Environmental Influences on Largemouth Bass Recruitment in a Southern Great Plains Reservoir

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Abstract: We analyzed relationships between largemouth bass *(Micropterus salmoides)* recruitment and environmental characteristics in Skiatook Lake, Oklahoma, from 1997 through 1999. Catch rates of young-of-year (YOY) were positively associated with inflows into the reservoir during the spawning season (April–May), whereas juvenile catch rates were positively related to reservoir releases during the post-spawning period (Jun–Nov). Abundance of juvenile fish in fall electrofishing samples increased from 1997 through 1999. No evidence of over-winter mortality was detected. Estimated swim-up dates for young-of-year largemouth bass were later each year from 1997 to 1999. Growth of YOY largemouth bass was not correlated with any of the measured environmental variables. Our results show that increased water levels during the spawning period and distribution of nutrients throughout the reservoir via water releases during the post-spawning period enhanced largemouth bass production in Skiatook Lake.

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Environmental variability has long been known to affect population dynamics of largemouth bass *(Micropterus salmoides)*. Recruitment is particularly susceptible to environmental variability and has been quantified directly by measuring production of offspring after spawning (Miranda et al. 1984, Ploskey 1986, Fisher and Zale 1991, Ploskey et al. 1996) and indirectly by measuring juvenile growth and timing of spawn (Goodgame and Miranda 1993, Miranda and Hubbard 1994*a, b*). Because largemouth bass reproduce only once per year, recruitment varies as environmental conditions change from year to year.

Environmental factors that have been shown to affect recruitment of largemouth bass in reservoirs can be grouped into 2 categories: hydrology and weather. Most of the research on environmental correlates with largemouth bass recruitment have fo-

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cused on hydrology. Reservoir hydrology has been found to affect largemouth bass abundance (Rainwater and Houser 1975, Summerfelt and Shirley 1978, Fisher and Zale 1991, Reinert et al. 1995, Ploskey et al. 1996), survival (Miranda et al. 1984), and spawning success (Kohler et al. 1993).

The effects of weather on largemouth bass recruitment are not as well understood. Summerfelt and Shirley (1978) found no significant correlations between year-class strength and weather variables (wind velocity, air temperature, and water temperature). However, over-winter survival of largemouth bass has been shown to be a major factor influencing recruitment. Over-winter survival of largemouth bass has been shown to be length-dependent (Miranda and Hubbard 1994*a*, *b*), with larger fish having higher fat reserves which give them a higher probability of survival during periods of starvation such as winter. Goodgame and Miranda (1993) showed that earlier swim-up dates of larval largemouth bass, which could be influenced by weather and/or reservoir hydrology, resulted in lower over-winter mortality.

Our objective was to examine the effects of reservoir hydrology and weather on recruitment of largemouth bass in Skiatook Lake, a southern Great Plains reservoir in Oklahoma. To achieve our objective, we measured trends in abundance of YOY and juvenile largemouth bass, searched for correlations among those trends and reservoir hydrology and weather, examined the impact of overwinter mortality on juvenile fish, measured growth of YOY fish and temporal trends in YOY swim-up dates, and searched for correlations between YOY growth and reservoir hydrology and weather.

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Methods

Study Area

Skiatook Lake is a 4,266-ha flood control impoundment of Hominy Creek in north-central Oklahoma formed in 1984. The lake has a total drainage area of 917 km^2, a mean depth of 9.7 m, and a shoreline development index of 11.3. The lake perimeter consists largely of steep, bedrock substrate with little aquatic vegetation. The upper end of the reservoir is more turbid than the lower end, with average spring Secchi depths of 0.1 m and 1.2 m, respectively. The difference in water transparency between the upper end and the lower end is due mainly to primary production (Fisher et al. 2000). The top of the conservation pool is 217.6 m above mean sea level and the mean monthly release rate from 1997 to 1999 was 360.68 m^3/seconds/day. Largemouth bass were supplementally stocked in 1985 and 1986 and non-native smallmouth bass were stocked in 1990 and 1991.

