FACTORS AFFECTING SPAWNING LOCATIONS AND REPRODUCTIVE SUCCESS OF STRIPED BASS IN THE ARKANSAS RIVER, OKLAHOMA

By

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INTRODUCTION

This thesis is composed of 3 manuscripts written in the format suitable for submission to Transactions of the American Fisheries Society. Each manuscript is complete without supporting materials. The order of arrangement for each manuscript is text, literature cited, tables, and figures.

CHAPTER II

SPATIAL AND TEMPORAL DISTRIBUTIONS OF STRIPED BASS EGGS IN THE ARKANSAS RIVER, OKLAHOMA, 1987 AND 1988.

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Abstract.-Striped bass inhabiting Lake Keystone, Oklahoma, spawn in a 150-km long reach of the Arkansas River below Kaw Dam. I sampled ichthyoplankton in this river reach from mid-March through May in 1987 and 1988 to determine when and where striped bass spawning occurred. Collections were made twice weekly with conical plankton nets fished just below the surface from four bridges and by boat in the Kaw Dam tailwater. Spawning was initiated in mid-April of both years at 11.8-14.9°C, peaked in late April to early May at temperatures of 15.0 to 22.3°C and terminated in mid-May when water temperatures were 25.3 to 27.5°C. Peak densities of striped bass eggs generally increased with distance from Kaw Dam. Striped bass spawning was concentrated near the confluence of the Salt Fork and Arkansas rivers where discharges and water temperatures increased abruptly.

The striped bass, <u>Morone saxatilis</u>, is an anadromous species native to the Atlantic and Gulf coasts, but is able to complete its life cycle in freshwater (Scruggs 1957). Striped bass were stocked into many reservoirs and lakes (Surber 1958; Bailey 1975), both because of their popularity as a sportfish (Worth 1912; Stevens 1958; Mensinger 1970; Combs 1982; Deppert and Mense 1979) and their tendency to prey on abundant clupeid fishes (Stevens 1958; Mensinger 1970; Combs 1978). Unfortunately, only eight reservoirs support reproducing populations of striped bass in the United States (Gustaveson et al. 1984) because of the specific spawning habitat requirements of this species. Reservoir populations are usually sustained by stocking larvae or fingerlings (Bailey 1975; Crance 1984).

Striped bass were first introduced into Oklahoma waters in the 1960's. Over 2.75 million striped bass were stocked into Lake Keystone, west of Tulsa, Oklahoma, between 1965 and 1969 (Mensinger 1970; Combs 1979). Natural reproduction of striped bass in the Arkansas River above Lake Keystone was documented in 1970 (Mensinger 1970) and reproduction has continued annually since that time (Mark Ambler, Oklahoma Department of Wildlife Conservation, personal communication), despite summer mortalities of large striped bass in Lake Keystone (Hicks 1981; Combs 1982; Zale et al. 1988), increased angling pressure (Combs 1982), and a blockage of their spawning migration by Kaw Dam. Prior to the completion of Kaw Dam in 1976, striped bass migrated upstream in the Arkansas River into Kansas (Don Hicks, Oklahoma Department of Wildlife Conservation, personal communication).

I sampled striped bass ichthyoplankton in the Arkansas River from mid-March through May in 1987 and 1988, prior to the addition of a hydroelectric turbine at Kaw Dam in the autumn of 1989, to determine when and where striped bass spawning occurred in this river reach.

Methods

Sampling with conical plankton nets was conducted twice weekly from mid-March through May during 1987 and 1988 (Appendix A). Nets were fished from four bridges (Ponca City, Belford, Ralston, and Blackburn) along the Arkansas River and by boat in the Kaw Lake tailwaters (Figure 1). The bridges were located 14 km, 78 km, 95 km, and 119 km downstream from Kaw Dam. The Kaw Dam and Ponca City sites are hereafter referred to as the upstream sites, and the remaining sites are referred to as the downstream sites.

The nets were 2.5 m in length, had a 0.5-m diameter circular mouth opening, and a mesh size of 0.5 mm. The nets were attached to a rope with a three-point bridle. Because vertical stratification is absent in shallow and relatively well-mixed riverine systems (Potter et al. 1978), nets were fished just below the surface in the main current. Kornegay and Humphries (1976) and Combs (1979) used similar methods to collect striped bass ichthyoplankton. Three nets were set during each sampling period. Sampling durations were one hour during 1987 and 15 minutes in 1988; sampling durations were decreased to reduce clogging. Sampling was conducted during daylight hours. Sampled water volumes were measured with General Oceanics Model 2030 flow meters (General Oceanics Inc., Miami, Florida) attached in the mouth of each net. A 5.4 kg weight was suspended from the frame of each net to stabilize and properly position it in the water column.

Water temperature, conductivity, dissolved oxygen concentration, and pH were measured using a Hydrolab Surveyor II (Hydrolab Corporation, Austin, Texas) or YSI meters (Yellow Springs Instrument Company, Yellow Springs, Ohio) concurrently with ichthyoplankton sampling. River water velocity was measured with a Teledyne Gurley Model 622 current meter (Teledyne Gurley, Troy, New York). Concurrent discharge rates were obtained from the U.S. Army Corps of Engineers for Kaw Dam and from the U.S. Geological Service for a gaging station located at the Ralston sampling site.

Upon collection, ichthyoplankton samples were preserved in 5% unbuffered formalin (Gates et al. 1987) and stored in plastic buckets. Rose bengal was added to the samples to facilitate sorting of ichthyoplankton (Mitterer and Pearson 1977). Ichthyoplankton samples were sorted in the laboratory and debris and other organisms were removed.

Sorted ichthyoplankton were stored in 5% unbuffered formalin.

Striped bass eggs were identified using a binocular dissecting microscope and descriptions of striped bass eggs in Pearson (1938), Mansueti (1958), Bayless (1972), and Combs (1979). Densities of striped bass eggs were calculated by dividing the number of eggs collected in each net by the volume of water filtered by the net, and mean egg densities for each sample site and date were calculated. Daily egg abundance values at sampling sites were calculated by multiplying mean egg densities by the total daily discharge (m^3) for that site. Discharges from Kaw Dam were used for the upstream sites; Ralston discharges were used for the downstream sites.

To determine spawning locations, striped bass eggs were put into 9 developmental stages (Appendix B) using photographs in Bayless (1972) and descriptions in Mansueti (1958). To correct for the influence of temperature on embryo development and obtain an accurate estimate of the true age of the egg (the stages described in Appendix B were based on a temperature of 18.9°C), the equation $D_e=10.77e^{-0.0934T}$ (where D_e=number of days to hatch and T=temperature [°C]) was used to adjust egg stages for different ambient temperatures (Rogers et al. 1977). This equation describes the relationship between hatching time of striped bass eggs (i.e., developmental rate) and water temperature. The calculated hatching time was divided by 1.8 (the hatching time [d] of striped bass eggs at 18.9°C) to derive a correction factor. This correction factor was multiplied by the age in hours estimated by egg stage periods to provide an estimate of the true age of an egg.

Spawning locations were estimated using corrected egg ages and egg transport rates (Combs 1979). Striped bass egg transport rates approximate 80% of water velocity (Neal 1971). The temperature-corrected egg ages were multiplied by 80% of the river velocity measured concurrent with each sample to estimate the distance upstream from the sampling site where spawning ostensibly occurred. Relative abundances of eggs spawned at each location (1-km intervals) were multiplied by the daily egg abundance estimates for each sampling site to estimate absolute abundances of eggs spawned at each location. Interval-specific estimates for each site and date were summed to determine annual abundances of eggs spawned at each river kilometer.

Results

Striped bass spawning began in mid-April during both years. Striped bass eggs were initially collected in 1987 on 13 April at the downstream sites (Table 1); initial collections of striped bass eggs at the upstream sites occurred about one week later (Table 1). In 1988, striped bass eggs were initially collected on 14 April at the Belford site, and were present at the Belford, Ralston, and Blackburn sites on 19 April (Table 2). Eggs were initially collected at Ponca City on 2 May in 1988 (Table 2); no striped bass eggs were collected at the Kaw Dam site during 1988.

Peak spawning periods occurred earlier at downstream sites than at upstream sites during both years (Tables 1 and 2). In 1987, peak densities of striped bass eggs occurred on 27 April at the downstream sites (Table 1); striped bass eggs were collected at Ponca City concurrently, but at a low density (Table 1). Spawning peaked at the upstream sites in early to mid-May; egg densities peaked at the Ponca City site on 7 May, and at Kaw Dam on 15 May (Table 1). In 1988, striped bass spawning peaked in early May at the downstream sites; peak densities occurred on 3 May at the Blackburn site, and on 6 May at the Belford and Ralston sites (Table 2). Striped bass eggs were collected at the Ponca City site on 2 May at a low density, but were not collected on 5 May (Table 2). Spawning peaked at the Ponca City site on 16 May 1988 (Table 2). Secondary spawning peaks occurred at the downstream sites in both years (Tables 1 and 2).

Striped bass spawning terminated in mid-May of both years. Striped bass eggs were not collected after 19 May in 1987 (Table 1). Similarly, striped bass eggs were not collected after 17 May in 1988 (Table 2).

Peak densities of striped bass eggs generally increased with distance from Kaw Dam. Peak densities of striped bass eggs in 1987 were 0.037, 0.905, 7.903, 6.169, and 22.154 eggs/m^3 at the Kaw Dam, Ponca City, Belford, Ralston, and

Blackburn sites, respectively (Table 1). In 1988, peak densities of striped bass eggs were 0.090, 1.778, 5.877, and 5.817 eggs/m^3 at the Ponca City, Belford, Ralston, and Blackburn sites, respectively (Table 2).

Striped bass eggs were initially collected at sampling sites when water temperatures were 11.8 to 13.3°C in 1987 (Table 3), and 14.1 to 14.9°C in 1988 (Table 4). Peak densities and daily estimated egg abundances at sampling sites occurred when temperatures were 18.9 to 22.3°C in 1987 (Table 3), and 15.0 to 19.4°C in 1988 (Table 4). Striped bass eggs were not collected in 1987 after water temperatures exceeded 21.9 to 22.8°C at the upstream sites and 25.2 to 26.2°C at the downstream sites (Table 3). In 1988, striped bass eggs were not collected after water temperatures reached 18.0°C at the upstream sites and 25.0 to 27.5°C at the downstream sites (Table 4).

Water quality variables were generally within optimum ranges during the striped bass spawning season; water temperatures, water velocities and pH briefly deviated from optimum values. Dissolved oxygen concentrations remained optimal throughout both striped bass spawning seasons (Table 5). Striped bass eggs were collected at water temperatures that ranged from 10.9 to 26.2°C in 1987 and from 13.6 to 26.0°C in 1988, and water velocities ranged from 0.235 to 1.782 m/sec and from 0.669 to 1.672 in 1987 and 1988, respectively (Table 5).

Striped bass spawning was concentrated within 50 km downstream of Kaw Dam in 1987 and 1988 (Figures 2 and 3). The majority of striped bass spawning appeared to occur near the confluence of the Salt Fork and Arkansas Rivers in both years (Figures 2 and 3); the confluence of these rivers is 26 km downstream from Kaw Dam (Figure 1). Fewer eggs were (erroneously) back-calculated to have been spawned upstream of Kaw Dam in 1987 (1.7%; Figure 3) than in 1988 (6.2%; Figure 3). Spawning location estimates ranged as far as 90 km upstream of Kaw Dam in 1988 and 80 km in 1987; estimates upstream of Kaw Dam probably resulted from striped bass eggs that were temporarily trapped in eddies in the river.

