Effect of Water Level Fluctuations on Abundance of Young-of-year Largemouth Bass in a Hydropower Reservoir

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Abstract: Trends in the abundance of young-of-year largemouth bass (*Micropterus salmoides*) and water level fluctuations from 1976 to 1988 in Grand Lake were evaluated to assess recruitment strength before (1976–1981) and after (1982–1988) a change in reservoir operations. Significantly positive relationships between abundance of young-of-year largemouth bass and days of littoral flooding during spawning and nursery seasons, drawdown during revegetation season in the previous calendar year, combinations thereof, and water levels during these seasons indicated recruitment of largemouth bass was influenced by water level fluctuations. Implementation of a new operating rule curve in 1982 seemed to affect recruitment only indirectly by minimizing drawdown during late summer, thereby decreasing the exposure of shoreline areas of the reservoir for revegetation during the latter part of the growing season. A difference in mean elevation of about 1.2–1.5 m between revegetation and nursery seasons elicited favorable conditions for recruitment of largemouth bass in Grand Lake.

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Moderate water level fluctuations enhance reproduction and recruitment of reservoir fishes whose life cycles are associated with littoral zones (Ploskey 1986, Prosser 1986). Flooding of vegetated terrestrial areas during spawning and nursery seasons increases spawning habitat (Vogele 1975), augments production of autochthonous (Aggus 1971, Keith 1975) and availability of allochthonous (Applegate and Mullan 1967, Mullan and Applegate 1968) food resources, and enhances young-of-year growth and survival (Rainwater and Houser 1975). Drawdowns in late summer and early autumn promote the growth of inundation-tolerant vegetation (Hoffman et al. 1986), which provides additional spawning and nursery habitat when flooded the following spring and early summer (Ploskey 1983).

Grand Lake, an 18,800-ha reservoir in northeastern Oklahoma, was developed by the Grand River Dam Authority primarily for hydropower generation, as well as flood control, water supply, and recreation. From 1957 to 1981, hydropower generation was governed by an operating rule curve whereby the reservoir was drawn down to a target elevation 223.7 m (734 ft) above mean sea level (MSL) during late summer and fall and could be drawn down to 222.5 m MSL (730 ft MSL) under extreme drought conditions. This is referred to as the old operating rule curve. In 1982, Grand River Dam Authority implemented a new operating rule curve under which the reservoir was drawn down to a target elevation of 225.5 m MSL (740 ft MSL) during late summer and fall; under extreme drought conditions the minimum elevation was 223.1 m MSL (732 ft MSL). Justification for implementing the new rule curve was to minimize the effects of drawdown on recreation, particularly the utility of private and commercial boat docks, in Grand Lake.

To ascertain the effect of water level fluctuations from the rule curve change on largemouth bass recruitment in Grand Lake, we analyzed recruitment data available from the Oklahoma Department of Wildlife Conservation and related them to water level data for the reservoir. Specifically, we 1) assessed annual, monthly, and seasonal water level patterns during the old (1976–1981) and new (1982–1988) rule-curve periods; 2) evaluated trends in abundance of young-of-year largemouth bass in Grand Lake from 1977 to 1988; and 3) related water levels and the number of days of shoreline inundation during the spawning and nursery seasons and shoreline exposure from drawdown during the growing season (in the previous calendar year) to young-of-the-year largemouth bass class strengths.

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Methods

Shoreline seining data from 1977 to 1988 were obtained from the Oklahoma Department of Wildlife Conservation's Standardized Sampling Procedure (SSP) data base and used to analyze trends in abundance of young-of-year largemouth bass. The following summarizes the shoreline-seine sampling methods from the Oklahoma Department of Wildlife Conservation's SSP manual. Seines were 12.2 m long and 1.8 m deep (4.8-mm mesh) with a 1.8 m × 1.8 m × 1.2 m bag (3.2-mm mesh). Optionally, a shorter 6.1-m long seine was used if warranted by local conditions. A quadrant method was used to precisely sample known areas; 1 end of the seine was held stationary at the water's edge while the other was extended perpendicularly from shore and then pulled through the water in an arc back to shore. Quadrant sizes were 117 m^2 for 12.2 m seines and 29 m^2 for 6.1 m seines. A minimum area (7 quadrants for 6.1 m seines, 4 quadrants for 12.2 m seines) was usually sampled at each station on each sampling date. Effort is expressed as the total area sampled per station.