Fisheries Data

In summers 1997–1999, we collected YOY largemouth bass by backpack electrofishing. We adjusted the output settings on the electrofishing unit only when fish appeared less susceptible to shocking (i.e., swimming un-stunned through the electrofishing field). Sites for collection of YOY fish were arbitrarily selected from probable spawning sites. We used the fish collected by electrofishing, along with supplemental seining at area boat ramps, to estimate daily age using otoliths. We mounted, sanded, and polished the sagittae otolith in the sagittal plane and then counted rings with a compound microscope (Miller and Storck 1982). One person counted the rings in each otolith until the counts differed by no more than 2 and then the highest count was assigned as the age in days since larval swim-up. Daily ring formation in otoliths has been validated for largemouth bass (Miller and Storck 1982).

In the spring and fall of 1997 through 1999, we electrofished at night for juvenile largemouth bass using a randomized sampling design with a boat-mounted electrofishing unit. We classified largemouth bass less than 226 mm as juveniles in spring and fall samples using data from Carlander (1977).

Environmental Data

We obtained daily weather data (average air temperature, average wind speed, and accumulated rainfall) from the Oklahoma Mesonet station at Skiatook, Oklahoma, and daily reservoir hydrology data (water elevation, storage, inflow, and release) for Skiatook Lake from the U.S. Army Corps of Engineers for 1997 through 1999 (Table 1). We grouped the daily environmental data into 2 seasons: spawning (Apr–May) and post-spawning (Jun–Nov) and calculated average air temperature, average wind speed, accumulated rainfall, average water elevation, average storage, accumulated water released, accumulated inflowing water, and number of days of flooding (above the conservation pool elevation of 217.6 m above mean sea level) for each year and season.

Statistical Analyses

We used correlation analysis (SAS 1992) to examine the relationships between environmental variables during the spawning season and mean catch rates (number of fish per electrofishing hour) of YOY largemouth bass captured in summer electrofishing, and between environmental variables during the spawning and post-spawning seasons and the mean catch rates of juvenile largemouth bass captured in fall electrofishing. We used ANOVA and orthogonal polynomial contrasts (Kuehl 1994) to compare catch rates of juvenile and YOY largemouth bass among years to determine recruitment trends for spring, summer, and fall 1997 through 1999. Additionally, we used ANOVA (SAS 1992) to compare catch rates of juvenile fish in fall

Table 1. Summary statistics for the environmental variables used in correlations with catch rates of young-of-year largemouth bass and juvenile largemouth bass at Skiatook Lake, Oklahoma, 1997–1999.

Year	XELE[a]	XSTO	SREL	SINF	TFLOOD	XTEM	XWND	SRAIN
				Spawning season				
1997	217.80	405,458,551	641.97	714.86	56	18.15	11.84	32.41
1998	217.90	410,046,057	1,131.74	1,203.61	47	20.58	13.15	28.45
1999	218.90	455,502,915	1,444.02	2,425.48	61	19.35	12.37	61.01
				Post-spawning season				
1997	217.67	400,037,108	507.75	660.35	29	25.27	9.35	36.88
1998	217.46	391,290,725	201.96	151.21	19	27.69	9.12	15.34
1999	217.66	399,201,850	785.91	312.62	23	27.85	10.45	6.30

a. XELE = mean water elevation (msl), XSTO = mean water storage in reservoir (m^3), SREL = sum of reservoir releases (m^3/second/day), SINF = sum of inflow to reservoir (m^3/second/day), TFLOOD = total number of days above conservation pool elevation, XTEM = mean air temperature (°C), XWND = mean wind speed (km/hour), SRAIN = sum of rainfall (cm).

1997 and 1998 with those in the following spring (1998 and 1999, respectively) as a measure of over-winter mortality.

