Effects of Hydrology on Black Bass Reproductive Success in Four Southeastern Reservoirs

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Abstract: We surveyed the extent and availability of fisheries data from major (>200 ha) impoundments in 2 southeastern U. S. drainage basins, the Apalachicola-Chattahoochee-Flint and Alabama-Coosa-Tallapoosa, both located primarily in the states of Georgia and Alabama. Data were used to generate regression models relating fish reproductive success to hydrologic variables. Results were used to define relationships between reservoir operations and abundance of young fishes. Of the 25 major mainstream and storage reservoirs in the 2 systems, 4 had sufficient historical data for fisheries and hydrologic variables to allow statistical analyses. Species of concern were black bass (largemouth bass, *Micropterus salmoides* and spotted bass, *M. punctulatus*), as they were abundant in both systems and have served as indicator species in similar studies in other basins. Regression models for predicting black bass abundance were statistically significant in 12 of 17 possible cases and included seasonal surface area, storage volume, and ratio of inflow to release volume as significant variables.

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 49:47–57

Fisheries biologists often associate strong year classes of warm-water fishes in reservoirs with years of above-average inflow and elevated water levels (Keith 1975, Rainwater and Houser 1975, Fisher and Zale 1991). Hydrologic patterns

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that enhance year-class strength involve substantial increases in inundated area, occur over several seasons or years, and may be accentuated by topography, soil conditions, and vegetation (Wood and Pfitzer 1960, Ploskey 1986). In contrast, daily or weekly fluctuations may have negative effects on spawning and hatching (Heisey et al. 1980, Bennett et al. 1985, Kohler et al. 1993), although not necessarily year-class strength (Gasaway 1970, Estes 1971, Kohler et al. 1993).

Responses to hydrologic variables by largemouth bass and, to a lesser extent, spotted bass, have been frequently studied because of their importance in warm-water fisheries and their sensitivity to water-level changes (Jenkins 1970). Increased reproductive success of largemouth bass in wet years has been attributed to many factors, including increased nutrient loading (Shirley and Andrews 1977, Aggus 1979), increased primary production (Benson 1968), and inundation of vegetated terrestrial vegetation (Houser and Rainwater 1975, Strange et al. 1982, Miranda et al. 1984). Water-level stability during the nursery stage of largemouth bass has also been shown as a significant factor affecting abundance (Willis 1986, Kohler et al. 1993). Willis (1986) found that summer drawdowns in Kansas reservoirs reduced largemouth bass abundance, presumably because young-of-the-year were forced from the cover of normal littoral zone habitats into deeper, more open habitats, thus exposing them to higher predation levels and adverse climatic conditions.

The objectives of our study were to inventory fisheries and hydrologic data available for the major (>200 ha) impoundments in the Apalachicola-Chattahoochee-Flint (ACF) and Alabama-Coosa-Tallapoosa (ACT) drainage basins, to identify those reservoirs suitable for further analysis, to derive correlation matrices based on these data to relate black bass reproductive success to hydrology, and to develop predictive models for black bass reproduction. This approach is similar to that used in a previous study in the Missouri River Basin (Ploskey et al. 1993). Predictive models are constrained by the quantity and quality of available hydrologic and fisheries data.

This project was conducted as part of the Tri-State Water Management Study for the U.S. Army Corps of Engineers (USACE), Mobile District, by the Georgia Cooperative Fish and Wildlife Research Unit, and USACE Waterways Experiment Station. Cooperators of the Unit include the National Biological Service, University of Georgia, Georgia Department of Natural Resources (GDNR), and Wildlife Management Institute. Permission was granted by the Chief of Engineers to publish this information. We thank the Alabama Department of Conservation and Natural Resources (ADCNR), the GDNR, and the USACE Mobile District, for assistance with data acquisition. We also thank Julie E. Wallin for providing comments on an earlier draft of this manuscript.

Methods

Study Area

ACF Drainage Basin.—The ACF drainage basin is located primarily in Georgia. It drains about 50,826 km^2, including a portion of eastern Alabama and most of western Georgia, flowing southward through the Florida panhandle to the Gulf of Mexico (Couch 1993). Contained within this basin are 10 major (>200 ha) impoundments, of which 5 are operated by the USACE and 5 are owned privately. They range in size from 396 to 18,499 ha.

ACT Drainage Basin.—The ACT drainage basin drains portions of northwestern Georgia, southeastern Tennessee, most of central Alabama, and eventually flows into Mobile Bay. Within the drainage area of 59,280 km^2, are 15 major impoundments, of which 10 are operated by the Alabama Power Company, and 5 are operated by the USACE (J. G. Ward, pers. commun.). They range in size from 234 to 15,600 ha.