At Grand Lake, seining was conducted annually during summer (Table 1) at permanent stations located throughout the lake. Twenty-two permanent stations were established, but the number of sampled stations ranged from 14 to 32 (Table 1). Sample catches were converted to catch-per-unit-effort (CPUE) rates (fish/100 m^2) using the total effort (m^2) for all collections at a station on each sampling date.

Daily water level records for Grand Lake from 1976 to 1988 were obtained from Grand River Dam Authority's Pensacola Dam powerhouse. These data were used to describe annual changes in lake elevations during the 12-year period and to compare monthly elevations before and after the rule curve change in 1982.

Largemouth bass in Grand Lake typically spawn from 15 April to 15 May (J. Smith, pers. commun.). The nursery period (encompassing early development and growth of largemouth bass young) follows the spawning period and ends at the beginning of Smith's (1983) recommended fall drawdown (7 Jul). Therefore, flooding of previously established shoreline vegetation during spawning and nursery seasons presumably maximizes available habitat and provides protective cover for spawning and young-of-year individuals. We quantified the total number of days of flooding of shoreline areas during the spawning (15 Apr–15 May) and nursery seasons (15 May–7 Jul) for each year from 1977 to 1988 by summing the number

Table 1. Number of stations sampled, sampling period, total effort, total catch, and CPUE rates (N/100 m^2) of young-of-year largemouth bass during old (1976–1981) and new (1982–1988) rule-curve periods, Grand Lake, Oklahoma.

Year class	Stations	Sample period	Effort (m^2)	Catch (N)	(CPUE ($\bar{x} \pm$ SD)
		Old rule curve			
1977	32	Jul 12–Aug 4	6,880	77	1.070 ± 1.481
1978	25	Jun 26–Jul 25	11,349	59	0.504 ± 0.623
1979	14	Jul 11–Jul 24	6,552	99	1.511 ± 1.426
1980	15	Jul 1–Jul 29	7,020	164	2.336 ± 2.128
1981	15	Jun 15–Jul 13	7,020	72	1.026 ± 1.223
		New rule curve			
1982	15	Jun 29–Jul 21	6,552	215	3.120 ± 4.184
1983	16	Jul 5–Jul 27	7,254	122	1.656 ± 1.735
1984	21	Jun 27–Jul 23	9,828	144	1.465 ± 1.929
1985	20	Jul 1–Jul 22	9,126	65	0.705 ± 1.439
1986	21	Jun 23–Jul 23	9,828	57	0.580 ± 0.991
1987	22	Jun 29–Jul 28	9,594	38	0.418 ± 0.473
1988	21	Jun 27–Jul 27	9,594	54	0.549 ± 0.142

of days when lake levels equaled or exceeded 226.5 m MSL (1.8 m above the average drawdown level during the old rule curve) during the appropriate intervals.

Revegetation of shoreline areas presumably occurs only during the growing season each year. For the Grand Lake area, the average growing season was estimated to extend from 7 April (last 50% probability frost date) to 29 October (first 50% probability frost date). We quantified the total number of days of exposure of shoreline areas during the revegetation period (8 Jul–29 Oct) for each year from 1976 to 1987 by summing the number of days the reservoir was drawn down and lake levels were equal to or less than 225.5 m MSL (the target end-of-month operating elevation under the new rule curve). These values were used in analyses of year class strength of largemouth bass in the following calendar year.

Differences in mean water levels during the flooding and revegetation (previous year) seasons were calculated and related to year-class strength. The inherent assumption was that the relative difference in water levels between the revegetation and flooding seasons reflected the availability of inundated vegetative cover established during exposure of shoreline areas.

Monthly and seasonal water levels, flooding and revegetation days, and CPUE rates ($\log_e + 1$ transformed) of young-of-year largemouth bass before and after the rule-curve change were compared with Student's t-tests. Linear regression analysis was used to examine relationships between CPUE rates ($\log_e + 1$ transformed) of young-of-year largemouth bass and the number of days of spawning and nursery flooding (in the same year) and drawdown during the revegetation season (in the previous calendar year) and the difference between water level during revegetation and nursery seasons during the 12-year period. Significance was set at the 0.05 level.