We used the age data from summer with ANOVA (SAS 1992) and 2-sample Kolmogorov-Smirnov (K-S) tests (Conover 1980) to compare swim-up dates (Julian days) among years (1997–1999) and ANOVA to compare average daily growth rates (mm/day) among years. Finally, we searched for correlations between mean growth rates of YOY bass and the environmental variables during the spawning season. Since the correlation analyses were based on small sample sizes and we were interested in finding biologically meaningful relationships, we used $P \leq 0.10$ to detect differences with these analyses. We used $P \leq 0.05$ for all other analyses. Table-wide error rates for alpha for the correlation analyses were controlled with a sequential-Bonferroni correction (Rice 1989). Because constructing a correlation matrix among several variables is similar to performing multiple statistical tests, the true error (experiment-wise) rate for all tests is greater than that for each individual test. The sequential-Bonferroni adjusts the true error rate to approximately equal the individual error rate while allowing for an increased power to detect differences.

Results

We collected 35, 87, and 83 YOY largemouth bass in summer 1997, 1998, and 1999, respectively. Young-of-year largemouth bass catch rates were not significantly correlated with any environmental variable after applying the sequential-Bonferroni correction to alpha ($P \leq 0.10$, k = 8, corrected $P \leq 0.01$), but the correlation with the lowest P-value was with accumulated inflow during the spawning season ($P = 0.02$, $r = 0.99$, Fig. 1).

Juvenile catch rates were not significantly correlated with any environmental variables after applying the sequential-Bonferroni correction to alpha ($P \leq 0.10$, k = 16, corrected $P \leq 0.01$). However, the correlation with the lowest P-value was with accumulated releases during the post-spawning season ($P = 0.02$, $r = 0.99$, Fig. 1).

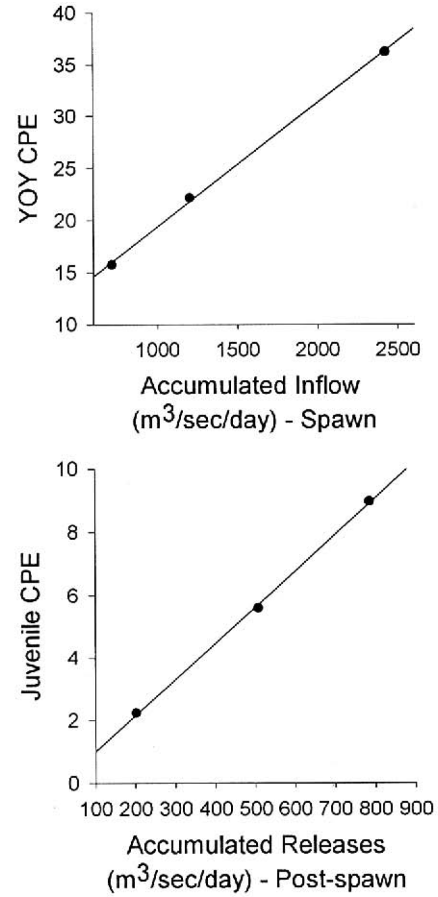

Figure 1. Correlations between environmental variables during the spawning and post-spawning seasons and catch rates (number of fish per electrofishing hour) of young-of-year (YOY) and juvenile largemouth bass in Skiatook Lake, Oklahoma.

Catch rates of juvenile largemouth bass increased from 1997 through 1999 in fall ($P < 0.01$, Table 2) but not in spring ($P = 0.08$, Table 2). We detected no evidence of over-winter mortality ($P > 0.05$, Table 2). Young-of-year catch rates increased steadily from 1997 to 1999, but the differences were not significant ($P = 0.32$, Table 3).

We estimated the age of 31, 79, and 69 YOY largemouth bass collected in summer 1997, 1998, and 1999, respectively. Mean Julian dates for largemouth bass swim-up were 133.4 in 1997, 132.1 in 1998, and 140.5 in 1999 and differed among years ($P < 0.01$, Fig. 2). Pairwise comparisons between years of the distribution of

Table 2. Mean electrofishing catch rate (number of fish per hour) statistics for juvenile largemouth bass in Skiatook Lake, Oklahoma, in fall and spring 1997, 1998, and 1999. SE = standard error. *P*-values for recruitment indicate significant differences among years for that season. *P*-values for LOF indicates quadratic or higher trend in means among years for each species. *P*-values for overwinter indicate differences between fall and subsequent spring of the indicated years.