Discussion

Striped bass spawning periods in the Arkansas River in 1987 and 1988 were similar to those reported earlier for this population (Combs 1979). Striped bass spawning began in mid-April and terminated in mid to late May during both 1987 and 1988. Similarly, striped bass spawning began in early to mid-April and terminated in mid to late May from 1976 to 1978 (Combs 1979). The spawning season of other populations extended from April to late May or early June (Scruggs 1957; Rathjen and Miller 1957; Kornegay and Humphries 1976; Neal 1976; Turner 1976; Setzler-Hamilton et al. 1981; Kernehan et al. 1981).

Major and secondary spawning peaks occurred in both 1987 and 1988. One spawning peak occurred in 1976, but three spawning peaks occurred in 1978 (Combs 1979). One to three spawning peaks occurred in other populations (Calhoun et al. 1950; Fish and McCoy 1959; Kernehan et al. 1981; Setzler-Hamilton et al. 1981; Black et al. 1988; Uphoff 1989). Secondary spawning peaks in the Arkansas River were associated with rising water temperatures in both 1987 and 1988. Secondary spawning peaks were critical in maintaining striped bass recruitment in the Choptank River, Maryland, when larvae spawned during the peak spawning period suffered catastrophic mortality (Uphoff 1989).

Striped bass in the Arkansas River continued to initiate spawning activity within the one week period (7-14 April) reported by Combs (1979), suggesting that photoperiod was an important cue in initiating spawning in this population. The initial dates of spawning varied widely in other populations and appeared temperature dependent (Calhoun et al. 1950; Setzler-Hamilton et al. 1981; Manooch and Rulifson 1989). The proximity of annual initial spawning dates in the Arkansas River did not appear to have been a function of consistent warming among years. Striped bass eggs were initially collected at lower water temperatures in 1987 and 1988 (12.2 to 14.9°C) than in 1976 to 1978 (Combs 1979; 15.5 to 18.5°C).

Although photoperiod appeared important for the initiation of spawning, spawning appeared to be influenced by water temperature also. Striped bass spawning began at 15.5 to 18.5°C, peaked at 16.0 to 22.0°C, and ceased at 17.0

to 26.5°C in the Arkansas River from 1976 to 1978 (Combs 1979). In my study, spawning was initiated at 11.8 to 14.9°C, peaked at 15.0 to 22.3°C, and terminated when downstream temperatures were 25.3 to 27.5°C in 1987 and 1988. The differences in temperature probably resulted because Combs (1979) reported the mean of water temperatures associated with several daily samples; I recorded a single water temperature at each site daily.

Peak egg densities in 1987 and 1988 were higher than in 1976, 1977, and 1978 (Combs 1979). Peak egg densities reached 22.154 eggs/m^3 in 1987 and 5.877 eggs/m^3 in 1988 at the same sampling sites used by Combs (1979). Peak striped bass egg densities were 0.0252, 0.0325, and 0.0156 eggs/m^3 in 1976, 1977, and 1978, respectively (Combs 1979). The increased densities may be the result of an increase in the spawning stock of striped bass, differences in sampling gear, or an interaction of these two factors. Abundances of both adult and young-of-the-year striped bass in Lake Keystone increased annually from 1978 through 1980 (Combs 1982). I used plankton nets that were longer (2.5 m) and had a larger mesh size (0.5 mm) than did Combs (1979; 1.6 m, 0.064 mm). Accordingly, my nets had a greater filtering capacity.

Striped bass spawn farther upstream during periods of high discharge (Calhoun et al. 1950; Fish and McCoy 1959; Farely 1966; Combs 1979; Manooch and Rulifson 1989). Kaw Dam discharge rates were moderate to high throughout April in 1987 and 1988. Accordingly, striped bass spawning was concentrated within 50 km downstream of Kaw Dam in 1987 and 1988. Similarly, over 50% of the striped bass eggs spawned during 1976, a year with moderate to high discharge rates from Kaw Dam throughout April, were estimated to have been spawned within 50 km of Kaw Dam (Combs 1979). Because striped bass eggs require suspension in the water column to successfully hatch, striped bass spawning success is dependent upon spawning in the upstream reaches of the river during periods of high discharge. Striped bass eggs spawned during the peak spawning periods in 1987 and 1988 required a minimum distance of 115 km and 127 km, respectively, to hatch before reaching the Lake Keystone headwaters.

Striped bass spawning appeared to be concentrated in the vicinity of the confluence of the Salt Fork and Arkansas Rivers in 1987 and 1988. The confluence of the Salt Fork and Arkansas Rivers is located about 124 km upstream from Lake Keystone. This distance roughly approximates the minimum distance upstream from Lake Keystone for successful striped bass reproduction during periods of high discharge. Over 20% of the striped bass eggs collected in 1976 were estimated to have been spawned near the confluence of the Salt Fork and Arkansas Rivers (Combs 1979). Conditions near the confluence probably provided an optimum spawning location for striped bass; discharge rates and water temperatures abruptly increased at this point.

The Salt Fork River is a small, relatively unimpounded river that flows east through northern Oklahoma. It is impounded about 130 km upstream from its confluence with the Arkansas River; accordingly, it warms faster than water releases from Kaw Dam. Water temperatures were about 2 to 4°C higher at sampling sites downstream of its confluence (Tables 3 and 4).

The Kaw tailwater was de-watered in the autumn of 1986 by the U.S. Army Corps of Engineers for routine maintenance of Kaw Dam, and an estimated 22,000 to 26,500 kg of striped bass were removed from the stilling basin (Don Hicks, personal communication). However, striped bass had recolonized the tailwater by March 1987; striped bass were included in the spring 1987 harvest of anglers that participated in a creel survey (Kenneth Cunningham, Oklahoma Cooperative Fish and Wildlife Research Unit, personal communication). The increased percentage of striped bass eggs back-calculated to have been spawned upstream of Kaw Dam in 1988 was probably the result of increased colonization of the tailwater by striped bass; striped bass harvest from the Kaw tailwater increased from 1987 to 1988 (Kenneth Cunningham, personal communication).

Striped bass spawned successfully in the Arkansas River in 1987 and 1988, prior to the initiation of hydropower operations at Kaw Dam. Striped bass spawning began in mid April, peaked in late April to early May, and ended in mid May in both years. Striped bass spawning was concentrated in the upstream reaches of the Arkansas River in 1987 and 1988, years characterized by moderate to high discharge rates from Kaw Dam throughout April and early May. In the future, hydropower operations at Kaw Dam may alter the temperature and discharge regimes in the Arkansas River. The alteration of these regimes during April and May may affect the timing and location of striped bass spawning and result in decreased spawning success in this river reach.

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Table 1.-Mean densities (N/m^3) and standard deviations (S.D.) of striped bass egg densities at sampling sites in the Arkansas River, Oklahoma, 1987. No striped bass eggs were collected in March 1987.

	Site									
	Kaw Dam		Ponca City		Belford		Ralston		Blackburn	
Date	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
April										
02	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
05	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.011	0.004	0.001	0.001	0.008	0.011
16	0.000	0.000	0.008	0.002	0.001	0.001	0.000	0.000	0.000	0.000
20	0.001	0.002	0.001	0.002	--	--	--	--	--	--
21	--	--	--	--	0.906	0.473	0.690	0.469	0.753	0.759
23	0.000[a]	0.000	0.002	0.001	0.962	0.233	0.234	0.047	0.275[a]	0.072
27	0.000	0.000	0.003	0.003	7.903	2.316	6.169	1.207	22.154	3.922
30	0.008	0.003	0.003	0.003	2.804	0.543	1.380	0.209	2.724[a]	0.139
May										
04	0.001	0.004	0.056	0.068	--	--	--	--	--	--
05	--	--	--	--	0.286	0.180	0.194	0.263	0.872	0.912
07	0.003	0.005	0.905	1.658	--	--	--	--	--	--
08	--	--	--	--	0.789	0.589	0.060	0.066	0.675	0.766
12	0.000	0.000	0.000	0.000	1.178	0.786	0.000	0.000	1.882	0.961
15	0.037	0.009	0.002	0.003	0.426	0.026	0.265	0.091	0.506	0.286
19	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

[a] Denotes collections represented by only 2 samples.

Table 2.-Mean densities (N/m^3) and standard deviations (S.D.) of striped bass egg densities at sampling sites in the Arkansas River, Oklahoma, 1988. No striped bass eggs were collected in March 1988, and no striped bass eggs were collected in the Kaw Dam tailwater in 1988.

	Site							
	Ponca City		Belford		Ralston		Blackburn	
Date	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
April								
04	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
07	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.122[a]	0.042	0.000	0.000	0.000	0.000
19	0.000	0.000	0.009	0.024	0.091	0.041	0.066	0.071
22	0.000	0.000	0.002	0.004	0.256	0.050	0.000	0.000
26	0.000	0.000	0.163	0.045	0.057	0.008	0.152	0.008
29	0.000	0.000	0.383	0.036	0.068[a]	0.010	0.016	0.010
May								
02	0.001	0.003	--	--	--	--	--	--
03	--	--	0.608	0.174	0.952	0.190	5.817	0.948
05	0.000	0.000	--	--	--	--	--	--
06	--	--	1.778	2.787	5.877	9.723	0.647	0.857
10	0.000	0.000	--	--	--	--	--	--
11	--	--	0.616	0.677	1.418	1.832	1.102	1.231
13	0.000	0.000	0.249	0.004	0.216	0.061	0.008	0.007
16	0.090	0.051	--	--	--	--	--	--
17	--	--	0.000	0.000	0.000	0.000	0.025	0.025
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

[a] Denotes collections represented by only 2 samples.

Table 3.-Water temperatures (°C) at sampling sites measured concurrently with ichthyoplankton sampling in the Arkansas River, Oklahoma, 1987.

Date	Site				
	Kaw Dam	Ponca City	Belford	Ralston	Blackburn
April					
02	9.8	10.2	10.3	10.5	10.5
05	9.8	--	--	--	--
08	--	10.3	10.6	10.8	10.1
10	8.8	10.9	11.7	11.7	12.1
13	10.1	10.4	12.3[a]	12.2[a]	13.3[a]
16	10.4	12.7[a]	13.4	12.6	13.0
20	11.8[a]	12.9	--	--	--
21	--	--	15.9	16.2	17.1
23	12.8	13.1	16.8	17.7	18.4
27	14.1	14.1	18.9[b]	20.2[b]	21.1[b]
30	16.0	18.4	20.1	20.0	20.6
May					
04	18.9	19.6	--	--	--
05	--	--	19.9	20.2	20.3
07	19.6	20.3[b]	--	--	--
08	--	--	18.9	18.4	19.5
12	17.6	20.0	22.5	22.3	22.7
15	22.8[bc]	21.9[c]	25.2[c]	26.2	26.2[c]
19	20.0	24.6	25.0	25.2[c]	25.7
22	21.2	24.3	22.6	23.0	24.7
26	20.0	19.7	23.4	24.4	24.8

[a] Denotes initial collection of eggs at site.
[b] Denotes date of peak egg densities and abundances at site.
[c] Denotes final date eggs were collected at site.

Table 4.-Water temperatures (°C) measured concurrently with ichthyoplankton sampling in the Arkansas River, Oklahoma, 1988.

