ENVIRONMENTAL CORRELATES TO YEAR-CLASS STRENGTH OF LARGEMOUTH BASS IN LAKE CARL BLACKWELL

Robert C. Summerfelt* and Kenneth E. Shirley

Oklahoma Cooperative Fishery Research Unit†, Oklahoma State University, Stillwater, Oklahoma

Estimates of ecological density (number per unit of area of suitable habitat) of young-of-the-year (YOY) largemouth bass were made for 11 consecutive year-classes (1965-75) in Lake Carl Blackwell, a reservoir in which large annual variations in recruitment have been observed. The estimates ranged from 0.13 to 447 YOY bass per hectare (average 121). Significant positive correlations were obtained for the relation between year-class strength and water level, change in water level, and turbidity; significant negative correlations were obtained between year-class strength and water hardness, alkalinity, and pH. The correlations between year-class strength and wind velocity, air and water temperature and number of brood bass were not statistically significant. Strong year-classes developed in years of high water level when conditions simulated those occurring in a newly impounded lake. Water level also affected the physical and chemical composition of the water.

INTRODUCTION

The success of a fishery for largemouth bass (*Micropterus salmoides*) depends on optimization of the many factors affecting recruitment, growth, and harvest. In many waters, the most important limiting factor is inadequate or highly variable recruitment (1, 2). A variety of factors are believed to affect largemouth bass recruitment (or year-class strength): temperature, wind and wave action, cover, predation, water level fluctuations, turbidity and siltation, food supply, disease, pH, dissolved oxygen, salinity, number of brood fish, and various pollutants.

Temperature is often regarded as the most important factor influencing year-class strength of black bass. In general, falling water temperatures during the egg and larval stages have been associated with small year-classes. Kramer (3) found high positive correlations between water temperature during the egg and larvae stages and year-class strength, though these correlations were not statistically significant, perhaps because the span of years covered was insufficient (he had data for only four year-classes). Kramer found 100% egg mortality when the water temperature fell below 10˚C after the bass had spawned (they spawned at about 15.6˚C) and high fry mortality after any sharp drop in water temperature. He speculated that an accelerated rate of development under high temperatures would benefit the population by reducing the time during which eggs and larvae were subject to predation. Other researchers, however, have concluded that temperature fluctuations of the magnitude expected in nature would not cause high mortality in eggs and fry, but that sharp drops in water temperature would cause the male to abandon the nest making it more susceptible to predation, fungus, and siltation.

Eipper (1) concluded that year-class fluctuations often believed to be related to temperature may be a result of wind and wave action, since strong spring and summer winds often occur during periods of low temperatures. Kramer (3) found that wave action was the single most important factor influencing year-class strength in Lake George, Minnesota, and documented nest destruction by wave action. Summerfelt (2) observed that largemouth bass spawning in Lake Carl Blackwell was interrupted as a result of cold fronts which produced high winds and low temperatures.

Large fluctuations in water level may be an important factor influencing bass recruitment. Bross (4) found that year-class strength of largemouth bass in Canton Lake, Oklahoma, was positively correlated with

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*Present address: Department of Animal Ecology, Iowa State University, Ames, Iowa 50011.
†Cooperators are the Oklahoma Department of Wildlife Conservation,
the Oklahoma State University Environmental Institute, and the U.S. Fish and Wildlife Service.

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spring and summer water levels. Jester (5) and Von Geldern (6) demonstrated that year-classes of bass were small in years when the water level fell during and after spawning. Aggus and Elliot (7) reported a significant positive correlation between the amount of flooded terrestrial vegetation and the duration of the flooding during the spring and summer and the numbers of YOY bass in fall samples collected after the application of rotenone in coves of Bull Shoals Lake. This correlation suggests that food and cover are important factors influencing bass year-class strength. Fish hatchery personnel have observed a high mortality of bass fry in ponds with insufficient plankton blooms but this relation has not been demonstrated in nature.

Within normal fresh water limits, salinity, pH, and alkalinity are not believed to influence largemouth bass year-class strength. Bass can tolerate pH's between 4.2 and 10.3 (8), total alkalinites up to 900 ppm (9), and salinities up to 3.6% (10). The number of brood fish is also now believed to have little effect on year-class strength, since other factors influence the survival of the eggs and larvae to such a great extent that the number of eggs laid is not a factor (1).