	Year	Mean	SE
Fall	1997	5.60	1.47
	1998	2.23	1.13
	1999	8.98	1.02
	Recruitment	$P < 0.01$	
	LOF	$P < 0.01$	
Spring	1997	1.71	0.66
	1998	3.91	0.75
	1999	3.21	0.67
	Recruitment	$P = 0.08$	
	LOF	$P = 0.10$	
	Overwinter 1997–98	$P = 0.19$	
	Overwinter 1998–99	$P = 0.36$	

Table 3. Mean electrofishing catch rate (number of fish per hour) statistics for young-of-year largemouth bass in Skiatook Lake, Oklahoma in summer 1997, 1998, and 1999. SE = standard error. *P*-values for recruitment indicate significant differences among years.

Year	Mean	SE
1997	15.74	11.30
1998	22.14	8.35
1999	36.27	8.76
Recruitment	$P = 0.32$	

swim-up dates were significantly different for all comparisons ($P < 0.05$). Growth of YOY largemouth bass increased significantly from 1997 through 1999 ($P < 0.01$, Table 4) but was not correlated with any of the environmental variables.

Discussion

Our observations in Skiatook Lake indicate 2 critical periods influencing recruitment of largemouth bass: the spawning period and the post-spawning period. During the spawning period, catch rates of YOY largemouth bass tended to be

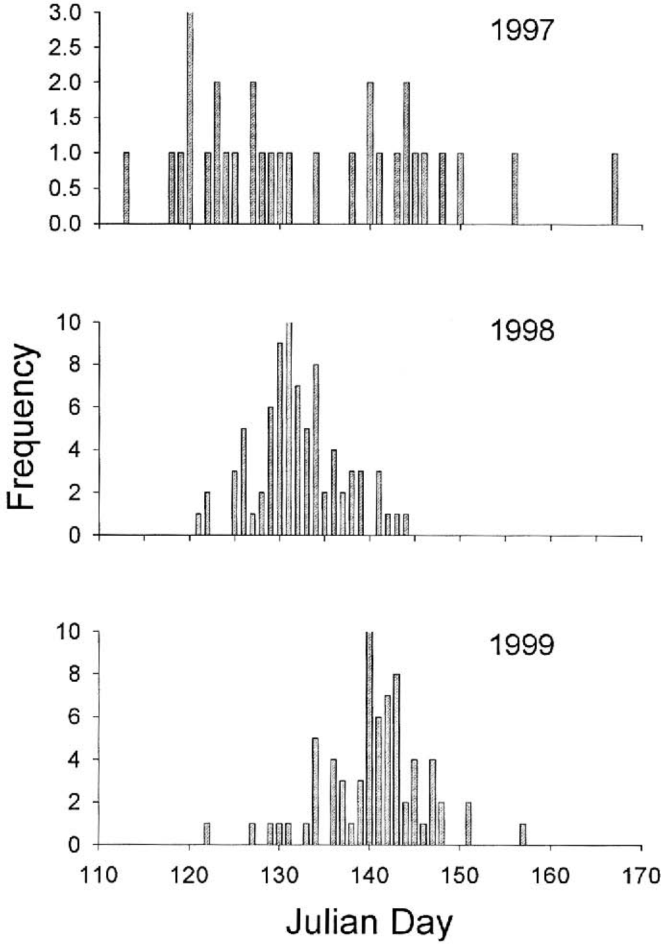

Figure 2. Distribution of swim-up dates of young-of-year largemouth bass in Skiatook Lake, Oklahoma 1997–1999.

greater in years with increased inflow into the reservoir. This is consistent with the hypothesis that increased inflows and subsequent water levels during the spawning season result in enhanced fish production (Ploskey 1986, Ploskey et al. 1996). During the post-spawning period, increased reservoir releases coincided with higher catch rates of juvenile largemouth bass. Although the input of nutrients are largely independent of reservoir operations, the distribution of those nutrients are affected by reservoir operations (Kennedy and Walker 1990). Therefore, reservoir operations at Skiatook Lake during the post-spawning period seem to have influenced the recruitment of largemouth bass.