Results

During 1977 to 1988, CPUE rates of young-of-year largemouth bass in Grand Lake fluctuated appreciably (Table 1). Mean catch rates were high in 1980 and 1982 (>2.0 fish/100 m^2), intermediate in 1977, 1979, 1981, 1983, and 1984 (1.0–2.0 fish/100 m^2), and low in 1978 and 1985–1988 (<1.0 fish/100 m^2). Following implementation of the new rule curve in 1982, catch rates exhibited a declining trend; however, catch rates did not differ between the old (1977–1981) and new (1982–1988) rule-curve periods.

Water levels in Grand Lake exhibited large annual fluctuations during the old rule-curve period (Fig. 1); levels ranged from 223.3 m to 229.4 m MSL and averaged 225.5 m MSL. Patterns of annual water level fluctuation changed markedly after institution of the new rule-curve in 1982 (Fig. 1); fluctuations were dampened and the mean water level was considerably higher than in the earlier period ($t = -35.370$, df = 3967.5, $P = 0.0001$).

Mean monthly water levels were higher during the new rule-curve period than during the old rule-curve period in all months except June and July (Fig. 1). Mean water levels during the 2 periods were not different for June, and mean levels in

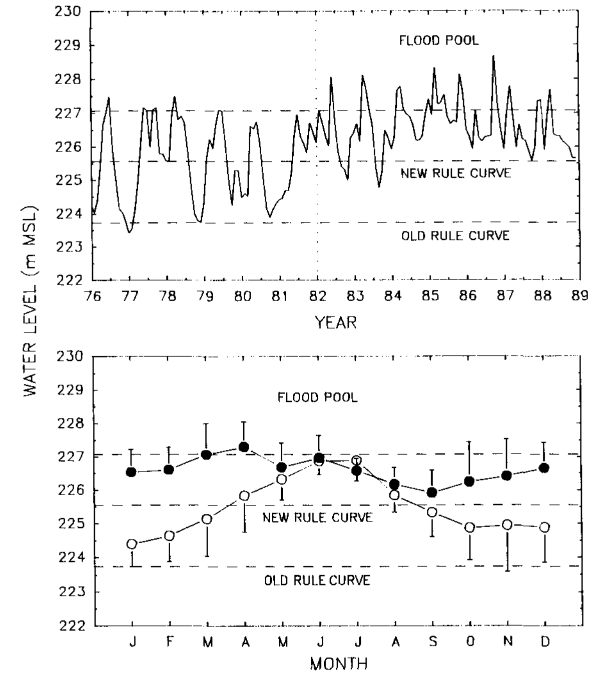

Figure 1. Mean monthly water levels (m MSL) from 1976 to 1988 (top) and during old (open circles, 1976–1981) and new (closed circles, 1982–1988) rule curve periods (bottom), Grand Lake, Oklahoma. Vertical dotted line (top) indicates 1982 rule curve change, and vertical error bars (bottom) indicate 1 SE.

July were higher (t = 5.8113, df = 294.7, P = 0.0001) under the old rule curve that under the new rule-curve period. Water levels during the 2 periods were similar from May through August, but diverged from September through April (Fig. 1).

Revegetation drawdown days were more numerous during the old rule-curve period than during the new rule-curve period (t = −2.2794, df = 10, P = 0.0458; Table 2). No differences existed between the old and new rule-curve periods in spawning flooding days, nursery flooding days, combined spawning and nursery days, combined spawning and revegetation days, combined nursery and revegetation days, or combined flooding and revegetation days in all 3 seasons.

Largemouth bass young-of-year CPUE rates were positively related to nursery flooding days (Y = 0.322 + 0.006X; F = 11.09; df = 1,235; R^2 = 0.045, P = 0.001), revegetation drawdown days (Y = 0.422 + 0.004X; F = 11.46; df = 1, 235; R^2 = 0.046, P = 0.0008), combined nursery and revegetation days (Y = 0.308 + 0.003X; F = 11.09; df = 1, 235; R^2 = 0.065; P = 0.0001; Fig. 2), combined spawning and revegetation days (Y = 0.392 + 0.003X; F = 7.52; df =

Table 2. Annual spawning (SPA), nursery (NUR), and revegetation (REV; previous year) days, and mean water levels (m MSL) during nursery and revegetation seasons, and their difference (DIFF) associated with year classes during old (1976–1981) and new (1982–1988) rule-curve periods, Grand Lake, Oklahoma.