Data Acquisition

Major reservoirs were inventoried to identify impoundments having sufficient fisheries data for the proposed analyses. Our analyses required at least 6 years (preferably consecutive) of fisheries and accompanying hydrologic data (Ploskey et al. 1993). The ADCNR, GDNR, Auburn University, Alabama Power Company, and USACE Mobile District, were contacted regarding availability of data. We obtained information on sampling years, methods, seasons, spatial extent, data format, and data availability. Data formats typically included field sheets, summary reports, computer files, and publications.

Hydrologic data were requested from the USACE Mobile District, Georgia Power Company, and Crisp County (Georgia) Power Company. Data consisted of elevation-area-volume tables and measurements of daily inflow, release volume, and water surface elevation.

Selected Sites and Gears

Sufficient fisheries data were available for 7 reservoirs, 5 in the ACF basin and 2 in the ACT basin; however, hydrologic data were available only for the 5 of these operated by the USACE. Lake Seminole, in the ACF basin, had available fisheries and hydrologic data, but the high abundance of aquatic vegetation potentially confounded analyses of hydrologic effects, so this reservoir was deleted from further analysis (L. Keefer, pers. commun.). This left only 2 reservoirs in each basin with sufficient fisheries and hydrologic data (Table 1).

In the ACF, West Point Reservoir and Walter F. George Reservoir are 2 USACE mainstream impoundments of the Chattahoochee River on the Georgia-Alabama border. West Point Reservoir is located near La Grange, Georgia, and Walter F. George Reservoir is located further south, near Columbus, Georgia. Full-pool was established for West Point Reservoir in May 1975. The reservoir occupies 10,482 ha and is currently maintained at 193.5 m above mean sea level (MSL) (Miranda et al. 1984). Walter F. George Reservoir was created in 1962 and is maintained at 58 m above MSL. It occupies a surface area of 18,499 ha (Keefer 1980).

In the ACT, Allatoona Reservoir and Carter's Reservoir are 2 USACE impoundments in northwest Georgia. Allatoona Reservoir is a mainstream impoundment of the Etowah River. Formed in 1949, it is maintained at 256 m

Table 1. Number of years of available fisheries data for selected reservoirs in the Apalachicola-Chattahoochee-Flint (ACF) and Alabama-Coosa-Tallapoosa (ACT) drainage basins, GDNR = Georgia Department of Natural Resources.

Reservoir	Electrofishing		Summer rotenone	Primary source of fisheries data
	spring	fall		
ACF basin				
West Point	10	13	8	GDNR
W. F. George	9	1	13	GDNR
ACT basin				
Allatoona	10	4	8	GDNR
Carter's	8	6	4	GDNR

above MSL and has a normal pool surface area of 4,802 ha (Beisser 1989). Carter's Reservoir is a mainstream impoundment of the Coosawattee River. It was formed in 1975, is maintained at 327 m above MSL, and has a normal pool surface area of 1,304 ha (Beisser 1987).

Cove sampling with rotenone and electrofishing were the only sampling methods performed with enough consistency to be considered here. Rotenone sampling generally consisted of August-September sampling of 3 coves ranging in size from <1 to 2 ha for each reservoir. Block nets were employed and fish were collected for up to 3 days following treatment with rotenone (Keefer 1988, Beisser 1989). Electrofishing was conducted using boat-mounted electrofishing units employing either alternating or direct current and timed shoreline transects at a minimum of 10 selected stations (GDNR 1981, 1985). Although frequently performed, gillnetting was not included in our database. Biologists with the GDNR indicated that black basses are not the primary target in seasonal gillnetting, and this method would not be appropriate for inclusion here. Seining, usually performed in the summer and targeting centrarchid young-of-the-year, was not a sufficiently consistent sampling method.

Data Analyses

Our index of reproductive success of black bass was computed as $\log_{10}$ (catch + 1) for age-0 and age-1 fish, where catch was expressed as kg/ha for cove-rotenone samples and *N*/hour for electrofishing. Age was estimated from length-frequency data for each reservoir and species.

We defined 34 hydrologic variables based upon flow, volume, area, or selected ratios thereof (Table 2), and estimated simple correlation coefficients between these variables and fish abundance. Variables were separated into seasonal time segments potentially affecting fish reproductive success. Many variables were expressed relative to reservoir surface area in order to use dimensions consistent with those used to quantify fish standing crop. Reservoir volume and area were calculated from elevation using quadratic equations fit to empirical data for each reservoir. All equations were highly significant ($r^2 > 0.99$, $P <$

Table 2. Abbreviations and definitions of temporal hydrologic variables.