	Site				
Date	Kaw Dam	Ponca City	Belford	Ralston	Blackburn
April					
04	9.8	9.9	11.8	12.1	12.5
07	11.2	11.2	14.1	14.9	15.2
11	11.6	11.2	12.8	12.6	12.7
14	12.3	11.5	14.9[a]	15.5	15.9
19	12.5	12.1	13.6	14.2[a]	14.4[a]
22	12.9	13.1	17.7	18.9	19.2
26	14.3	13.9	15.8	16.6	17.1
29	14.2	14.1	16.1	16.2	16.2
May					
02	14.6	14.1[a]	--	--	--
03	--	--	15.0	14.9	15.0[b]
05	15.0	15.5	--	--	--
06	--	--	18.8[b]	19.4[b]	19.4
10	16.0	17.5	--	--	--
11	--	--	19.0	20.5	20.0
13	19.0	18.0	25.0[c]	25.0[c]	26.0
16	19.0	18.0[bc]	--	--	--
17	--	--	24.0	23.0	24.0[c]
19		19.0	26.0	27.5	27.5
20	18.0	--	--	--	--
23	14.0	19.0	20.0	20.5	18.0
26	25.0	25.0	32.0	29.0	26.0
31	16.8	18.5	23.3	24.7	25.0

[a] Denotes initial collection of striped bass eggs at site.
[b] Denotes peak densities and abundances of eggs at site.
[c] Denotes final date eggs were collected at site.

Table 5.-Ranges of water quality variables measured during periods of sampling when striped bass eggs were collected in 1987 and 1988, and conventionally accepted optima for water quality variables.

Variable	Range 1987	Range 1988	Optimum
Water temperature (°C)	10.9-26.2	13.6-26.0	18.0[a]
Water velocity (m/sec)	0.235-1.782	0.670-1.672	0.5-1.5[b]
Dissolved oxygen (mg/L)	6.2-12.6	6.4-12.8	≥5.0[b]
pH	7.6-8.1	7.4-8.5	7.5-8.5[c]

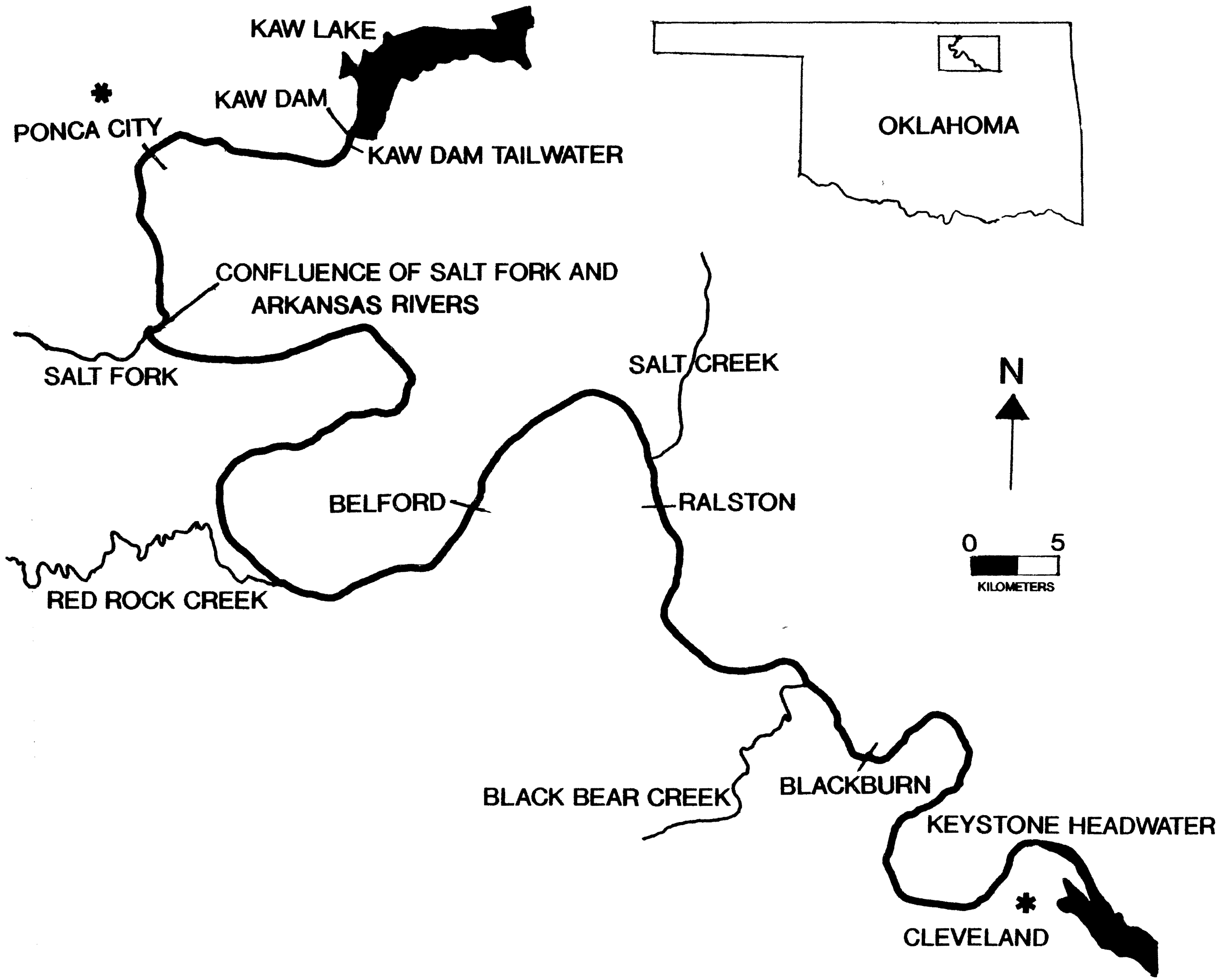
[a]Rogers 1978; [b]Crance 1984; [c]Bonn et al. 1976

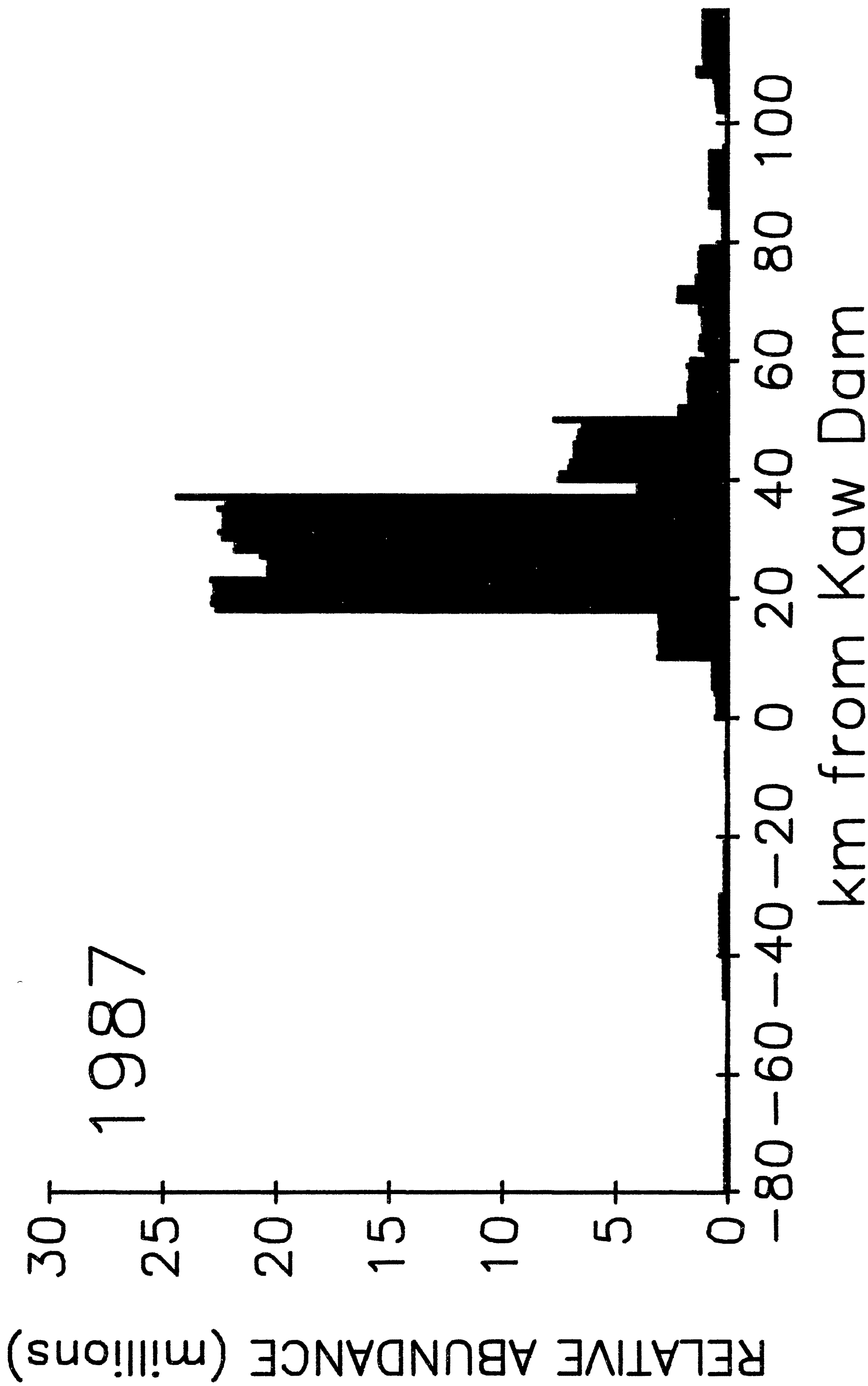
FIGURE CAPTIONS

1.- Striped bass ichthyoplankton sampling sites in the Arkansas River, Oklahoma, March to May, 1987 and 1988. Sampling sites included the Kaw Dam tailwater, and four bridges (Ponca City, Belford, Ralston, and Blackburn). Sampling sites upstream of the confluence of the Salt Fork and Arkansas Rivers were designated as upstream sites; sites downstream of the confluence were designated as downstream sites.