Year class	*N* days			Mean water level		
	SPA[a]	NUR[b]	REV[c]	NUR[b]	REV[c]	DIFF
			Old rule curve			
1977	0	44	65	226.95	225.48	1.47
1978	30	54	23	226.89	226.16	0.73
1979	1	54	66	227.04	225.24	1.80
1980	16	54	59	226.68	225.50	1.18
1981	0	20	91	226.16	224.69	1.47
			New rule curve			
1982	0	48	7	227.50	226.23	1.27
1983	30	54	64	227.23	225.75	1.48
1984	30	54	72	226.76	225.41	1.35
1985	30	54	0	227.42	226.44	0.98
1986	18	8	0	226.18	226.71	−0.53
1987	13	25	0	226.41	226.95	−0.54
1988	19	0	11	226.32	225.95	0.37

[a]Water levels ≥226.5 m MSL, 15 April–15 May.
[b]Water levels ≥226.5 m MSL, 15 May–8 July.
[c]Water levels ≤225.6 m MSL, 8 July–29 October.

1, 235; R^2 = 0.031, P = 0.0066), and combined spawning, nursery, and revegetation days (Y = 0.299 + 0.003X; F = 12.0; df = 1, 235; R^2 = 0.049; P = 0.0006). CPUE rates were not related to spawning flooding days and combined spawning and nursery flooding days.

Differences in mean water levels between nursery and revegetation (previous year) seasons were not different between the old and new rule-curve periods (Table 2). CPUE rates were positively related to differences in mean water levels during the two seasons (X = 0.380 + 0.209X; F = 19.64; df = 1, 235, R^2 = 0.077, P = 0.0001; Fig. 2).

Discussion

Our analysis revealed that seasonal water level fluctuations influenced largemouth bass recruitment in Grand Lake. However, the analysis was hindered by a lack of complementary data necessary to perform a more thorough analysis. For example, we lacked specific areal data (hectare-days of shoreline exposure and subsequent flooding, annual vegetative production) and therefore substituted approximations (mean water levels and days of flooding and exposure above and below arbitrary limits) for this component. We also lacked data for advanced year-classes which prevented us from tracking recruitment success. Nevertheless, our analysis suggests that abundance of young-of-year largemouth bass in Grand Lake was

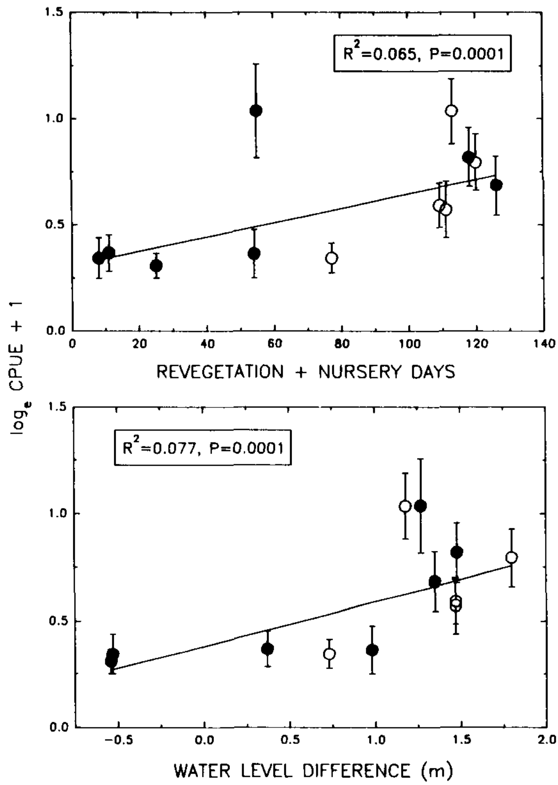

Figure 2. Mean (± 1 SE) CPUE rates (N/100 m^2) of young-of-year largemouth bass in relation to total number of days of revegetation drawdown (previous year) and nursery flooding (top), and difference in mean water levels between revegetation and nursery seasons (bottom), during old (open circles, 1976–1981) and new (closed circles, 1982–1988) rule-curve periods, Grand Lake, Oklahoma.

affected by water level fluctuations, as has been documented in other reservoir systems (e.g., Bross 1969, Aggus and Elliott 1975, Shirley and Andrews 1977, Orth 1978, Miranda et al. 1984). Low water levels during the revegetation season (8 Jul–29 Oct) followed by high water levels during the subsequent nursery season (15 May–8 Jul) seemed to promote production of habitable cover.