Variable	Definition
CASUSP	Change in area, summer-spring = mean of ha on 31 Mar, 30 Apr, and 31 May minus mean on 30 Jun, 31 Jul, and 31 Aug of year-1 divided by mean on 30 Jun, 31 Jul, and 31 Aug of year-1
CASUSP2	Change in area, summer-spring = mean of ha on 30 Apr, 31 May, and 30 Jun minus mean on 30 Jun, 31 Jul, and 31 Aug of year-2 divided by mean on 30 Jun, 31 Jul, and 31 Aug of year-2
CASUSU	Change in area, summer-summer = mean of ha on 30 Jun, 31 Jul, and 31 Aug minus mean for the same dates in year-1 divided by mean on the same dates of year-1
CASUSU2	Change in area, summer-summer = mean of ha on 30 Jun, 31 Jul, and 31 Aug minus the mean for the same dates in year-2 divided by mean on the same dates of year-2
XVOL1–8	Mean volume = mean of Log_{10}(end-of-month $m^3 \times 10^6$)/8, Jan–Aug
SINF1–8	Inflow volume = $\text{Log}_{10}(m^3 \times 10^6)$, Jan–Aug
SREL1–8	Release volume = $\text{Log}_{10}(m^3 \times 10^6)$, Jan–Aug
FR1–8	Flushing rate = sum of release volume divided by mean volume, Jan–Aug
RIR1–8	Ratio of inflow to release = inflow divided by release, Jan–Aug
XCMS1–8	Mean flow = flow(m^3/s), Jan–Aug
XVOL9–11	Mean volume = mean of $\text{Log}_{10}(m^3 \times 10^6)$ on 30 Sep, 31 Oct, and 30 Nov of the previous year
SINF9–11	Inflow volume = $\text{Log}_{10}(m^3 \times 10^6)$, Sep–Nov (previous year)
SREL9–11	Release volume = $\text{Log}_{10}(m^3 \times 10^6)$, Sep–Nov (previous year)
FR9–11	Flushing rate = sum of release divided by mean volume, Sep–Nov (previous year)
RIR9–11	Ratio of inflow to release = inflow divided by release, Sep–Nov (previous year)
XA9–11	Mean area = mean of Log_{10}(ha) on 30 Sep, 31 Oct, and 30 Nov (previous year)
PA9–11	Perimeter area = mean Log_{10}(ha depths $\leq$6 m) on 30 Sep, 31 Oct, and 30 Nov (previous year)
CA9–11	Change in area = (30-Nov area minus 30-Sep area) divided by 30-Nov area (previous year)
XVOL3–5	Mean volume = mean of $\text{Log}_{10}(m^3 \times 10^6)$ on 31 Mar, 30 Apr, and 31 May
SINF3–5	Inflow volume = $\text{Log}_{10}(m^3 \times 10^6)$, Mar–May
SREL3–5	Release volume = $\text{Log}_{10}(m^3 \times 10^6)$, Mar–May
FR3–5	Flushing rate = sum of release divided by mean volume, Mar–May
RIR3–5	Ratio of inflow to release = inflow divided by release, Mar–May
XA3–5	Mean area = mean of $\log_{10}$(ha) on 31 Mar, 30 Apr, and 31 May
PA3–5	Perimeter area = mean of Log_12_0(ha over depths $\leq$6 m) on 31 Mar, 30 Apr, and 31 May
CA3–5	Change in area = (31 Mar area minus 31 May area) divided by 31 Mar area
XVOL6–8	Mean volume = mean of $\text{Log}_{10}(m^3 \times 10^6)$ on 30 Jun, 31 Jul, and 31 Aug
SINF6–8	Inflow volume = $\text{Log}_{10}(m^3 \times 10^6)$, Jun–Aug
SREL6–8	Release volume = $\text{Log}_{10}(m^3 \times 10^6)$, Jun–Aug
FR6–8	Flushing rate = sum of release divided by mean volume, Jun–Aug
RIR6–8	Ratio of inflow to release = inflow divided by release, Jun–Aug
XA6–8	Mean area = mean of Log_{10}(ha) on 30 Jun, 31 Jul, and 31 Aug
PA6–8	Perimeter area = mean of Log_{10}(ha over depths $\leq$6 m) on 30 Jun, 31 Jul, and 31 Aug
CA6–8	Change in area = (30 June area minus 31 Aug area) divided by 30 Jun area

0.0001, and $N > 40$). We defined the annual hydrograph as running from September through August to coincide with annual cove sampling of fish.

We developed predictive relationships by estimating regression parameters for models relating abundance of young black bass to reservoir hydrology. Abundance data were matched with the water year in which a given year class was spawned (i.e., yearling hydrology was lagged by 1 year). Models were selected in a stepwise fashion and evaluated according to r^2 improvement, with a significance level of $\alpha < 0.05$ (Dowdy and Wearden 1991).

Results

There were 578 possible correlations between black bass abundance and hydrology, of which 61 were significant ($\alpha < 0.05$; Table 3). There were 7 variables positively correlated 3 or more times: mean volume in spring, mean perimeter area (area ≤6m in depth) in spring, change in summer surface area over 1 and 2 years, inflow:release ratios for January–August and June–August, and mean surface area in spring. Mean volume, January–August, was positively correlated twice and negatively correlated once. Decrease in summer area was negatively correlated 3 times.

