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. We sampled ichthyoplankton in this 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 4 bridges and by boat in the Kaw Dam tailwater. Spawning was initiated in mid-April of both years at water temperatures of 11.8°–14.9° C, peaked in late April to early May at temperatures of 15.0°–22.3° C and terminated in mid-May when water temperatures were 25.3°–27.5° C. Peak densities of striped bass eggs generally increased with distance (to about 50 km) 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.

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Striped bass were first introduced into Oklahoma waters in the 1960s. More than 2.75 million striped bass were stocked into Lake Keystone, Oklahoma, between 1965 and 1969 (Mensinger 1970, Combs 1979). Natural reproduction of striped bass in the Arkansas River above Lake Keystone was first documented in 1970 (Mensinger 1970), and reproduction has continued annually since that time (Mark Ambler, Okla. Dep. Wildl. Conserv., pers. commun.) despite summer mor-

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talities of large striped bass in Lake Keystone (Combs 1982, Zale et al. 1988), increased angling pressure (Combs 1982), and a blockage of 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, Okla. Dep. Wildl. Conserv., pers. commun.).

We sampled striped bass ichthyoplankton in the Arkansas River during 1987 and 1988 to establish baseline characteristics of striped bass spawning patterns prior to the addition of a hydroelectric turbine at Kaw Dam in the autumn of 1989. The objective of this research was to determine when and where spawning occurred in this river reach. Similar research was done by Combs from 1976 to 1978 (Combs 1979). It was imperative to confirm the validity of Comb's (1979) conclusions and findings because of the importance of continued reproduction to the Lake Keystone striped bass population.

Methods

Sampling with conical plankton nets was conducted twice weekly from mid-March through May in 1987 and 1988. Nets were fished from 4 bridges along the Arkansas River located 14, 78, 95, and 119 km downstream from Kaw Dam and by boat in the Kaw Lake tailwaters. Sampling sites were identical to those used by Combs (1979). Sampling sites located 78, 95, and 119 km downstream from Kaw Dam are hereafter referred to as the downstream sites, and the remaining sites are referred to as the upstream sites.

The nets were 2.5 m long, had a 0.5-m diameter circular mouth opening, and had a mesh size of 0.5 mm. The nets were attached to a rope with a 3-point bridle and 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 1 hour during 1987 and 15 minutes in 1988; sampling duration was decreased to reduce clogging. Sampling was conducted during daylight hours. Sampled water volumes were measured with a General Oceanics Model 2030 flow meter (General Oceanics Inc., Miami, Fla.) 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 with a Hydrolab Surveyor II (Hydrolab Corp., Austin, Texas) or YSI meters (Yellow Springs Instrument Company, Yellow Springs, Ohio) concurrently with ichthyoplankton sampling. Water velocity was measured with a Teledyne Gurley Model 622 current meter (Teledyne Gurley, Troy, N.Y.). 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 95-km downstream sampling site.

Ichthyoplankton samples were preserved in 5% unbuffered formalin and stored in plastic buckets. Rose bengal was added to the samples to facilitate sorting. Ichthyoplankton samples were sorted in the laboratory and debris and other organ-

isms were removed. Sorted ichthyoplankton samples were stored in 5% unbuffered formalin.

Striped bass eggs were identified with a binocular dissecting microscope, based on descriptions of striped bass eggs in 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 for that site. Discharges from Kaw Dam were used for the upstream sites; the gaging station discharges were used for the downstream sites.

To determine spawning locations, striped bass eggs were aged using photographs in Bayless (1972). Eggs were categorized into 1 of 8 stages based on their developmental status. Egg-stages were classified into 5-hour time periods using photographs from Bayless (1972). To correct for the influence of temperature on embryo development and obtain an accurate estimate of the true age of the egg (the estimated egg age was based on comparisons of striped bass eggs collected in samples with the photographs of eggs developing at 18.9° C from Bayless [1972]), the equation $D_e = 10.77e^{-0.0934T}$ (where D_e = number of days to hatch and T = temperature [° C] at which eggs were collected) was used to adjust egg-stages for different ambient temperatures (Rogers et al. 1977). This equation describes the relationship between hatching time or 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 then multiplied by the age in hours estimated by egg stage periods to provide an estimated range of the true age of an egg.