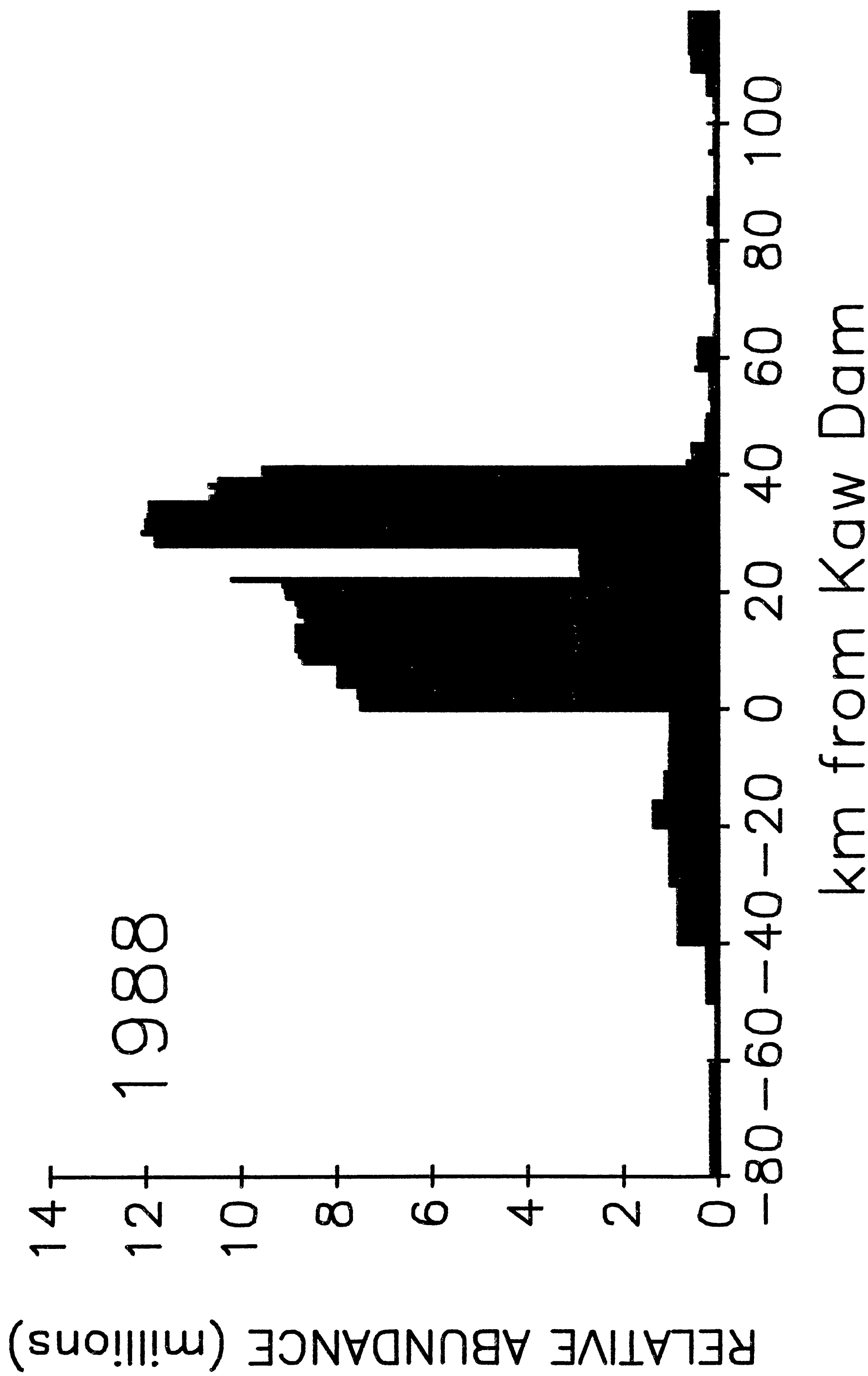
2.-Distribution of striped bass spawning location estimates in the Arkansas River, Oklahoma, 1987. Negative values represent kilometers upstream of Kaw Dam.

3.-Distribution of striped bass spawning location estimates in the Arkansas River, Oklahoma, 1988. Negative values represent kilometers upstream of Kaw Dam.


KAW LAKE
KAW DAM
PONCA CITY
KAW DAM TAILWATER
OKLAHOMA
CONFLUENCE OF SALT FORK AND ARKANSAS RIVERS
SALT FORK
SALT CREEK
N
BELFORD
RALSTON
0 5
KILOMETERS
RED ROCK CREEK
BLACK BEAR CREEK
BLACKBURN
KEYSTONE HEADWATER
CLEVELAND



1987
RELATIVE ABUNDANCE (millions)
0 5 10 15 20 25 30
−80 −60 −40 −20 0 20 40 60 80 100
km from Kaw Dam


1988
RELATIVE ABUNDANCE (millions)
0
2
4
6
8
10
12
14
−80
−60
−40
−20
0
20
40
60
80
100
km from Kaw Dam

CHAPTER III

FACTORS AFFECTING TIMING AND INTENSITY OF STRIPED BASS SPAWNING IN THE ARKANSAS RIVER, OKLAHOMA

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Abstract.-I sampled striped bass ichthyoplankton in a 150-km reach of the Arkansas River downstream from Kaw Dam, Oklahoma, twice weekly from mid-March through May in 1987 and 1988, to determine which, if any, environmental factors affected the timing and intensity of striped bass spawning. Stepwise multiple regression modeling and simple correlation analyses suggested that photoperiod was the most important factor affecting the timing and intensity of striped bass spawning. Deviations from the optimal temperature and pH for striped bass eggs were also important variables.

The striped bass, Morone saxatilis, is an anadromous species native to the Atlantic and Gulf Coasts. Since the discovery that striped bass were able to complete their life cycle in freshwater (Scruggs 1957), this species has been extensively stocked into freshwater lakes and reservoirs (Bailey 1975). However, reproducing populations of inland striped bass exist in only eight reservoirs (Gustaveson et al. 1984).

Reproducing populations of both marine and freshwater stocks of striped bass are regulated primarily by events affecting early life stages (Ulanowicz and Polgar 1980; Cooper and Polgar 1981). Factors affecting spawning success of striped bass include discharge rates (Chadwick et al. 1977; Kernehan et al. 1981), water velocity (Albrecht 1964; Crance 1984), water temperature (Kornegay and Humphries 1976; Rogers 1978; Combs 1979; Uphoff 1989), photoperiod (Kornegay and Humphries 1976; Smith and Jenkins 1988), dissolved oxygen concentrations (Harrell and Bayless 1981; Crance 1984), and pH (Doroshev 1970; Bonn et al. 1976). However, the relative influences of these factors on the timing and intensity of striped bass spawning have not been assessed. I sampled striped bass ichthyoplankton in the Arkansas River, Oklahoma, from mid-March through May in 1987 and 1988, to determine which environmental factors influenced the timing and intensity of striped bass spawning in this river reach.

Methods

I sampled ichthyoplankton in the Arkansas River, Oklahoma, from mid-March through May during 1987 and 1988 (Appendix A). Collections were made twice weekly with conical plankton nets at five sites; nets were fished from four bridges (Ponca City, Belford, Ralston, and Blackburn) along the Arkansas River and by boat in the Kaw Lake tailwaters (Chapter II). The bridges were located 14 km, 78 km, 95 km, and 119 km downstream from Kaw Dam. The Kaw Dam and Ponca City sites are hereafter referred to as the upstream sites, and the remaining sites are referred to as the downstream sites.

The nets were 2.5 m in length, had a 0.5-m diameter circular mouth opening, and a mesh size of 0.5 mm. Nets were fished just below the surface in the main current (Kornegay and Humphries 1976; Combs 1979). Three nets were set during each sampling period. Sampling durations were one hour during 1987 and 15 minutes in 1988; durations were decreased to reduce clogging. Sampling was conducted during daylight hours. Sampled water volumes were measured with General Oceanics Model 2030 flow meters (General Oceanics Inc., Miami, Florida) attached in the mouth of each net.

Water temperature, conductivity, dissolved oxygen concentration, and pH were measured using a Hydrolab Surveyor II (Hydrolab Corporation, Austin, Texas) or YSI meters (Yellow Springs Instrument Company, Yellow Springs, Ohio) concurrently with ichthyoplankton sampling. River water velocity was measured with a Teledyne Gurley Model 622 current meter (Teledyne Gurley, Troy, New York). Concurrent discharge rates were obtained from the U.S. Army Corps of Engineers for Kaw Dam and from the U.S. Geological Service for a gaging station located at the Ralston sampling site. Sunrise/sunset information was acquired from newspaper weather reports (Tulsa Tribune, Tulsa, Oklahoma) to calculate daily photoperiod.

Striped bass eggs were identified using a binocular dissecting microscope and descriptions of striped bass eggs in Pearson (1938), Mansueti (1958), Bayless (1972), and Combs (1979). Densities of striped bass eggs were calculated by dividing the number of eggs collected in each net by the volume of water filtered by the net. Mean egg densities for each sample site and date were multiplied by the total daily discharge (m^3) for that site to estimate daily egg abundance. Discharges from Kaw Dam were used for the upstream sites; Ralston discharges were used for the downstream sites.

Simple correlation was used to determine which, if any, environmental variables were associated with striped bass spawning. Stepwise multiple regression was used to determine relationships between striped bass egg abundances and environmental variables, and to rank environmental variables in order of importance. Independent variables included the deviation from the optimum value for the following environmental variables: water temperature (18.0°C; Rogers 1978), water velocity (1.0 m/sec; Crance 1984)), pH (8.0; Bonn et al. 1976) and photoperiod (13.6 h). I used the mid-points of the optimum ranges for pH (7.5-8.5; Bonn et al. 1976) and water velocity (0.5-1.5 m/sec; Crance 1984). An optimum value of photoperiod (13.6 h) for this population was determined by compiling photoperiod information from 1976 to 1978 and combining it with trends in peak egg production from a previous study on the Lake Keystone population (Combs 1979). The absolute values of the deviations from the optimum values were used in the analyses. Other environmental variables included in the analyses were the mean daily discharge rates at Kaw Dam and Ralston (cfs), dissolved oxygen concentrations (mg/l), and accumulated discharges (2-d, 1-week, and 2-week) at Kaw Dam and Ralston. Logarithmically transformed (base 10) values of striped bass egg abundances were used as dependent variables (Uphoff 1989). For all analyses, probability values <0.05 were considered indicative of significant differences. Data analyses were performed using PC SAS version 6.03 (SAS Institute 1988).

Results

Striped bass spawning began in mid-April during both years. Striped bass eggs were initially collected in 1987 on 13 April at the downstream sites (Chapter II). In 1988, striped bass eggs were initially collected on 14 April at the Belford site (Chapter II). Striped bass spawning peaked in late April in 1987 and in early May in 1988. Striped bass spawning terminated in mid to late May in 1987 and 1988.

All of the environmental variables, except conductivity and 2-week accumulated discharge at Kaw Dam, were significantly associated with $\log_{10}$ abundances of striped bass eggs (Table 1). Deviation from the optimum photoperiod ($r=0.69$, $P<0.001$), deviation from the optimum temperature ($r=-0.51$, $P<0.001$), and dissolved oxygen concentration ($r=-0.42$, $P=<0.001$) were strongly correlated with $\log_{10}$ abundances of striped bass eggs. However, auto-correlation among environmental variables was evident (Table 1) and the relative importance of associations between $\log_{10}$ abundances of striped bass eggs and environmental variables was not distinct.

Deviation from the optimum photoperiod, deviation from the optimum temperature, deviation from the optimum pH, conductivity, and mean daily discharge at Ralston were identified as important variables affecting the timing and intensity of striped bass spawning by the multiple regression analysis (Table 2). Standardized partial regression coefficients indicated that the deviation from the optimal photoperiod was the most effective variable at describing abundances of striped bass eggs in the Arkansas

River (Table 2). The other four variables significantly affected striped bass spawning, but were of lesser importance overall.

Discussion

Photoperiod was the principal factor influencing the timing and intensity of striped bass spawning in the Arkansas River. Photoperiod is an important spawning cue with salmonids (Henderson 1963), cyprinids (deVlaming 1972; deVlaming and Vodicnik 1975; Yaron et al. 1980) and gasterosteids (Borg 1982).

A consistent pattern of striped bass spawning occurred in the Arkansas River. Striped bass spawning in 1987 and 1988 was initiated within the same one week period (7-14 April) reported by Combs (1979). Spawning began at lower temperatures in 1987 and 1988 (12.2 to 14.9°C) than in 1976 to 1978 (15.5 to 18.5°C; Combs 1979). Striped bass spawning peaked in late April in 1987 and in early May in 1988. Combs (1979) reported that spawning peaked in late April to early May from 1976 to 1978. Striped bass spawning terminated in mid to late May in 1987 and 1988. Similarily, striped bass spawning terminated in mid to late May from 1976 to 1978 (Combs 1979).