At Lake Carl Blackwell, Oklahoma, we obtained late summer estimates of year-class strength of largemouth bass for 11 consecutive years (1965 through 1975), along with measurements of several physical and chemical factors. We believe that these empirical observations are a unique collection of paired data, the analysis of which can provide insight into the relation between bass year-class strength and the environmental conditions which affect bass populations before and during the spawning season, and for the first summer of life.

STUDY AREA

Lake Carl Blackwell (Fig. 1) is a turbid reservoir, 12.8 km west of Stillwater in Payne County, Oklahoma, formed by the impoundment of Stillwater Creek. At spillway elevation, 287.8 m above mean sea level (m.s.l.), the lake has a surface area

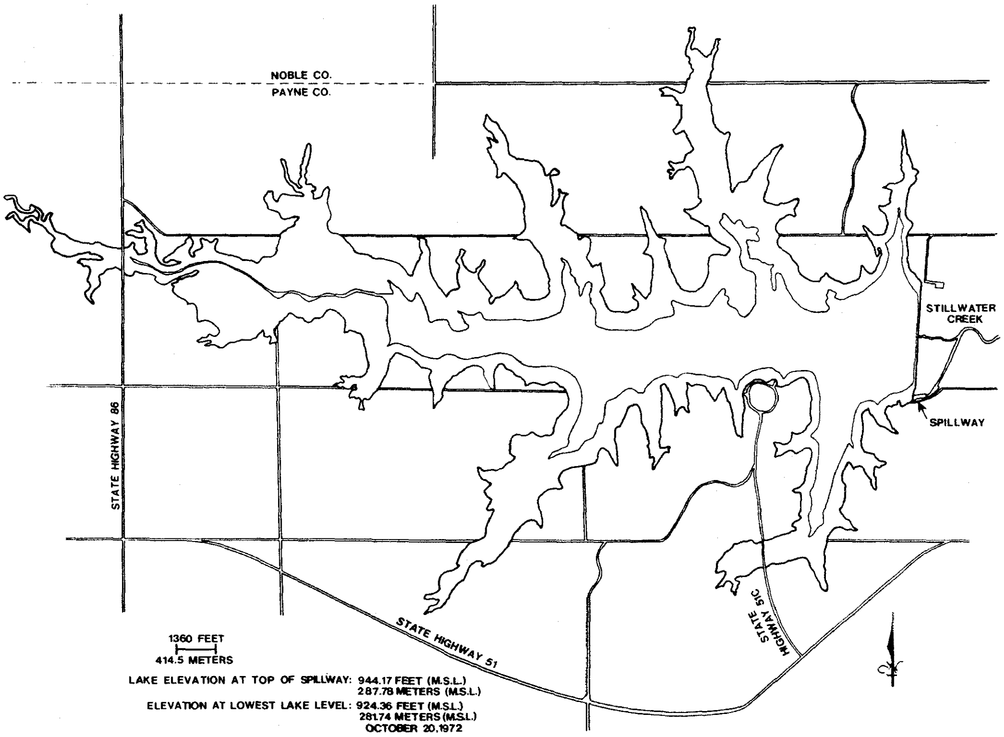


FIGURE 1. Map of Lake Carl Blackwell showing the shoreline at spillway level and at the lowest level since impoundment (281.25 m, m.s.l. on 20 October 1972).