Spawning locations were estimated using corrected egg age ranges and egg transport rates (Combs 1979). Striped bass egg transport rates approximate 80% of water velocity (Neal 1971). The temperature-corrected egg age ranges were multiplied by 80% of the river velocity measured concurrent with each sample to determine a range upstream from the sampling site where spawning ostensibly occurred. Relative abundances of eggs spawned at each kilometer within the estimated spawning range 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 (1-km) 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. In 1987, striped bass eggs were initially collected on 13 April at the downstream sites (Table 1); initial collections of striped bass eggs at the upstream sites occurred about 1 week later (Table 1). In 1988, striped bass eggs were initially collected on 14 April at the 78-km site, and were present at all of the downstream sites on 19 April (Table 2).

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

	Site									
	Tailwater		14-km		78-km		95-km		119-km	
Date	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Apr										
02	0	0	0	0	0	0	0	0	0	0
05	0	0	0	0	0	0	0	0	0	0
08	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0.011	0.004	0.001	0.001	0.008	0.011
16	0	0	0.008	0.002	0.001	0.001	0	0	0	0
20	0.001	0.002	0.001	0.002						
21					0.906	0.473	0.690	0.469	0.753	0.759
23	0[a]	0	0.002	0.001	0.962	0.233	0.234	0.047	0.275[a]	0.072
27	0	0	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	0	0	0	1.178	0.786	0	0	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	0	0	0	0	0	0.001	0.001	0	0
22	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0

[a]Denotes collections represented by only 2 samples.

Eggs were initially collected at the 14-km site on 2 May in 1988 (Table 2); no striped bass eggs were collected at the tailwater site during 1988.

Peak spawning periods occurred earlier at downstream sites than at upstream sites in both years (Tables 1,2). In 1987, peak densities of striped bass eggs occurred on 27 April at the downstream sites; striped bass eggs were collected at the 14-km site concurrently, but at a low density (Table 1). Spawning peaked at the upstream sites in early to mid-May; egg densities peaked at the 14-km 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 119-km site, and on 6 May at the 78-km and 95-km sites (Table 2). Striped bass eggs were collected at the 14-km site on 2 May at a low density, but were not collected on 5 May (Table 2). Spawning peaked at the 14-km site on 16 May (Table 2). Secondary spawning peaks occurred at the downstream sites in both years.

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

Peak densities of striped bass eggs generally increased with distance from Kaw Dam. In 1987, peak densities of striped bass eggs were 0.037, 0.905, 7.903,

Table 2. Mean densities (N/m^3) and standard deviations (S.D.) of striped bass eggs 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							
	14-km		78-km		95-km		119-km	
Date	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Apr								
04	0	0	0	0	0	0	0	0
07	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
14	0	0	0.122[a]	0.042	0	0	0	0
19	0	0	0.009	0.024	0.091	0.041	0.066	0.071
22	0	0	0.002	0.004	0.256	0.050	0	0
26	0	0	0.163	0.045	0.057	0.008	0.152	0.008
29	0	0	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	0						
06			1.778	2.787	5.877	9.732	0.647	0.857
10	0	0						
11			0.616	0.677	1.418	1.832	1.102	1.231
13	0	0	0.249	0.004	0.216	0.061	0.008	0.007
16	0.090	0.051						
17			0	0	0	0	0.025	0.025
19	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0

[a]Denotes collections represented by only 2 samples.

6.169, and 22.154 eggs/m^3 at the Kaw Dam tailwater, 14-km, 78-km, 95-km, and 119-km 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 14-km, 78-km, 95-km, and 119-km sites, respectively (Table 2.)