The elevated abundance of young-of-year largemouth bass in 1982 probably resulted from inordinately high water levels that flooded woody terrestrial vegetation during the nursery season and created extensive nursery habitat. Summerfelt and Shirley (1978) postulated that an increase in water levels in Lake Carl Blackwell, Oklahoma, and concomitant inundation of flooded terrestrial vegetation improved production of bass by increasing production of food resources for young-of-year, providing additional spawning habitat and cover for nests, reducing the effects of wave action on nests, and enhancing survival of early life stages through reduced predation.

Implementation of the new rule curve in 1982 seemed to affect recruitment of largemouth bass in Grand Lake only indirectly. After its implementation, catch rates were not significantly different than before despite an apparent decline in CPUE rates of young-of-year largemouth bass. However, the new rule curve reduced drawdown of the reservoir during late summer and therefore decreased the area of shoreline exposed during the latter part of the growing season. Following the rule curve change, littoral expanses on the upper half of Grand Lake, which comprise about 2,000 ha of wetland habitat between elevations 224.0 to 226.2 m MSL, were rarely exposed during the growing season (Erickson and Leslie 1988). Therefore, establishment of vegetation in this zone was unlikely, and wave action probably hindered establishment of emergent and submerged plants (Davis and Brinson 1980). For 5 of the 7 years after the rule curve change, the number of days of littoral exposure during the revegetation season when water levels were equal or below 225.6 m MSL was ≤11. Under the old rule curve, shoreline exposure during this season exceeded 58 days in 4 of 5 years. Nevertheless, the rule curve is merely a target and can be overshadowed by climatic events (drought or excessive inflows). For example, water levels during the revegetation and nursery seasons associated with the 1983 and 1984 year classes were favorable for littoral exposure and subsequent flooding and were followed by strong year classes. In fact, only during the revegetation seasons during 1 of these 2 years did mean water levels achieve the rule-curve target (225.6 m MSL).

A difference in mean pool elevation of about 1.2 to 1.5 meters between the revegetation and nursery seasons elicited favorable conditions for recruitment of largemouth bass in Grand Lake. Orth (1978) documented a similar relationship for young-of-year largemouth bass and water levels in Lake Carl Blackwell, Oklahoma. The water level management plan by the Kansas Fish and Game Commission (Groen and Schroeder 1978, Willis 1986) prescribes fluctuations of this magnitude and may therefore be appropriate for Grand Lake. The plan consists of: 1) a spring rise to flood terrestrial vegetation, 2) a drawdown in summer of about 1.2 m to allow revegetation, 3) a rise of about 0.6 m in autumn to flood some terrestrial vegetation and attract waterfowl, and 4) a drawdown in winter to protect vegetation from water damage (Willis 1986). This plan provides adequate habitat for fish, provides opportunities for waterfowl exploitation, limits water level fluctuations to a safe range for the recreational public, and can be accommodated by the hydropower operator.

Water level fluctuations are only 1 of several abiotic and biotic factors that influence recruitment of largemouth bass in reservoirs of the southern United States. Density independent factors such as climate (air and water temperatures and wind action) affected largemouth bass year-class strength in a harsh prairie reservoir environment (Summerfelt 1975, Summerfelt and Shirley 1978). In contrast, density dependent factors (limited carrying capacity, reduced forage availability, and predator success), resulting from water level manipulations, presumably contributed to a decline in growth and first-year survival of young-of-year largemouth bass in a mild subtropical reservoir environment (Miranda et al. 1984). Furthermore, young-of-year densities of largemouth bass vary geographically across the southern United States. For example, Miranda et al. (1984) reported young-of-year largemouth densities that were about an order of magnitude greater than those reported by

Summerfelt and Shirley (1978); both studies estimated densities from cove rotenone samples. The estimated densities in our study, which were obtained with a different collecting method, approximated those of Summerfelt and Shirley (1978). Davies et al. (1982) conceptualized a prey-dependent recruitment model for largemouth bass based on bass-bluegill relationships in impoundments that ranged from farm ponds to mainstem reservoirs in the southeastern United States. We conjecture that regional differences in climatic factors in the southern United States, coupled with reservoir operations, influence the role of density dependent and density independent factors on largemouth bass year-class strength.

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