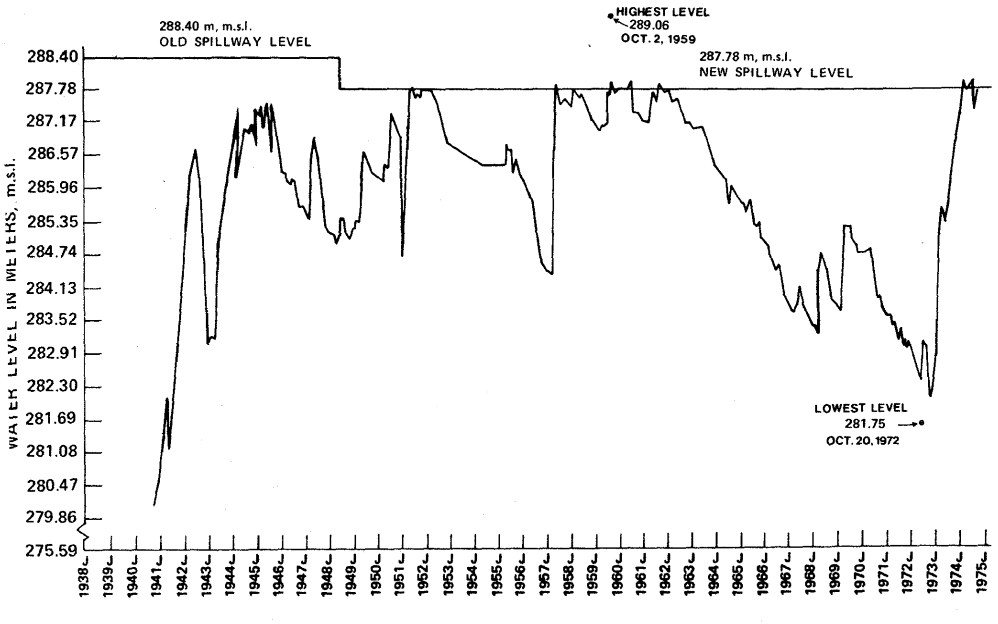
of 1401 ha, a shoreline length of 90.4 km, and a shoreline development index (SDI) of 6.8. Because the reservoir has a relatively small watershed in a region characterized by cyclic rainfall, it is subject to large fluctuations in water level (Fig. 2). Between January 1961 and October 1972 low rainfall resulted in a general downward trend in water level (except for spring rises in 1968 and 1969) and on 20 October 1972, the lake reached its record low level (281.3 m, m.s.l.). The surface area was then only 491.7 ha, the shoreline 22.7 km long, and the SDI only 3.5. During the winter of 1972-73, heavy rains raised the water level 4 m and in March 1974, the lake reached spillway elevation for the first time since 1961. It remained at or within 1 m of spillway level for the rest of this study (through 1975).

During the years when water level declined progressively, the shallow littoral zone was without aquatic macrophytes or flooded terrestrial vegetation. Shoreline cover consisted of a few old building foundations, rocks on some points, and rock rip-rap on the dam. Seral stages of terrestrial vegetation that followed the receding shoreline were inundated when the water level rose in the springs of 1968, 1969, 1973 and 1974. The water remained high after the 1973 rise, and vegetation flooded at that time remained flooded through the 1975 season. During the period from spring 1973 through summer 1975 while water levels were relatively stable, aquatic macrophytes developed to a moderate degree in embayments protected from the prevailing southwesterly winds.

METHODS AND MATERIALS

Density Estimation

Estimates of numerical density of YOY largemouth bass in Lake Carl Blackwell were made from: (a) collections of fish made after the application of rotenone in coves, (b) mark-recapture population studies, and (c) electrofishing catch rates. From 1966 through 1975, personnel of the Oklahoma Cooperative Fishery Research Unit collected 14 population samples from cove areas, 0.4 to 1.5 ha, by use of the rotenone-poisoning technique (Table 1). Rotenone (3 ppm) was applied to a cove of known area and volume which had been isolated from the reservoir with a blocking net (6 m deep, 6.4 mm square mesh). Fish were collected in the blocked portion of the cove for 3 days, identified, and weighed (either individually or en masse). Largemouth bass were measured individually and scales were taken for age determination. The density of YOY bass was determined



GURE 2. Water level fluctuations at Lake Carl Blackwell from impoundment to August 1975.

by dividing the total number collected by the area of water enclosed by the net. We used counts of dead fish collected over 3 days and did not expand these using percentage recovery by area of the cove. When more than one cove was treated in the same season, a mean was obtained by weighting the estimates by area of the coves.

These samples resulted in direct estimates of seven year-classes: 1966, 1967, 1968, 1971, 1973, 1974, and 1975. Cove samples were not taken in 1965, 1969, 1970, and 1972. The strength of the 1965 and 1970 year-classes was back-calculated by applying mortality estimates to numbers of yearling bass in the 1966 and 1971 cove collections (Table 2). Back-calculations were done on an exponential model for mortality (11) where back-calculated density is (N_o) is:

Table 1. *Estimates of abundance of YOY largemouth bass in Lake Carl Blackwell, 1966-75.*

Date	Area of cove (ha)	No. per cove	Density (no/ha)	Adjusted[a] density (no/ha)
8-13-75	0.31	83	266.4	266.4
8-13-74	0.38	78	205.0	205.0
8-13-74	0.31	61	195.8	195.8
8-13-73	0.19	72	378.5	378.5
8-13-73	0.66	270	406.8	406.8
8-13-73	0.19	126	662.4	662.4
9-13-71	0.79	2	2.5	2.6
8-25-71	0.44	2	4.6	4.7
8-11-71	0.72	3	4.1	4.1
7-30-71	0.40	6	15.1	14.8
8-05-68	0.61	60	98.8	97.6
6-24-68	0.61	51	84.0	77.9
10-23-67	0.53	45	85.6	95.2
12-06-66	0.53	11	20.9	24.8

[a] Density on dates shown has been adjusted to number present on 13 August by assuming a constant daily instantaneous mortality rate of 0.00150 from date of observation.