Table 4. Mean growth rates (mm/day) of young-of-year largemouth bass in Skiatook Lake in 1997, 1998, and 1999. *N* = number of fish used to calculate mean growth, SE = standard error, and LOF indicates quadratic or higher trend in means among years.

Year	*N*	Mean	SE
1997	31	0.80	0.03
1998	79	1.07	0.02
1999	69	1.14	0.02
ANOVA		$P < 0.01$	
LOF		$P < 0.01$	

In general, water inflowing into a reservoir brings nutrients from upstream and water releases from the dam act to distribute those nutrients from the eutrophic upper-end to the rest of the reservoir (Kennedy and Walker 1990) and increase mixing (Ford 1990). Inflow and releases are driven by rainfall and reservoir operations. High levels of rainfall increases inflow, thus increasing releases to regulate storage in the reservoir. Without a wet spring to enhance nutrient input, increased releases may not increase fish production (Miranda et al. 1984, Ploskey et al. 1996). However, after spring rains have ceased (i.e., post-spawning period), reservoir releases still work to distribute the up-reservoir nutrients to the down-reservoir areas and, thus, are a primary factor affecting food production and, consequently, juvenile abundance during this time.

Although we have shown that increased inflow in spring corresponded with increased YOY abundance, and reservoir releases during summer and fall coincided with increased juvenile abundance in Skiatook Lake, it remains unclear as to which of these conditions benefited the fishery in terms of recruitment to adults. Miranda et al. (1984) showed that, although YOY largemouth bass abundance was positively related to water level in West Point Reservoir, Alabama-Georgia, growth was inversely related to abundance. They suggested that West Point Reservoir was able to sustain a particular biomass, rather than abundance, of largemouth bass. Because smaller fish often experience higher rates of mortality during the over-winter period due to starvation (Miranda and Hubbard 1994*b*), it is likely that increases in abundance will lead to overall smaller juvenile fish in that year class due to decreased growth. The more abundant, but smaller fish, may then suffer from large incidents of overwinter mortality leading ultimately to reductions in recruitment. In Skiatook Lake, this was not evident because we saw a concurrent positive trend between YOY growth and abundance. Additionally, winters that occurred during our study period may not have been severe enough for substantial overwinter mortality of YOY fish because we detected no differences in catch rates of juveniles between fall and the subsequent spring.

The general lack of statistically significant relationships between environmental variability and recruitment of black bass in Skiatook Lake suggests that environmental effects on recruitment are minimal in this reservoir, although longer-term research or inclusion of other environmental variables may reveal trends. For example, the hydrology of Skiatook Lake is much less variable than other reservoir systems in the southeastern United States (e.g., Bull Shoals Reservoir) that have been studied more extensively. Aggus and Elliott (1975) found that the average water level fluctuation in Bull Shoal Reservoir from 1968–1973 was 6.9 m. The mean water level fluctuation from 10 years of record at Skiatook Lake was 2.9 m and the greatest was 4.2 m. Furthermore, Aggus and Elliott (1975) found that the density of YOY largemouth bass in Bull Shoals Lake was directly related to acre-days of flooding of terrestrial vegetation in August, and Rainwater and Houser (1975) reported that reproductive success of black basses, including largemouth bass, in this same lake was indirectly related to water level fluctuations during the 3-month spawning season. Although conditions at Skiatook Lake may not act in a similar manner on resident largemouth bass populations, at least not at the scale we measured them, long-term sampling and finer-scale measurements at Skiatook Lake are needed to better determine the causative factors between environmental variability and largemouth bass recruitment in this system.

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