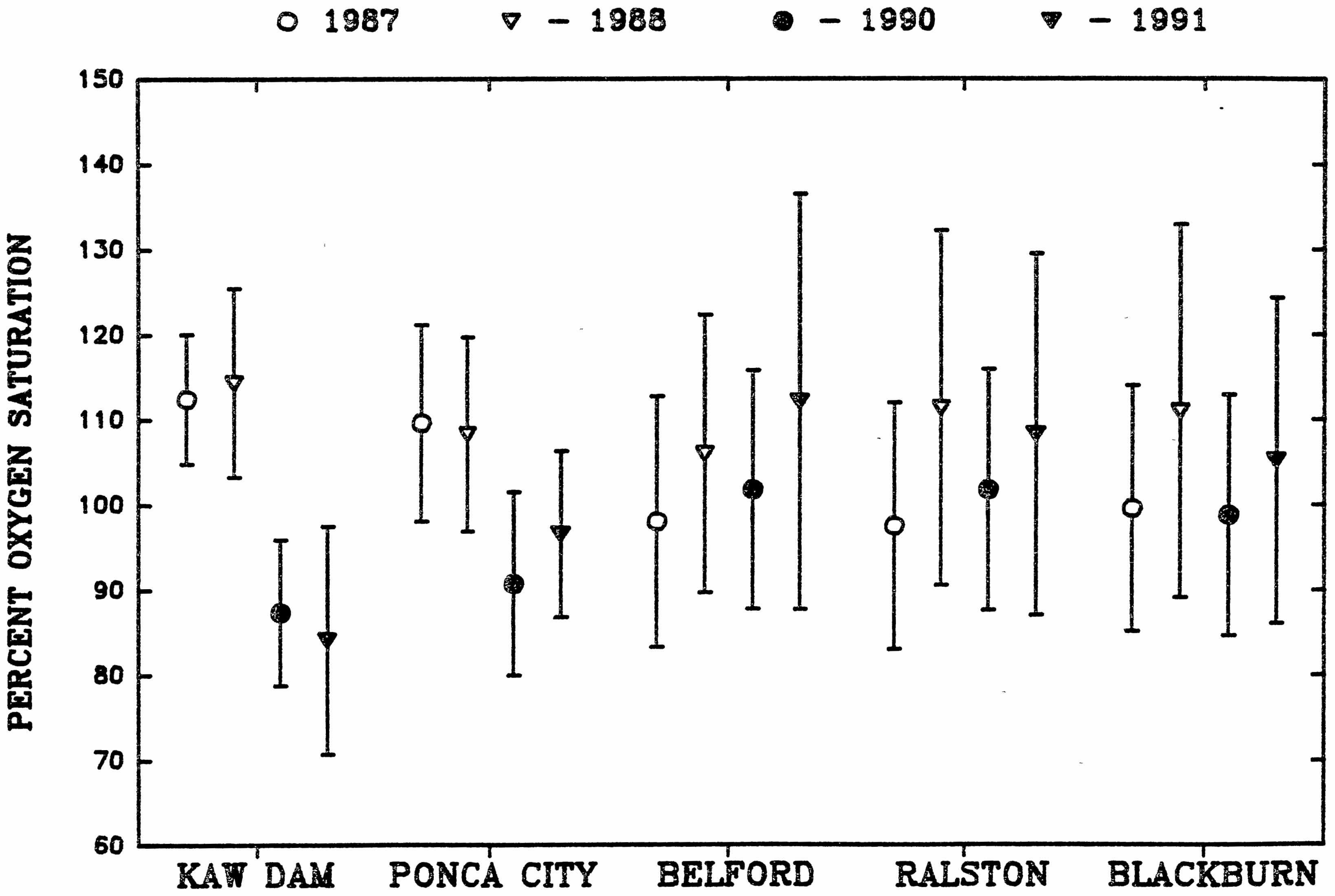

KAW RESERVOIR
PONCA CITY
KAW DAM
SALT FORK
BELFORD
RALSTON
ARKANSAS RIVER
BLACKBURN
KEYSTONE RESERVOIR
N
0
5
10
15
KILOMETERS


KAW DAM
DISCHARGE (m^3/s)
800
600
400
200
0
1987
1988
1990
1991
MARCH
APRIL
MAY
JUNE


○ 1987
▽ — 1988
● — 1990
▼ — 1991
PERCENT FLUCTUATION
700
600
500
400
300
200
100
0
−100
KAW DAM
RALSTON


BELFORD
● — 1987
▼ — 1988
□ — 1990
△ — 1991
TEMPERATURE (°C)
0
5
10
15
20
25
30
35
MARCH
APRIL
MAY
JUNE


○ - 1987
▽ - 1988
● - 1990
▼ - 1991
TEMPERATURE (°C)
30
25
20
15
10
5
KAW DAM
PONCA CITY
BELFORD
RALSTON
BLACKBURN



○ 1987
▽ – 1988
● – 1990
▼ – 1991
150
140
130
120
110
100
90
80
70
60
PERCENT OXYGEN SATURATION
KAW DAM
PONCA CITY
BELFORD
RALSTON
BLACKBURN

VITA

Marvin Keith Shutters

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF THE ADDITION OF HYDROPOWER TO KAW DAM ON STRIPED BASS EGG ABUNDANCES IN THE ARKANSAS RIVER, OKLAHOMA

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