$N_t = N_o e$ N_t = the back-calculated density of YOY bass the previous year
N_o = the density of yearling bass in the cove sample (s)
e = base of natural log
i = the daily instantaneous mortality rate
t = the number of days between the back-calculated estimate and the three cove samples

The mortality rate (i), 0.00150, was derived from the estimated daily instantaneous rate for the 1973 year-class for the corresponding period of life.

The strength of the 1969 and 1972 year-classes could not be similarly estimated from the cove sample data because no cove samples were taken in 1970, and no yearlings were collected in the cove samples of 1973. The 1972 year-class was estimated during the fall of 1972 by the mark-recapture using the Schnabel formula as given by Ricker (11) and the technique developed by Lewis et al. (13), in which bass were collected by shoreline electrofishing, marked (by punching a hole in the caudal fin), and released for later recapture. A unit of effort was a single complete trip around the lake. From 5 September to 6 November 1972, eight units of effort totaling about 130 hours and 226 km shoreline were completed.

The strength of the 1969 year-class was estimated by comparing the electrofishing catch rate of that year-class with that of the 1968 year-class, which had been estimated by cove sampling. Zweiacker (12) collected bass during both 1968 and 1969 by shoreline electrofishing for population estimation, but did not estimate the YOY population. He did, however, record the numbers of YOY and adult bass, and the catch rate of YOY bass was determined from the ratio of YOY to adults in his 1968 and 1969 collections. The density of the 1969 year-class was calculated by multiplying the estimated density of the 1968 year-class by the ratio of the electrofishing catch rates.

Table 2. *Density estimates of YOY largemouth bass in Lake Carl Blackwell, based on collections made in coves after the application of rotenone, back-calculated to 13 August of the previous year.*

Date	Year class	Area of cove (ha)	Ecological density (no/ha)	Back-calculated density (no/ha)
12/06/66	1965	0.53	26.60	54.6
9/13/71	1970	0.79	3.80	6.9
8/25/71	1970	0.44	2.27	4.0
8/11/71	1970	0.72	4.17	7.2
7/30/71	1970	0.40	7.50	12.7

Since estimates of density were made on different days each year, it was necessary to adjust them to a constant date for com-

TABLE 3. *Schnabel estimates of the young-of-the-year largemouth bass populations in Lake Carl Blackwell, fall 1972 through spring 1974.*

Year class	Date	Units of effort	$\Sigma C_t M_t$	ΣR_t	$\hat{N}$	$C.I._{.05}$
1972	10-06-72	8	29	1	29	5-290
1973	9-30-73	7	3,105,436	26	119,436	81,720-182,667
1973	5-12-74	4	1,449,884	17	85,287	55,765-146,453

parative analysis. This was done by assuming that the population number declined in the form of a negative exponential. The estimated daily instantaneous mortality rate (0.00150) used in the formula was calculated from two large-sample Schnabel estimates of the 1973 year-class made on 30 September 1973 and 12 May 1974 (Table 3). The constant date chosen was 13 August because several cove samples were taken on that date and it is now considered the standard date for cove sampling at Lake Carl Blackwell.

Cove samples most closely approximate the ecological density (number per unit of area of suitable habitat) of Odum (14), since YOY bass are largely inhabitants of the littoral zone. Therefore, to compare mark-recapture estimates with cove rotenone estimates, one must divide the mark-recapture estimate by the area of acceptable habitat rather than the area of the entire lake. This was done by computing the area of water less than 2 m deep: lake area at the date of the estimate minus lake area at 2 m below that level. The daily water levels were obtained courtesy of Hydraulics Research Laboratory, U.S. Department of Agriculture.

Once estimates of largemouth bass population density were obtained for all 11-year-classes, these values were correlated with a series of biotic and abiotic environmental factors: water level (m, msl), change in water level, pH, methyl orange alkalinity (ppm), hardness (ppm), turbidity (Jackson turbidity units), wind velocity, and number of spawners. Daily measurements of water temperature, pH, alkalinity, hardness, and turbidity were made by the Oklahoma State University Water Treatment Plant from 1 January 1965 through 30 September 1974 and January through December 1975. Average wind velocities and air temperatures were obtained daily from Oklahoma State University Agronomy Research Station.