Dates of the initiation, peak, and termination of striped bass spawning in the Arkansas River are similar to those of striped bass populations throughout the United

States. Several authors have reported similar spawning seasons for striped bass in California (Calhoun 1950; Turner 1976), Delaware (Kernehan et al. 1981), Maryland (Rathjen and Miller 1957; Setzler-Hamilton et al. 1981), North Carolina (Kornegay and Humphries 1975), South Carolina (Scruggs 1957), and Virginia (Neal 1976).

Many authors have considered water temperature alone to be the principal factor affecting the timing and intensity of striped bass spawning (Calhoun et al. 1950; Combs 1979; Kernehan et al. 1981; Setzler-Hamilton et al. 1981). However, spawning was associated with different water temperatures and peak spawning occurred in late April to early May in each case. Striped bass spawning began at 15.5°C and peaked at 16.1 to 16.7°C in the Sacramento River system, California (Calhoun et al. 1950). Striped bass spawning began at water temperatures of 9.0 to 11.9°C, peaked at 14.5 to 18.4°C, and terminated at temperatures above 22.4 to 23.7°C in the Potomac estuary, Maryland (Setzler-Hamilton et al. 1981). Spawning occurred between 8.4 to 29.0°C, and peaked at temperatures of 12.5 to 18.0°C in the Chesapeake and Delaware Canal system (Kernehan et al. 1981). In the Tar River, North Carolina, striped bass spawning was initiated at temperatures of 14.4 to 15.0°C, peaked at 17.8 to 20.0°C, and ended at temperatures above 22.2°C (Kornegay and Humphries 1976).

My findings have important management implications for striped bass populations whose spawning areas are affected by dams or other water diversion structures. The deviation from the optimal spawning temperature for striped bass, deviation from the optimal pH, conductivity, and mean daily discharge rate were significant variables influencing the timing and intensity of striped bass spawning, but were of lesser importance than photoperiod. Because photoperiod was the principal factor affecting striped bass spawning, I recommend that mitigative regulations for dams or other structures be based upon optimum photoperiod, not climatic variables as recommended by Neal (1976). Neal (1976) recommended that mitigative discharges from the Leesville-Smith Mountain hydroelectric facility in Virginia, be based on climatic variables, but with little supporting evidence. My findings, and a review of the peak spawning periods of other striped bass populations, suggest that the optimum photoperiod for striped bass occurs in late April to early May in temperate North America. Accordingly, dams or other diversion structures that are detrimental to striped bass conditions for striped bass during this time period.

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Table 1.-Correlations matrix between between $\log_{10}$-transformed striped bass egg abundances and environmental variables, 1987 and 1988. Data from Kaw Dam in 1988 were excluded because no eggs were collected at this site. P values are listed below correlation coefficients.

	Environmental Variables[a]							
	AB	PP	DT	DO	RN2	P2	R1	K1
AB	--	0.69	-0.51	-0.42	-0.33	-0.28	-0.25	0.25
		(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)
PP	0.69	--	0.63	0.44	0.45	0.54	0.38	-0.09
	(<0.01)		(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(0.15)
DT	-0.51	0.63	--	0.55	0.37	0.45	0.32	-0.21
	(<0.01)	(<0.01)		(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)
DO	-0.42	0.44	0.55	--	0.35	0.23	0.29	0.09
	(<0.01)	(<0.01)	(<0.01)		(<0.01)	(<0.01)	(<0.01)	(0.14)
RN2	-0.33	0.45	0.37	0.35	--	0.58	0.86	0.13
	(<0.01)	(<0.01)	(<0.01)	(<0.01)		(<0.01)	(<0.01)	(0.03)
P2	-0.28	0.54	0.45	0.23	0.58	--	0.53	-0.13
	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)		(<0.01)	(0.03)
R1	-0.25	0.38	-0.24	0.29	0.86	0.53	--	0.06
	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)		(0.30)
K1	0.25	-0.27	-0.21	0.09	0.13	-0.13	0.06	--
	(<0.01)	(<0.01)	(<0.01)	(0.14)	(0.03)	(0.03)	(0.30)	
KW2	-0.23	0.35	0.35	0.44	0.40	0.48	0.77	0.21
	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)
RN	-0.20	0.41	0.31	0.11	0.83	0.57	0.76	0.06
	(<0.01)	(<0.01)	(<0.01)	(0.07)	(<0.01)	(<0.01)	(<0.01)	(0.29)
R2	-0.19	0.34	0.48	0.31	0.60	0.46	0.71	-0.15
	(0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(0.02)
KW	0.18	0.33	0.31	0.39	0.81	0.52	0.84	0.15
	(0.01)	(<0.01)	(0.01)	(<0.01)	(<0.01)	(<0.01)	(<0.01)	(0.01)
F2	-0.17	0.14	0.10	-0.04	0.20	0.25	0.10	-0.20
	(0.01)	(0.02)	(0.09)	(0.57)	(<0.01)	(<0.01)	(0.09)	(<0.01)
CD	0.11	-0.04	-0.22	0.55	-0.39	-0.37	-0.34	<0.01
	(0.06)	(<0.01)	(<0.01)	(0.01)	(<0.01)	(<0.01)	(<0.01)	(0.98)
K2	-0.03	0.07	0.17	0.34	0.40	0.17	0.49	0.42
	(0.64)	(0.26)	(0.01)	(<0.01)	(<0.01)	(0.01)	(<0.01)	(<0.01)

Table 1. Continued.

	Environmental Variables[a]						
	KW2	RN	R2	KW	F2	CD	K2
AB	-0.23 (<0.01)	-0.20 (<0.01)	-0.19 (<0.01)	-0.18 (0.01)	-0.17 (0.01)	0.11 (0.06)	-0.03 (0.64)
PP	0.35 (<0.01)	0.41 (<0.01)	0.38 (<0.01)	0.33 (<0.01)	0.14 (0.02)	-0.04 (0.53)	0.07 (0.26)
DT	0.35 (<0.01)	0.31 (<0.01)	0.48 (<0.01)	0.31 (<0.01)	0.11 (0.09)	-0.22 (<0.01)	0.17 (<0.01)
DO	0.44 (<0.01)	0.11 (<0.01)	0.31 (<0.01)	0.39 (<0.01)	-0.04 (0.58)	-0.15 (0.01)	0.34 (<0.01)
RN	0.80 (<0.01)	0.83 (<0.01)	0.60 (<0.01)	0.81 (<0.01)	0.20 (<0.01)	-0.49 (<0.01)	0.40 (<0.01)
P2	0.48 (<0.01)	0.57 (<0.01)	0.46 (<0.01)	0.52 (<0.01)	0.25 (<0.01)	-0.37 (<0.01)	0.17 (<0.01)
R1	0.77 (<0.01)	0.76 (<0.01)	0.71 (<0.01)	0.84 (<0.01)	0.10 (0.09)	-0.34 (<0.01)	0.49 (<0.01)
K1	0.21 (<0.01)	0.06 (0.29)	-0.15 (0.02)	0.15 (0.01)	-0.20 (<0.01)	<0.01 (0.98)	0.42 (<0.01)
KW2	--	0.54 (<0.01)	0.63 (<0.01)	0.93 (<0.01)	-0.07 (0.24)	-0.33 (<0.01)	0.58 (<0.01)
RN	0.55 (<0.01)	--	0.53 (<0.01)	0.63 (<0.01)	0.30 (<0.01)	-0.40 (<0.01)	0.24 (<0.01)
R2	0.63 (<0.01)	0.53 (<0.01)	--	0.66 (<0.01)	0.19 (<0.01)	-0.50 (<0.01)	0.58 (<0.01)
KW	0.93 (<0.01)	0.63 (<0.01)	0.66 (<0.01)	--	-0.03 (0.64)	-0.34 (<0.01)	0.52 (<0.01)
F2	-0.07 (0.24)	0.30 (<0.01)	0.19 (<0.01)	-0.03 (0.64)	--	-0.38 (<0.01)	-0.01 (0.84)
CD	-0.33 (<0.01)	-0.49 (<0.01)	-0.50 (<0.01)	-0.39 (<0.01)	-0.38 (<0.01)	--	-0.33 (<0.01)
K2	0.58 (<0.01)	0.24 (<0.01)	0.58 (<0.01)	0.52 (<0.01)	-0.01 (0.84)	-0.33 (<0.01)	--

Table 1. Continued.

[a] AB=$\log_{10}$ abundances of striped bass eggs; PP=deviation from the optimum photoperiod (hours); DT=deviation from the optimal temperature for striped bass eggs (°C); DO=dissolved oxygen concentration (mg/l); RN2=2-d accumulated discharge at Ralston (m^3); P2=deviation from the optimum pH; R1=1-week accumulated discharge at Ralston (m^3); K1=1-week accumulated discharge at Kaw Dam (m^3); KW2=2-d accumulated discharge at Kaw Dam (m^3); RN=Ralston mean daily discharge (m^3); R2=2-week accumulated discharge at Ralston (m^3); KW=mean daily discharge at Kaw Dam (cfs); F2=deviation from the optimum water velocity (m/sec); CD=conductivity (micromhos); K2=2-week accumulated discharge at Kaw Dam (m^3).

Table 2.-Multiple-regression model describing relationships between $\log_{10}$ abundances of striped bass eggs (AB) and environmental variables in the Arkansas River, Oklahoma, 1987 and 1988. Collections and environmental factors associated with the Kaw Dam site in 1988 were excluded because no striped bass eggs were collected there in 1988. Partial regression coefficients (b) for environmental variables are listed below each variable. Model and all variables within model were significant ($P<0.05$); the R^2 value for the model was 0.52.

Model[a]
AB=4.405-5.874(PP)-0.147(DT)+1.141(PH)+0.001(CD)+0.001(RN)
(0.48) (0.01) (0.01) (0.01) (0.01)

[a] PP=deviation from the optimum photoperiod (hours); DT=deviation from the optimal temperature for striped bass eggs (°C); P2= deviation from the optimum pH; CD=conductivity (micromhos); RN= Ralston mean daily discharge (m^3).

CHAPTER IV

POTENTIAL EFFECTS OF THE INITIATION OF HYDROPOWER GENERATION AT KAW DAM ON STRIPED BASS SPAWNING IN THE ARKANSAS RIVER, OKLAHOMA

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Abstract.-Striped bass inhabiting Lake Keystone, Oklahoma, spawn in the 150-km river reach of the Arkansas River downstream from Kaw Dam. I sampled striped bass icthyoplankton in this river reach during periods of normal non-hydropower releases and simulated-hydropower releases from Kaw Dam to assess the potential effects of hydropower generation on striped bass spawning success in the Arkansas River. Significant differences did not exist in egg densities or abundances between periods of normal and simulated-hydropower discharges. Striped bass spawned farther downstream during periods of simulated-hydropower releases from Kaw Dam. These results suggest that hydropower operations at Kaw Dam will not affect striped bass spawning success. However, logistical constraints of this research limit strict acceptance of these results. Hydropower operations have been detrimental to striped bass spawning success in other river systems.