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

Water quality variables were generally within optimal ranges during the striped bass spawning season; water temperatures, water velocities, and pH deviated briefly from optimal values. Dissolved oxygen concentrations $\geq$5.0 mg/liter are considered

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

Date	Site				
	Tailwater	14-km	78-km	95-km	119-km
Apr					
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.

optimal for striped bass egg development (Crance 1984); dissolved oxygen concentrations measured when striped bass eggs were collected ranged from 6.2 to 12.6 mg/liter in 1987 and from 6.4 to 12.8 mg/liter in 1988. 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; 18.0° C is considered optimal for striped bass egg development (Rogers 1978). Water velocities ranged from 0.2 to 1.8 m/second in 1987 and from 0.7 to 1.7 in 1988, respectively. Water velocity between 0.5 and 1.5 m/second is considered optimal for striped bass spawning (Crance 1984). Striped bass eggs were collected at pH levels that ranged from 7.6 to 8.1 in 1987 and from 7.4 to 8.5 in 1988. The optimal pH range for striped bass eggs is 7.5 to 8.5 (Bonn et al. 1976).

Striped bass spawning was concentrated within 50 km downstream of Kaw Dam in 1987 and 1988 (Figs. 1, 2). Most striped bass spawning appeared to occur near the confluence of the Salt Fork and Arkansas rivers 26 km downstream from Kaw Dam. Fewer eggs were back-calculated to have been spawned upstream of Kaw Dam in 1987 (1.7%; Fig. 1) than in 1988 (6.2%; Fig. 2). Spawning location estimates ranged as far as 90 km upstream of Kaw Dam in 1988 and 80 km in 1987;

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

Date	Site				
	Tailwater	14-km	78-km	95-km	119-km
Apr					
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.

estimates upstream of Kaw Dam probably resulted from striped bass eggs being trapped in eddies.

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 in both years. Similarly, striped bass spawning began in early to mid-April and terminated in mid- to late May from 1976 to 1978 (Combs 1979).

Major and secondary spawning peaks occurred in 1987 and 1988. One spawning peak occurred in 1976, but 3 spawning peaks occurred in 1978 (Combs 1979). One to 3 spawning peaks occurred in other populations (Kernehan et al. 1981, Uphoff 1989). Secondary spawning peaks in the Arkansas River were associated with rising water temperatures in 1987 and 1988. Secondary spawning peaks were

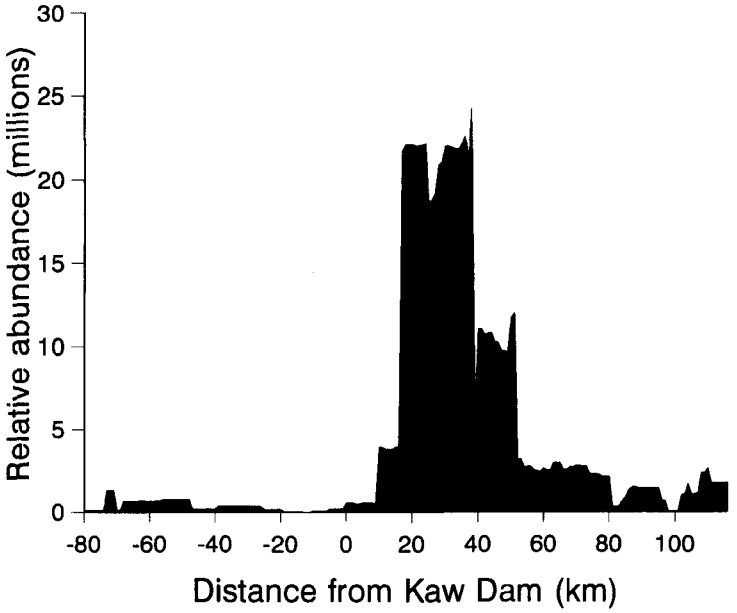

Figure 1. Distribution of striped bass spawning location estimates in the Arkansas River, Oklahoma, 1987. Negative values represent kilometers upstream of Kaw Dam.