Correlations were made between estimated density of YOY largemouth bass and the monthly maximum, minimum, and mean, and seasonal mean (winter = January-March, spring = April-June, and summer = July-August) for each factor except number of spawners and water levels. Correlations were also made between YOY largemouth bass density and the water level on the 1st and 15th of each month (January-August), monthly change in water level, (water level on the first of the month minus water level on the first of the following month), change in water level since the end of the previous growing season (the water level on the 1st and 15th of each month minus the water level on 1 October the previous fall), and the estimated number of spawners in those years when reliable mark-recapture estimates of adult bass were made.

RESULTS

The estimated ecological density of YOY largemouth bass on 13 August of each year ranged from 0.13 fish/ha in 1972 to 447.4 in 1973 and averaged 121.1 (Table 4). There were significant ($P < 0.05$) positive correlations between annual variation in density of YOY largemouth bass and water level, water level fluctuation, and turbidity; but significant negative correlations with

TABLE 4. *Estimated ecological density of 11 year-clsses of YOY largemouth bass in Lake Carl Blackwell, Oklahoma.*

Year-class	Estimated density (no./ha)
1965	54.6
1966	24.8
1967	95.2
1968	87.2
1969	141.9
1970	7.4
1971	5.5
1972	0.13
1973	447.4
1974	200.5
1975	266.4
Mean	121.1

hardness, alkalinity, and pH. Correlations between density of YOY bass and water and air temperature, wind, and number of spawners were not significant.

Water Level

Correlation coefficients between abundance of YOY bass and water levels on the lst and 15th of each month, January through 15 August, ranged from +0.0532 (*p* = 0.8839) for 1 January to 0.6687 (*p* = 0.0489) for 15 August (Table 5). All r values for the 1 May through 15 August interval were significant at the 0.10 level; the r values for 1 June, 1 July, and 15 August were significant at the 0.05 level.

Correlation coefficients between the abundance of YOY bass and change in lake level from the 1st or 15th, of each month to 15 May, the mid-point of the bass spawning season, yielded significant positive correlations at the 0.01 level, for all dates after 15 March (Table 5). The highest correlations were obtained for 1 April (r = 0.8913) and 15 May (r = 0.8888, *p* = 0.0003).

We computed correlations between monthly water level fluctuations and year-class strength to determine when the most crucial times for water level fluctuations occurred. Significant correlations were found for January (r = 0.9237), March (r = 0.8909, April (r = 0.6382), and August (r = 0.8538, Table 5). The lack of pattern in these correlations indicates that they were influenced by the large monthly changes in water level in 1973 and 1974. The four smallest year-classes occurred when the water level decreased during May and June; in all other years the level increased significantly in one or both months.

Turbidity

Turbidity in Lake Carl Blackwell averaged 40 JTUs for the 11-year period. The monthly averages varied from 6 in January in 1967 to 240 in March 1973. High positive correlations were found between year-class strength and both maximum and mean monthly turbidity from January through April. An exceptionally high correlation was obtained for maximum turbidity in February and year-class strength adjusted to 13 August (r = 0.9150, *p* = 0.0001; Table 6). For the months May through August the r values were generally low.

TABLE 5. *Correlation coeffecients (r) and probabilities (P) between year-class strength and water level, change in water level from the end of the previous growing season, monthly change in water level, and mean monthly air temperature.*

	Water level		Overall change in water level		Monthly change in water level		Mean air temperature	
Period	r	*p*	r	*p*	r	*p*	r	*p*
Jan. 1	+0.05	0.8839	+0.70	0.0257	+0.92	0.0001	−0.05	0.8744
Jan. 15	+0.06	0.8856	+0.76	0.0177				
Feb. 1	+0.15	0.6741	+0.88	0.0009	+0.15	0.7164	−0.21	0.5316
Feb. 15	+0.13	0.7351	+0.86	0.0031				
Mar. 1	+0.07	0.8681	+0.78	0.0208	+0.89	0.0030	+0.12	0.7363
Mar. 15	+0.33	0.3894	+0.84	0.0049				
Apr. 1	+0.41	0.2673	+0.89	0.0013	+0.64	0.0643	−0.43	0.2192
Apr. 15	+0.55	0.1010	+0.89	0.0006				
May 1	+0.55	0.0781	+0.85	0.0009	+0.29	0.3934	−0.16	0.6608
May 15	+0.60	0.0521	+0.89	0.0003				
June 1	+0.60	0.0492	+0.87	0.0006	−0.20	0.5576	−0.60	0.0495
June 15	+0.59	0.0538	+0.85	0.0008				
July 1	+0.60	0.0498	+0.85	0.0008	+0.06	0.8716	−0.08	0.8036
July 15	+0.60	0.0505	+0.85	0.0008				
Aug. 1	+0.56	0.0900	+0.86	0.0014	+0.85	0.0034	−0.05	0.8763
Aug. 15	+0.67	0.0489	+0.86	0.0027				
Winter							−0.01	0.9862
Spring							−0.59	0.0697
Summer							−0.10	0.7586