The Oklahoma Department of Wildlife Conservation stocked over 2.75 million striped bass into Lake Keystone, Oklahoma, between 1965 and 1969 (Mensinger 1970; Combs 1979). Natural reproduction of striped bass in the Arkansas River upstream from Lake Keystone was documented in 1970 (Mensinger 1970) and reproduction has continued annually since that time (Mark Ambler, Oklahoma Department of Wildlife Conservation, personal communication).

Since the completion of Kaw Dam in 1976, striped bass have been subjected to controlled water releases from Kaw Dam, but no apparent detrimental effect on spawning was observed under conventional release regimes (Combs 1979). Water was released on a daily run-of-river basis from Kaw Dam by tainter or sluice gates prior to the addition of a hydroelectric turbine in the autumn of 1989.

The Oklahoma Municipal Power Authority was granted a license to construct, operate, and maintain a hydroelectric facility at Kaw Dam. Striped bass spawning success in the Arkansas River may be affected by hydropower operations at Kaw Dam. To assess the possible effects of hydropower operations at Kaw Dam on striped bass spawning in the Arkansas River, Oklahoma, I sampled striped bass ichthyoplankton at three sites between Kaw and Keystone Lakes in early May of 1987 and 1988 during periods of normal non-hydropower releases and simulated-hydropower releases from Kaw Dam.

Methods

Striped bass ichthyoplankton was sampled at three sites along the Arkansas River between Lakes Kaw and Keystone. Sampling sites were three bridges located progressively downstream from Kaw Dam (Belford, Ralston, and Blackburn; Chapter II).

Conical plankton nets were used to collect striped bass ichthyoplankton. The nets were 2.5 m in length, had a 0.5-m diameter circular mouth opening, and a mesh size of 0.5 mm. Nets were fished just below the surface in the main current (Kornegay and Humphries 1976; Combs 1979). Three nets were set during each sampling period. Sampling periods were one hour during 1987 and 15 minutes in 1988; sampling periods were decreased to reduce clogging. Sampled water volumes were measured with General Oceanics Model 2030 flow meters (General Oceanics Inc., Miami, Florida) attached in the mouth of each net. A 5.4 kg weight was suspended from the frame of each net to stabilize and properly position it in the water column.

Ichthyoplankton sampling was conducted in early May in 1987 and 1988. Two sampling days occurred in 1987 and two occurred in 1988. Two of the sampling days (8 May 1987, and 11 May 1988), corresponded with U.S. Army Corps of Engineers attempts to simulate hydropower discharges from Kaw Dam. Two days (5 May 1987, and 6 May 1988) served as controls;

the U.S. Army Corps of Engineers maintained normal non-hydropower flows from Kaw Dam on these dates. Ichthyoplankton was sampled every 6 hours at each sampling site. Initial samples were at about 0000, 0200, and 0400 hours at the Belford, Ralston, and Blackburn sites, respectively.

Water temperature, conductivity, dissolved oxygen concentration, and pH were measured using a Hydrolab Surveyor II (Hydrolab Corporation, Austin, Texas) or YSI meters (Yellow Springs Instrument Company, Yellow Springs, Ohio) concurrently with ichthyoplankton sampling. River water velocity was measured with a Teledyne Gurley Model 622 current meter (Teledyne Gurley, Troy, New York). Concurrent discharge rates were obtained from the U.S. Army Corps of Engineers for Kaw Dam and from the U.S. Geological Service for a gaging station located at the Ralston sampling site.

Upon collection, ichthyoplankton samples were preserved in 5% unbuffered formalin (Gates et al. 1987) and stored in plastic buckets. Rose bengal was added to the samples to facilitate sorting of ichthyoplankton (Mitterer and Pearson 1977). Ichthyoplankton samples were sorted in the laboratory and debris and other organisms were removed. Sorted ichthyoplankton were stored in 5% unbuffered formalin.

Striped bass eggs were identified using a binocular dissecting microscope and descriptions of striped bass eggs in Pearson (1938), Mansueti (1958), Bayless (1972), and Combs (1979). Densities of striped bass eggs were calculated by dividing the number of eggs collected in each net by the volume of water filtered by the net. Mean egg densities for each sample site, time, and date were multiplied by the total hourly discharge (m^3) for that site to estimate hourly egg abundance. Hourly discharge rates at sampling sites were estimated by extrapolating discharge rates from the Ralston site.

To determine spawning locations, striped bass eggs were put into 9 developmental stages (Appendix C) using photographs in Bayless (1972) and descriptions in Mansueti (1958). To correct for the influence of temperature on embryo development and obtain a more accurate estimate of the true age of the egg (the stages described in Appendix C were based on a temperature of 18.9°C), the equation $D_e=10.77e^{-0.0934T}$ (where D_e=number of days to hatch and T=temperature [°C]) was used to adjust egg stages for different ambient temperatures (Rogers et al. 1977). This equation describes the relationship between hatching time of striped bass eggs (i.e., developmental rate) and water temperature. The calculated hatching time was divided by 1.8 (the hatching time [d] of striped bass eggs at 18.9°C) to derive a correction factor. This correction factor was multiplied by the age in hours estimated by egg stage periods to provide an estimate of the true age of an egg.

Spawning locations were estimated using corrected egg ages and egg transport rates (Combs 1979). Striped bass egg transport rates approximate 80% of water velocity (Neal 1971). The temperature-corrected egg ages were multiplied by 80% of the river velocity measured concurrent with each sample to estimate the distance upstream from the sampling site where spawning ostensibly occurred. Relative abundances of eggs spawned at each location (1-km) intervals were multiplied by hourly egg abundance estimates for each sampling site to estimate absolute abundances of eggs spawned at each location. Interval-specific estimates for each site, date, and hour were summed to determine annual abundances of eggs spawned at each river kilometer. I also estimated the spawning time of striped bass by using the corrected egg ages and sampling times for individual samples.

Simulated-hydropower discharges from Kaw Dam released daily accumulated inflows into Kaw Lake, but discharge rates varied diurnally. Discharge rates from Kaw Dam were increased to 5,900 cfs at about 0800 hours and remained at this rate until about 1400 hours; discharge rates were then decreased to release the remainder of the daily accumulated inflow into Kaw Lake. The estimated discharge capacity for this facility was 5,900 cfs, but was revised to 5,500 cfs after the generator was installed in the autumn of 1989. The U.S. Army Corps of Engineers simulated hydropower discharges for three consecutive days, and intensive netting began on the third day. The U.S. Army Corps of Engineers did not alter discharge rates from Kaw Dam during control periods; daily accumulated inflows into Kaw Lake were released at a constant rate.

Analysis of variance (ANOVA) was used to compare densities and abundances of striped bass eggs during simulated-hydropower versus control releases from Kaw Dam. Because a few collections were represented by only 2 samples (instead of the normal 3 samples), the mean value of the two samples was used for a third data point to allow statistical inferences to be made (Zar 1984). For all analyses, probability values <0.05 were considered indicative of significant differences. Data analyses were performed using PC SAS version 6.03 (SAS Institute 1988).

Results

Two pairs of control versus simulated hydropower sampling periods were completed (5 May versus 8 May, 1987, and 6 May versus 11 May, 1988). However, the effects of simulated-hydropower discharges on downstream discharge rates in 1987 were diminished because local rainfall increased tributary inflows. Accordingly, striped bass that spawned in downstream reaches were not affected by the simulated hydropower discharges. Because of these conditions, I did not analyze these data to determine the effects of hydropower on striped bass spawning.

Conversely, downstream discharge rates oscillated as a function of the simulated-hydropower releases from Kaw Dam in 1988 (Figure 1). The distance between Kaw Dam and Ralston (95 km) prevented immediate downstream effects of the simulated-hydropower discharges; accordingly, changes in water discharge rates were delayed by about 1 d at the Ralston site. Water discharge rates fluctuated as much as 2,590 cfs within 24 h at the Ralston station during the simulated hydropower releases in 1988 (Figure 1). Hourly discharge readings at Ralston mimicked the simulated-hydropower releases from Kaw Dam (Figure 1). Water discharge rates at the Ralston gaging station fluctuated only 500 cfs within 24 h during normal water releases from Kaw Dam on 5 May 1988. The maximum and minimum discharge rates at the Ralston gaging station on 5 May 1988 were 12,300 and 11,800 cfs, respectively.

Water temperatures were more variable diurnally during simulated-hydropower releases than during normal releases in May 1988 (Figure 2). Water temperatures ranged from 19.0 to 25.0°C and 18.1 to 19.9°C at the sampling sites during simulated-hydropower and normal discharges, respectively.

Striped bass spawned during control and simulated-hydropower releases from Kaw Dam in 1988. Analysis of variance suggested that the effects of hydropower would be minimal on striped bass spawning success. No significant differences in densities or estimated abundances of striped bass eggs at the sites existed between the control and simulated-hydropower releases during 1988 (Tables 1 and 2).

Significant differences existed between both diel densities and abundance estimates at the sampling sites (Tables 1 and 2). Back-calculated spawning times of striped bass varied. The estimated peak spawning times of striped bass on 6 May 1988 occurred between 2200 to 0800. However, peak spawning occurred occurred between 1000 to 1600 on 11 May 1988.

Striped bass spawning was concentrated farther downstream during simulated-hydropower discharges than during normal releases in 1988 (Figure 3). Striped bass eggs spawned on 5 May 1988 required a minimum of 126 km to hatch before reaching Lake Keystone. Striped bass eggs spawned on 11 May 1988 required a minimum of 67 km to hatch before reaching Lake Keystone. The maximum distance downstream from Kaw Dam where striped bass could spawn successfully was 24 km and 83 km for eggs spawned on 5 and 11 May 1988, respectively.

Discussion

My findings suggest that hydropower operations at Kaw Dam will not be detrimental to striped bass spawning success in the Arkansas River. Significant differences did not exist in egg densities or abundances between periods of normal and simulated-hydropower discharges from Kaw Dam.

Although striped bass spawning was concentrated farther downstream during simulated-hydropower discharges from Kaw Dam, the majority of spawning occurred far enough upstream from Lake Keystone to allow the eggs to successfully hatch.

Strict acceptance of these results is cautioned because of logistical constraints associated with this research. Hydropower conditions were simulated from Kaw Dam for only three days each year and simulations occurred after the peak spawning period of striped bass. Also, these findings are based on only one year of simulated-hydropower conditions in the Arkansas River. Hydropower operations have been detrimental to striped bass spawning success in the Roanoke River system in Virginia (Fish and McCoy 1959; Neal 1976; Manooch and Rulifson 1989).

Because Kaw Dam operates on a run-of-the-river basis, hydropower operations will only affect discharge rates <5,500 cfs. Discharge rates from Kaw Dam were <5,500 cfs about 50% of the time during the striped bass spawning season in 1987 and 1988. Striped bass spawning peaked in 1987 and 1988 during periods when discharge rates from Kaw Dam were >5,500 cfs (Chapter I and Appendix C); accordingly, striped bass spawning peaked during periods when hydropower operations would not be of consequence. Kaw Dam discharge rates decreased to levels ostensibly affected by hydropower discharges within one week of the peak spawning period in both years.

Hydropower-regulated discharges from Kaw Dam will alter discharge and temperature regimes in the Arkansas River. Water temperatures were more variable at sampling sites during periods of simulated-hydropower discharges. Discharge rates at the Ralston gaging station were more variable during periods of simulated-hydropower discharges from Kaw Dam and mimicked the discharge pattern from Kaw Dam. Striped bass spawning success may be affected if alterations of the temperature and discharge regimes create sub-optimal conditions during the peak striped bass spawning period in late April to early May.