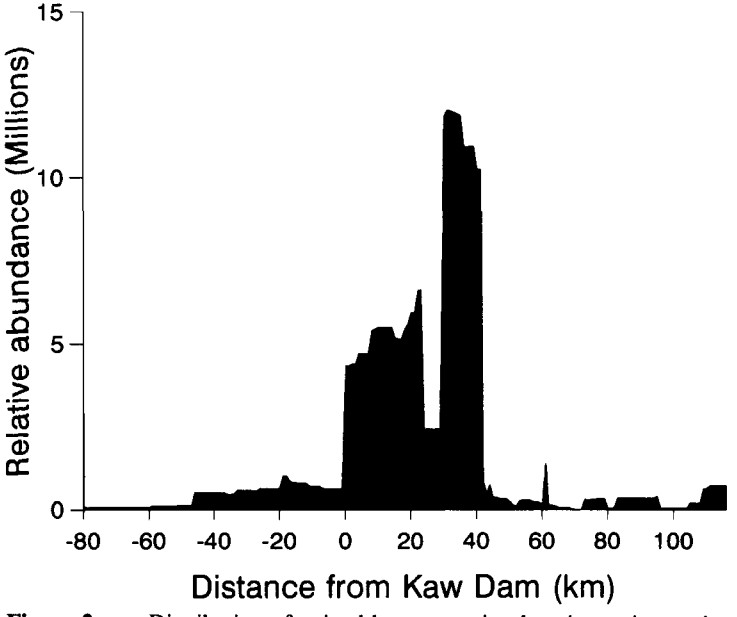

Figure 2. Distribution of striped bass spawning location estimates in the Arkansas River, Oklahoma, 1988. Negative values represent kilometers upstream of Kaw Dam.

critical in maintaining striped bass recruitment in the Choptank River, Maryland, when larvae spawned during the peak spawning period suffered catastrophic mortality (Uphoff 1989).

In 1987 and 1988, striped bass in the Arkansas River initiated spawning activity within the 1-week period (7–14 April) reported by Combs (1979), indicating 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, Kernehan et al. 1981). The similarity of annual initial spawning dates in the Arkansas River did not appear to be related to water temperatures. Striped bass eggs were collected at lower initial water temperatures in 1987 and 1988 (12.2°–14.9° C) than in 1976 to 1978 (Combs 1979; 15.5°–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°–18.5° C, peaked at 16.0°–22.0° C, and ceased at 17.0°–26.5° C in the Arkansas River from 1976 to 1978 (Combs 1979). In our study, spawning began at 11.8°–14.9° C, peaked at 15.0°–22.3° C, and ceased when downstream temperatures were 25.3°–27.5° C in 1987 and 1988. The differences in temperature probably are the result of how temperatures were reported in the 2 studies. Combs (1979) reported the mean of water temperatures associated with several daily samples; we 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 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. 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 2 factors. Abundances of adult and young-of-the-year striped bass in Lake Keystone increased annually from 1978 through 1980 (Combs 1982). We 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, respectively). Accordingly, our nets had greater filtering capacity.

Striped bass spawn farther upstream during periods of high discharge (Calhoun et al. 1950, Fish and McCoy 1959, Combs 1979). Kaw Dam discharge rates were moderate to high throughout April in both 1987 and 1988, and striped bass spawning was concentrated within 50 km downstream of Kaw Dam in these years. Similarly, >50% of the striped bass eggs spawned in 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).

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. More than 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 optimal spawning location for striped bass; discharge rates and water temperatures increased abruptly at this point.

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

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. Establishment of this baseline information will allow future spawning in this river to be monitored and evaluated to determine the effects of the addition of hydropower generation capabilities at Kaw Dam.

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