Correlation coefficients between year-class strength and seasonal turbidities were 0.8264 (p = 0.0017) for winter, 0.6116 (p = 0.0456) for spring, and 0.1347 (p = 0.6929) for summer.

Hardness, pH, and Alkalinity

Hardness, pH, and alkalinity all showed high negative correlations with year-class strength. Total hardness ranged from 100 to 201 ppm and mean monthly hardness showed significant (0.05) correlations for March and April (Table 7). Correlations between year-class strength and mean seassonal hardness were -0.5296 (p = 0.0939) for winter, -0.5921 (p = 0.0549) for spring, and –0.5044 (p = 0.1136) for summer.

Alkalinity measurements ranged from 56 to 162 ppm. Mean monthly alkalinity was significantly correlated with year-class strength for March through August, exceeding the 0.01 level in June, July, and August. Correlations between year-class strength and mean seasonal alkalinity were -0.4613 (p = 0.1532) for winter, -0.7305 (p = 0.0107) for spring, and -0.8093 (p = 0.0025) for summer (Table 7).

The pH ranged from 7.1 to 8.4, and like hardness and alkalinity, it was often negatively correlated with year-class strength. All correlations between mean monthly pH (except February) and year-class strength were significant at the 0.05 level. Correlation coefficients between year-class strength and seasonal pH were -0.6442 (p = 0.0324) for winter, -0.7239 (p = 0.0118) for spring, and -0.7340 (p = 0.0101) for summer (Table 7).

TABLE 6. *Correlation coefficients (r) and probabilities (p) between year-class strength and turbidity, water temperature and wind.*

	Turbidity		Water Temperature		Wind	
Month	r	*p*	r	*p*	r	*p*
January						
Max.	+0.86	0.0007	−0.24	0.5131	--	--
Mean	+0.79	0.0039	−0.24	0.4875	--	--
Min.	+0.52	0.0986	+0.10	0.7848	--	--
February						
Max	+0.92	0.0001	−0.35	0.3122	--	--
Mean	+0.84	0.0011	+0.12	0.7312	--	--
Min.	+0.76	0.0072	+0.40	0.2522	--	--
March						
Max.	+0.73	0.0104	−0.31	0.3830	--	--
Mean	+0.75	0.0073	−0.25	0.4871	--	--
Min.	+0.70	0.0163	−0.45	0.1887	--	--
April						
Max.	+0.69	0.0183	−0.16	0.6549	−0.04	0.9597
Mean	+0.73	0.0112	−0.32	0.3634	−0.04	0.9625
Min.	+0.76	0.0061	−0.20	0.5871	+0.17	0.8333
May						
Max.	+0.37	0.2679	−0.13	0.7011	−0.51	0.1330
Mean	+0.48	0.1333	−0.14	0.6747	−0.15	0.6754
Min.	+0.40	0.2260	+0.05	0.8673	+0.67	0.0307
June						
Max.	+0.02	0.9418	−0.02	0.9491	−0.41	0.2052
Mean	+0.15	0.6559	−0.70	0.0156	−0.12	0.7290
Min.	+0.33	0.3196	−0.24	0.4715	+0.44	0.1724
July						
Max.	+0.17	0.6209	−0.51	0.1105	−0.24	0.4705
Mean	−0.13	0.7102	−0.22	0.5101	−0.31	0.3494
Min.	−0.18	0.5817	−0.32	0.3419	+0.20	0.5472
August						
Max.	+0.61	0.0473	−0.21	0.5272	−0.40	0.7493
Mean	+0.28	0.3960	−0.09	0.7908	+0.09	0.7943
Min.	−0.28	0.4038	+0.33	0.3160	+0.06	0.8619
Winter Mean	+0.83	0.0017	−0.33	0.3511	--	--
Spring Mean	+0.61	0.0456	−0.69	0.0282	−0.16	0.6664
Summer Mean	+0.13	0.6929	−0.24	0.4791	−0.15	0.6612

Wind, Air and Water Temperature and Number of Brood Fish

Correlation coefficients between year-class strength and wind, air and water temperature, and number of brood fish were generally low and statistically insignificant. The only significant correlation between year-class strength and monthly mean water temperature was for mean June water temperature (r = 0.7039, *p* = 0.0156; Table 6). The correlations between year-class strength and seasonal mean water temperature were -0.3304 (*p* = 0.3411) for winter, -0.6780 (*p* = 0.0282) for spring, and -0.2390 (*p* = 0.4791) for summer (Table 6). The occurrence of only 2 significant correlations (0.05 level) out of 27 may be considered to reflect the likely probability of occurrence of a few significant correlations in a large sample of correlation coefficients between uncorrelated events.