Extended periods of hydropower-regulated discharges from Kaw Dam during the striped bass spawning migration may also be detrimental to striped bass spawning success. Stable discharge from dams is important to striped bass during their spawning migration. For example, erratic discharges of a hydropower facility on the Roanoke (Staunton) River during the striped bass spawning migration period caused striped bass to spawn in the Dan River (Neal 1976).

Striped bass spawning success in the Arkansas River may decline if spawning continues to be concentrated farther downstream during periods of hydropower discharge from Kaw Dam. Striped bass spawning may become concentrated in the downstream reaches of the river because the effects of hydropower discharges are diminished slightly with increasing distance from Kaw Dam. Eggs spawned in the upstream reaches of the river are more likely to hatch before flowing into slack waters of Lake Keystone (Combs 1979).

Adverse effects of hydropower operations can be diminished by regulating the intensity, duration, and frequency of hydropower discharges. The Appalachian Power Company must maintain 19 consecutive days of uninterrupted stream flow from the Leesville-Smith Mountain hydroelectric facility on the Roanoke (Staunton) River, Virginia, during the striped bass spawning season under the direction of Virginia Commission of Game and Inland Fisheries personnel (Neal 1976). Discharge restrictions at the Roanoke Rapids Dam included stipulations that discharge rates could not fluctuate more than 1,500 cfs during a 1-h period (Manooch and Rulifson 1989). If discharge restrictions are needed at Kaw Dam, I recommend that the timing of the restrictions be based upon the optimum photoperiod for striped bass (Chapter III).

Striped bass spawning success in the Arkansas River was not affected by simulated-hydropower discharges from Kaw Dam in 1987 and 1988. Further monitoring of striped bass spawning success after the initiation of hydropower operations is being conducted. Ultimately, hydropower operations at Kaw Dam may not affect striped bass spawning success because discharge may not be hydropower-regulated for extended periods of time during the spawning season. Also, the duration of daily hydropower discharges will be longer than during our study because the maximum discharge capacity for the facility is less than initially estimated. Accordingly, it will take longer to release accumulated discharges through the hydropower turbine.

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Table 1.-Analysis of variance of the effects of discharge patterns, site, and sampling time on striped bass egg densities at the Belford, Ralston, and Blackburn sites during experimental flow trials concurrent with normal and simulated-hydropower releases from Kaw Dam, May 1988.

Source of Variation	DF	Sum of Squares	F value	P>F
Discharge Pattern	1	36.2020	0.039	0.8529
Site	4	122.1851	0.567	0.6898
Sampling Time	18	969.6360	29.466	<0.0001
Error	46	87.7530		

Table 2.-Analysis of variance of the effects of discharge patterns, site, and sampling time on striped bass egg abundances at the Belford, Ralston, and Blackburn sites during experimental flow trials concurrent with normal and simulated-hydropower releases from Kaw Dam, May 1988.

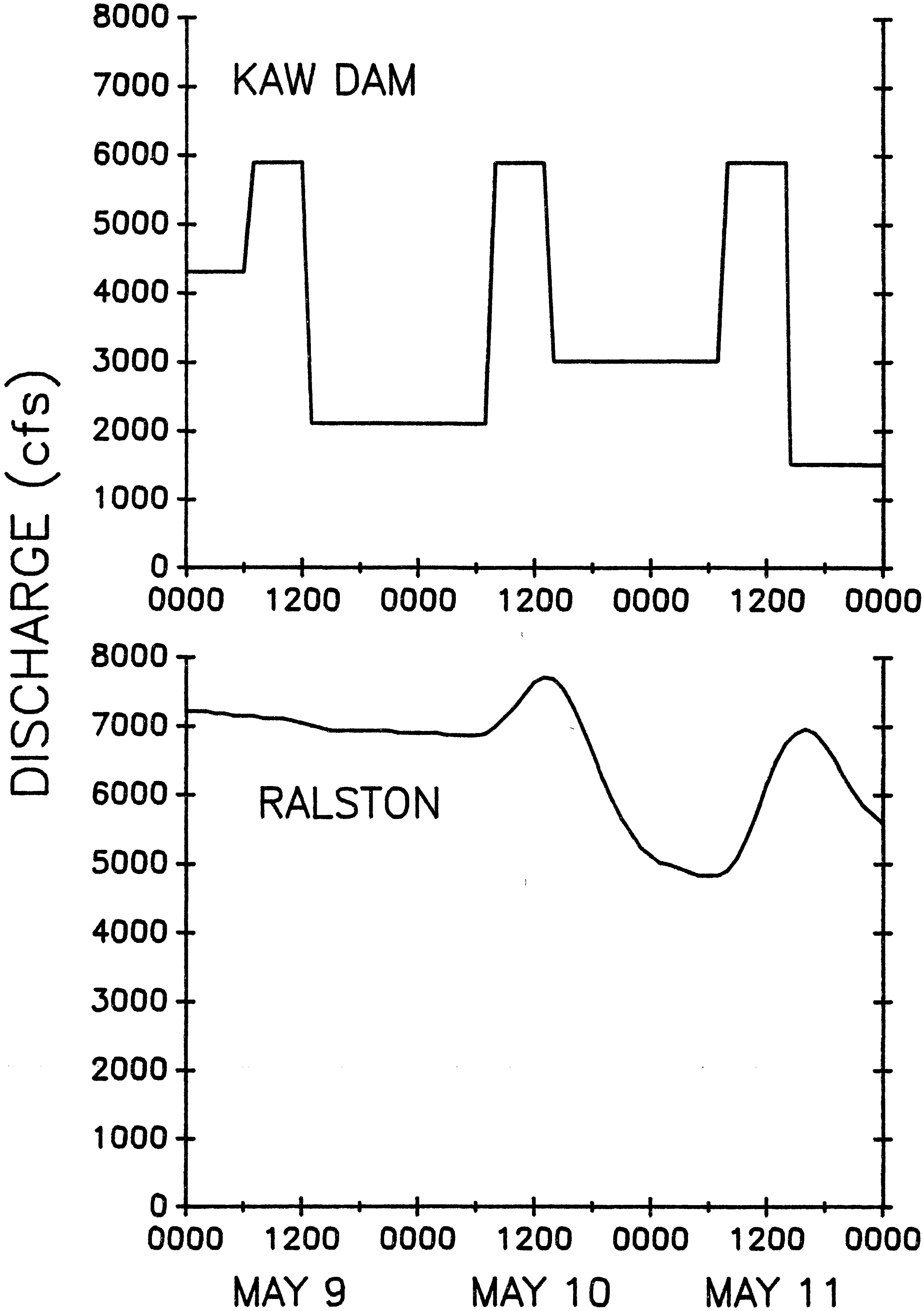
Source of Variation	DF	Sum of Squares	F value	P>F
Discharge Pattern	1	$1.057495\text{x}10^{14}$	2.234	0.2093
Site	4	$1.893547\text{x}10^{14}$	0.640	0.6403
Sampling Time	18	$1.329979\text{x}10^{15}$	27.406	<0.0001
Error	46	$1.294121\text{x}10^{14}$		