Only one correlation between mean air temperature and year-class strength was significant. The r value between year-class strength and mean June air temperature was –0.6031 (*p* = 0.0495; Table 5). Correlations between year-class strength and mean seasonal air temperature were -0.0059 (*p* = 0.9862) for winter, -0.5958 (*p* = 0.0697) for spring, and –0.1050 (*p* = 0.7586) for summer (Table 5). The only significant correlation between year-class strength and wind was for minimum May wind (r = 0.6795, *p* = 0.0307). Since no wind readings were obtained for January through March, no winter correlations were made; correlations between year-class strength and mean spring wind were –0.1563 (*p* = 0.6664) and those between

TABLE 7. *Correlation coefficients (r) and probabilities (*p*) between largemouth bass year-class strength and hardness, alkalinity, and pH.*

Month	Hardness		Alkalinity		pH	
	r	*p*	r	*p*	r	*p*
January						
Max.	—0.41	0.2054	—0.40	0.2276	—0.78	0.0128
Mean	—0.39	0.2383	—0.41	0.2114	—0.65	0.0314
Min.	—0.41	0.2143	—0.41	0.2065	—0.61	0.0452
February						
Max.	—0.56	0.0714	—0.43	0.1889	—0.54	0.0851
Mean	—0.56	0.0745	—0.43	0.1854	—0.59	0.0571
Min.	—0.54	0.0841	—0.43	0.1883	—0.30	0.3473
March						
Max.	—0.67	0.0245	—0.44	0.1757	—0.60	0.0498
Mean	—0.62	0.0441	—0.53	0.0913	—0.68	0.0217
Min.	—0.49	0.1253	—0.62	0.0423	—0.64	0.0347
April						
Max.	—0.64	0.0349	—0.74	0.0099	—0.63	0.0384
Mean	—0.66	0.0272	—0.70	0.0161	—0.75	0.0083
Min.	—0.68	0.0204	—0.62	0.0414	—0.72	0.0115
May						
Max.	—0.53	0.0914	—0.77	0.0063	—0.63	0.0384
Mean	—0.57	0.0696	—0.70	0.0160	—0.75	0.0083
Min.	—0.56	0.0700	—0.71	0.0139	—0.80	0.0032
June						
Max.	—0.42	0.1982	—0.79	0.0037	—0.74	0.0088
Mean	—0.45	0.1647	—0.78	0.0048	—0.70	0.0155
Min.	—0.47	0.1444	—0.79	0.0041	—0.60	0.0516
July						
Max.	—0.20	0.5534	—0.70	0.0156	—0.70	0.0160
Mean	—0.37	0.7355	—0.78	0.0047	—0.74	0.0093
Min.	—0.47	0.1417	—0.77	0.0057	—0.62	0.0401
August						
Max.	—0.49	0.1222	—0.72	0.0123	—0.68	0.0218
Mean	—0.63	0.0396	—0.82	0.0018	—0.71	0.0143
Min.	—0.72	0.0123	—0.84	0.0011	—0.67	0.0252
Winter Mean	—0.53	0.0939	—0.46	0.1532	—0.64	0.0324
Spring Mean	—0.59	0.0549	—0.73	0.0107	—0.72	0.0118
Summer Mean	—0.50	0.1136	—0.81	0.0025	—0.73	0.0101

year class strength and mean summer wind were -0.1493 (p = 0.6612, Table 6).

The correlation coefficient between estimates of brood bass population in fall mark-recapture estimates and year-class strength was -0.2441 (p = 0.1642; Table 8). There was a nearly perfect correlation (r = 0.99) between catch rates by electrofishing and mark-and-recapture population estimates (Table 9); thus, validating catch rate as an index of abundance.

Table 8. *Correlation between the estimated number of brood bass in fall mark-recapture estimates and the estimated year-class strength of YOY bass.*

Year	Estimated no. of brood bass (age III or more)	Estimated density of YOY bass (no./ha)	r	p
1968	1052[a]	87.80		
1972	166	0.13	−0.2551	0.8358
1973	244	447.40		

DISCUSSION

In Lake Carl Blackwell, the correlations between year-class strength and the various abiotic factors were complicated by the interrelations between those factors. No evidence was found in the literature that changes in pH, alkalinity, and hardness of the magnitudes observed in the present study would significantly affect year-class strength of largemouth bass. Certainly, a high positive correlation between turbidity and year-class strength would not be expected. There may be a relation between turbidity and lake level. Turbidity certainly increased following a large runoff which increased lake level, but turbidity also increased when lake level was exceptionally low and wind-driven currents resuspended shallow water sediments.

Turbidity and siltation are also suspected of influencing bass year-class strength. Buck (15) correlated production of YOY bass in experimental ponds with turbidity. Although the turbidity required to cause death of YOY bass (about 100,000 ppm) is much higher than would be expected in nature, high turbidity may limit primary productivity and therefore the production of plankton required for food for young bass. Also, bass apparently do not spawn on a soft silt substrate, even when it is the only substrate available (16).

The negative correlation between hardness and alkalinity with water level fluctuation may be due to concentration by evaporation when the water level is falling, and dilution when it is rising. The changes in pH seem to be more a result of the chemical charges in the water related to decaying flooded vegetation. Since the other ecological factors were not significantly correlated with year-class strength, we believe that water level fluctuation is the most important factor influencing year-class strength in Lake Carl Blackwell and possibly in other reservoirs which are subject to similar long-term fluctuations in water level.

Five of the six largest year classes occurred in years in which the water level rose significantly during the spring and summer, and the five weakest years when the water levels declined in May and June (during the spawning season and immediately after). The only exception was the

Table 9. *Correlation of catch rate with density estimates derived from mark-recapture population estimates.*

Sample	Estimated population	Lake area (ha)	Crude density (no./ha)	Catch/hr
Fall 1972	29	503.4	0.052	0.0770
Spring 1973	34	880.0	0.039	0.0085
Fall 1973	119,436	1201.5	99.406	12.4166
Spring 1974	85,287	1400.6	60.893	8.7336
				$r = 0.9964$
				$p = 0.0036$

large 1975 year-class, which occurred in spite of relatively stable water levels. During this period, however, the lake was at spillway level and could not rise significantly for an extended period. A large amount of residual flooded terrestrial vegetation also remained from the rise in 1973 and 1974. These observations suggest that the presence of the flooded terrestrial vegetation is a positive factor affecting year-class strength of largemouth bass.

We do not here imply that the other factors such as wave action do not cause early mortality of largemouth bass, but rather, that water level fluctuations reduce or increase the effects of the other factors sufficiently to overcome their negative effects. For example, production of bass is low along windswept shoreline areas of Lake Carl Blackwell and highly turbid coves with a silt substrate, even in years when the total year-class strength was high (17).

For smallmouth bass (*Micropterus dolomieui*), temperature after the larval stage appears to be as important as that during the egg and larval stages. Fry and Watt (18) observed a correlation between year-class strength of smallmouth bass and the algebraic sum of the monthly deviations from the mean air temperatures for July through October. Christie and Regier (19) also concluded that year-to-year differences in year-class strength of smallmouth bass were correlated with summer temperatures.

In the present study, the only significant ($p < 0.05$) correlations between abundance of YOY largemouth bass and monthly mean air temperature was for June ($r = -0.60$, $p = 0.049$), which is after spawning and after brood dispersal. Therefore the relation between summer temperature and year-class is not clear, except as a general factor influencing growth and mortality.

Apparently an increase in water level and the resulting inundation of flooded terrestrial vegetation improves the environment for bass production in the following ways: (a) a short-term increase in food supply results from the inundation of new shoreline, making terrestrial invertebrates available as food for YOY bass; (b) flooded terrestrial vegetation provides spawning substrate and cover for bass nests; (c) rising water levels reduce the effects of wave action on bass nests; (d) flooded vegetation provides cover for bass fry and fingerlings, reducing predation; and (e) decaying vegetation provides a nutrient source, increasing primary productivity and the production of invertebrates and other small fish and thereby increasing the food supply for YOY bass. On the other hand, falling water levels increase the effects of wave action and temperature fluctuations by reducing the depth of water over the nests; declining water levels reduce cover for fry and fingerling bass, and reduce littoral zone productivity by stranding invertebrates and plants.

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