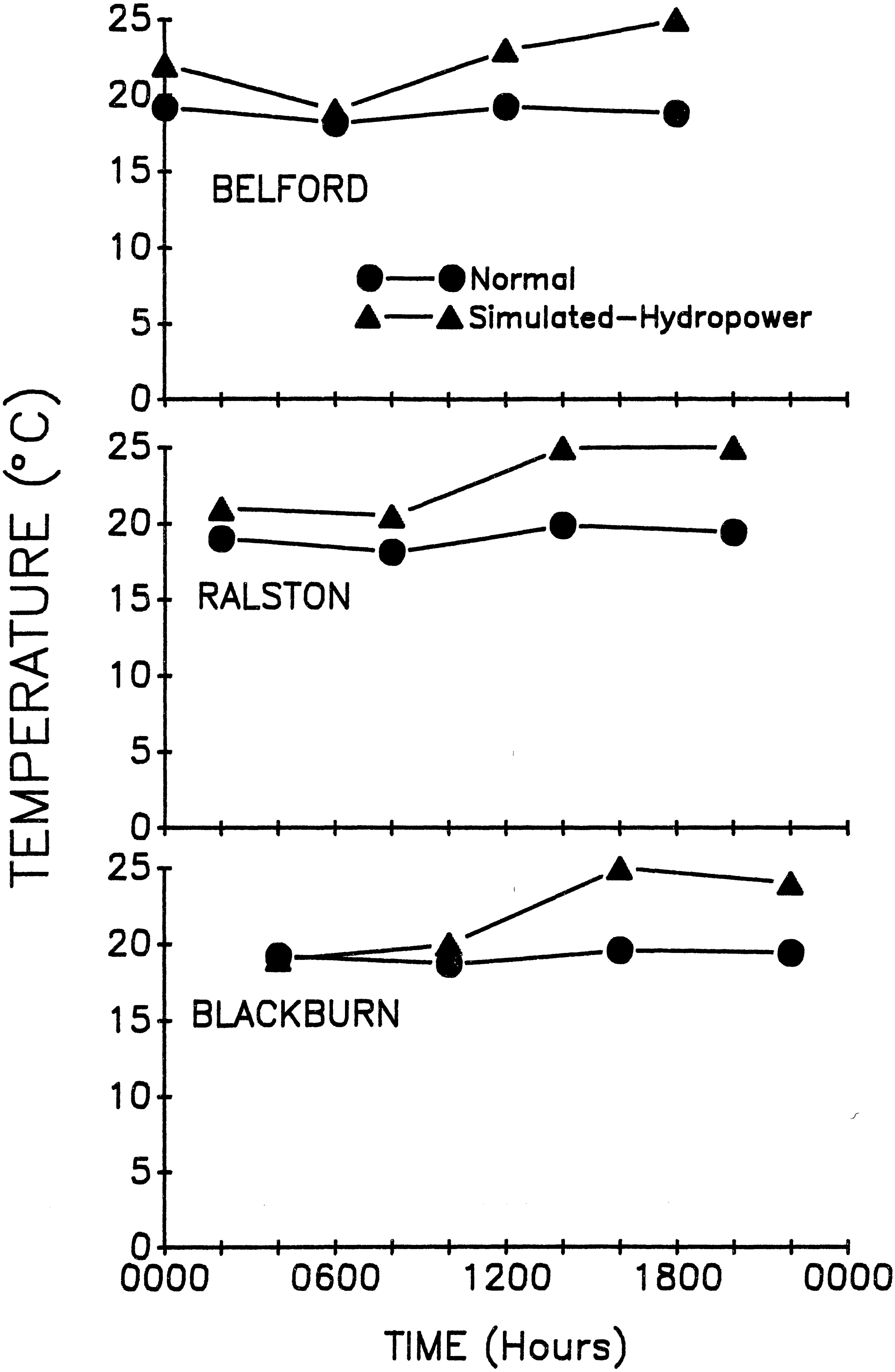
FIGURE CAPTIONS

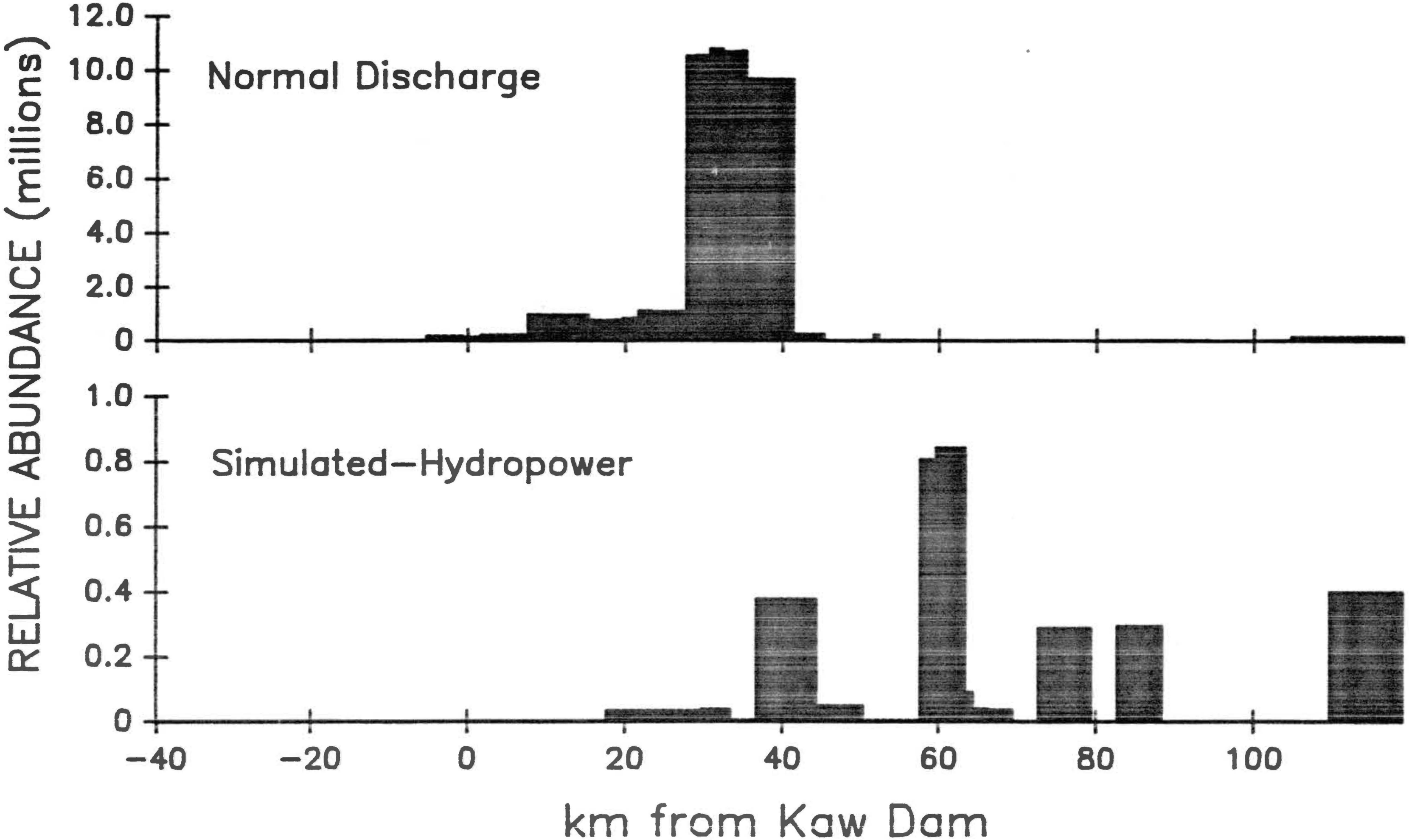
1.-Water discharge rates (cfs) at Kaw Dam and Ralston, Oklahoma, during simulated-hydropower discharges from Kaw Dam, May 1988. Discharge rates from Ralston are delayed by 1-d because of the distance from Kaw Dam (95 km).

2.-Water temperatures (°C) at sampling sites in the Arkansas River, Oklahoma, during experimental flow trials, May 1988.

3.-Striped bass spawning location estimates in the Arkansas River, Oklahoma, during experimental flow trials, May 1988.


KAW DAM
RALSTON
DISCHARGE (cfs)
8000
7000
6000
5000
4000
3000
2000
1000
0
0000
1200
0000
1200
0000
1200
0000
MAY 9
MAY 10
MAY 11


TEMPERATURE (°C)
BELFORD
Normal
Simulated-Hydropower
RALSTON
BLACKBURN
25
20
15
10
5
0
0000
0600
1200
1800
0000
TIME (Hours)


RELATIVE ABUNDANCE (millions)
12.0
10.0
8.0
6.0
4.0
2.0
0
Normal Discharge
1.0
0.8
0.6
0.4
0.2
0
Simulated—Hydropower
-40
-20
0
20
40
60
80
100
km from Kaw Dam

APPENDIXES

APPENDIX A

SAMPLING DATES AND SITES

Appendix A.1.-Ichthyoplankton sampling dates and sites in the Arkansas River, Oklahoma, 1987. Sites sampled are listed for dates when all sites were not sampled.

Date	Sites Sampled
March	
16	All
19	Kaw Dam, Ponca City, Belford, Ralston
23	Belford, Ralston, Blackburn
24	Kaw Dam, Ponca City
26	Belford, Ralston, Blackburn
27	Ponca City
30	Blackburn
31	Kaw Dam, Ponca City, Belford, Ralston
April	
02	All
05	Kaw Dam
08	Ponca City, Belford, Ralston, Blackburn
10	All
13	All
16	All
20[a]	Kaw Dam, Ponca City
21[a]	Belford, Ralston, Blackburn
23	All
27	All
30	All
May	
04[a]	Kaw Dam, Ponca City
05[a]	Belford, Ralston, Blackburn
07[a]	Kaw Dam, Ponca City
08[a]	Belford, Ralston, Blackburn
12	All
15	All
19	All
22	All
26	All

[a] Denotes dates of experimental flow trials.

Appendix A.2.-Ichthyoplankton sampling dates and sites in the Arkansas River, Oklahoma, 1988. Sites sampled are listed for dates when all sites were not sampled.

Date	Sites Sampled
March	
14	Ponca City, Belford, Ralston
17	Ponca City
21	Kaw Dam, Ponca City, Belford, Ralston
24	All
28	All
31	All
April	
04	All
07	All
11	All
14	All
19	All
22	All
26	All
29	All
May	
02[a]	Kaw Dam, Ponca City
03	Belford, Ralston, Blackburn
05	Kaw Dam, Ponca City
06[a]	Belford, Ralston, Blackburn
10[a]	Kaw Dam, Ponca City
11[a]	Belford, Ralston, Blackburn
13	All
16	Kaw Dam, Ponca City
17	Belford, Ralston, Blackburn
19	Ponca City, Belford, Ralston, Blackburn
20	Kaw Dam
23	All
26	All
31	All

[a] Denotes dates of experimental flow trials.

APPENDIX B

STRIPED BASS EGG CATEGORIES

Appendix B.-Descriptions of developmental egg stages used to age striped bass eggs.

Stage[a]	Age	Description
Dead	--	Eggs appear cloudy, yolk material ruptured.
1	0-5 h	Blastomeres large and often located laterally on the egg.
2	5-10 h	Blastomeres smaller and located on the animal pole.
3	10-15 h	Blastodisc present, covers up to half of the yolk mass, egg circular.
4	15-20 h	Blastodisc covering more than half of the yolk mass, egg often slightly oval.
5	20-25 h	Embryo outline present.
6	25-30 h	Anterior and posterior portions of embryo project prominently above yolk mass.
7	30-35 h	Embryo present, tail separated from yolk mass.
8	35-44 h	Embryo well developed, tail extends straight or curled up in egg, eyes well developed.

[a] Stages were based on photographs in Bayless (1972) and descriptions in Mansueti (1958).

APPENDIX C

DISCHARGE RATES AT KAW DAM AND RALSTON

Appendix C.1.-Mean daily discharges (cfs) in the Arkansas River recorded by the U.S. Army Corps of Engineers for Kaw Dam, Oklahoma, and by the U.S. Geological Survey at Ralston, Oklahoma, April and May 1987.

Date	Kaw Dam	Ralston	Date	Kaw Dam	Ralston
April			May		
1	20,400	27,200	1	3,400	3,800
2	20,400	26,200	2	3,400	5,010
3	22,600	26,700	3	3,400	4,990
4	22,600	26,000	4	3,400	4,850
5	22,600	25,000	5	1,500	4,360
6	22,600	23,700	6	140	3,180
7	14,400	19,300	7	2,900	6,000
8	8,200	15,300	8	3,000	24,500
9	8,200	13,000	9	6,000	26,400
10	8,200	12,600	10	6,000	14,300
11	8,200	12,200	11	6,000	12,100
12	8,200	11,800	12	5,000	10,800
13	8,200	11,600	13	5,000	9,590
14	8,200	11,500	14	5,000	8,960
15	5,000	9,800	15	2,430	7,540
16	5,000	9,060	16	2,430	5,710
17	7,100	10,400	17	2,430	5,240
18	7,100	10,900	18	2,430	4,900
19	7,100	10,700	19	1,700	4,520
20	7,100	10,400	20	1,700	4,000
21	7,100	10,500	21	1,700	810
22	7,100	10,300	22	2,010	3,800
23	7,100	10,100	23	2,010	4,100
24	7,100	10,000	24	2,010	3,980
25	7,100	9,800	25	2,010	4,440
26	7,100	9,590	26	2,010	6,040
27	7,100	9,320	27	2,010	10,400
28	550	6,150	28	5,100	51,400
29	550	3,190	29	150	78,900
30	1,650	2,800	30	150	72,000
			31	7,200	46,800

Appendix C.2.-Mean daily discharges (cfs) in the Arkansas River, Oklahoma, recorded by the U.S. Army Corps of Engineers for Kaw Dam, Oklahoma, and by the U.S. Geological Survey at Ralston, Oklahoma, April and May 1988.

Date	Kaw Dam	Ralston	Date	Kaw Dam	Ralston
April			May		
1	2,000	31,100	1	10,500	11,800
2	2,000	31,300	2	10,500	11,800
3	2,000	31,300	3	10,000	12,300
4	2,000	39,700	4	10,000	12,700
5	2,000	23,100	5	10,000	12,300
6	10,500	18,300	6	10,000	12,000
7	10,500	18,000	7	4,300	9,660
8	10,500	16,800	8	4,300	6,790
9	10,500	15,500	9	4,300	6,400
10	10,500	14,700	10	2,100	6,100
11	10,500	13,300	11	3,000	5,230
12	10,500	13,400	12	3,400	5,460
13	10,500	13,200	13	3,400	4,980
14	10,500	13,400	14	3,400	4,850
15	10,500	13,100	15	3,400	4,770
16	10,500	12,700	16	3,400	4,770
17	10,500	12,600	17	3,400	4,610
18	10,500	22,100	18	2,200	4,300
19	10,500	24,000	19	120	3,360
20	10,500	23,200	20	120	2,800
21	10,500	17,400	21	120	2,800
22	10,500	14,400	22	120	2,850
23	10,500	13,300	23	120	3,730
24	10,500	12,700	24	2,200	3,000
25	10,500	12,600	25	3,400	4,110
26	10,500	12,700	26	3,400	4,710
27	10,500	14,700	27	3,400	4,670
28	10,500	15,900	28	2,200	3,990
29	10,500	13,290	29	2,200	3,430
30	10,500	12,500	30	2,200	3,490
			31	2,200	3,460

VITA

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Candidate for the Degree of

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