There were 17 combinations of reservoir, fish species, age class, and sampling method that were used for modeling relationships between black bass abundance and the 34 hydrologic variables. Models were fit for the following cases: West Point Reservoir — age-0 and age-1 spotted and largemouth basses (both gears); Walter F. George Reservoir — age-0 largemouth bass (rotenone) and age-1 largemouth bass (both gears); Allatoona Reservoir — age-0 and age-1 spotted bass (both gears); and Carter's Reservoir — age-0 and age-1 spotted

Table 3. Occurrence of significant ($\alpha < 0.05$) correlation coefficients between hydrologic variables and age-0 or age-1 black bass abundance estimates in 4 southeastern reservoirs.

Variable[a]	*N* positive correlations	*N* negative correlations
XVOL3–5	6	0
PA3–5	5	0
CASUSU	4	0
CASUSU2	4	0
RIR1–8	3	0
XA3–5	3	0
RIR6–8	3	0
XVOL1–8	2	1
CA6–8	0	3
25 remaining variables	21	6
Total	51	10

[a] See Table 2 for variable definitions.

bass (electrofishing). For all other possible cases, species abundance was either too low or gears were used too infrequently to allow model development.

Significant ($\alpha < 0.05$) single-variable regression models were obtained in 12 of the 17 cases where models were attempted (Table 4). The stepwise addition of a second independent (hydrologic) variable did not significantly improve the predictability of any model. Significant regression models were obtained more commonly for largemouth bass (6 of 7 cases) than for spotted bass (6 of 10 cases). All 8 models based on rotenone sampling of fish abundance were significant, whereas only 4 of 9 models based on electrofishing data were significant.

Modeling results were generally similar to those obtained from correlation analyses. Abundance of young black bass showed greater abundance with increased reservoir surface area, increased reservoir volume, increasing reservoir elevation, and high inflow:release ratios during spring and summer (Table 4).

Discussion

The predictive models and correlations presented here emphasize the importance of high and stable water conditions in the spawning and nursery stages of black bass populations. In the regression models, 11 of the 12 significant variables were associated with increased area or volume in spring and summer (Table 4). The 7 variables found to be positively correlated 3 times or more with black bass abundance were also associated with high and stable spring and summer water levels (Table 3). Decrease in summer surface area was negatively correlated with black bass abundance, which indicates the importance of water-level stability during the nursery period.

Because the most important variable affecting production of strong year

Table 4. Significant ($\alpha < 0.05$) single variable regression models relating black bass abundance to reservoir hydrology. SPB = spotted bass, LMB = largemouth bass; YOY = young-of-the-year, YRL = yearling; ROT = rotenone, EF = electrofishing.

Reservoir	Species, age class	Gear	Model[a]	r^2
West Point	SPB, YOY	ROT	Log_{10}(kg/ha + 1) = −2.9 + 1.1(XVOL3–5)	0.70
	SPB, YRL	ROT	Log_{10}(kg/ha + 1) = 0.21 + 0.01(XA3–5)	0.99
	LMB, YOY	ROT	Log_{10}(kg/ha + 1) = −1.3 + 2.6(RIR6–8)	0.58
	LMB, YRL	ROT	Log_{10}(kg/ha + 1) = −3.3 + 4.5(RIR6–8)	0.75
	LMB, YRL	EF	Log_{10}(*N*/hour + 1) = −1.6 + 2.7(FR6–8)	0.82
W. F. George	LMB, YOY	ROT	Log_{10}(kg/hour + 1) = −23.2 + 7.9(XA3–5)	0.92
	LMB, YRL	ROT	Log_{10}(kg/ha + 1) = 1.4 + 1.8(CASUSP)	0.86
	LMB, YRL	EF	Log_{10}(*N*/hour + 1) = −54.7 + 18.5(XVOL3–5)	0.63
Allatoona	SPB, YOY	ROT	Log_{10}(kg/ha + 1) = −31.3 + 8.7(XA6–8)	0.82
	SPB, YOY	EF	Log_{10}(*N*/hour + 1) = −7.4 + 3.3(XVOL6–8)	0.80
	SPB, YRL	ROT	Log_{10}(kg/ha + 1) = −10.8 + 4.4(XVOL1–8)	0.86
Carter's	SPB, YOY	EF	Log_{10}(*N*/hour + 1) = 1.2 + 0.1(CASUSU)	0.94

[a] See Table 2 for variable definitions.

classes appears to be post-spawning survival of age-0 fish (Aggus and Elliott 1975, Summerfelt 1975, Fourt 1978, Kohler et al. 1993), water-level management to assure black bass year class success should consist of maintaining high water and acceptable habitat after a relatively wet spring. We could not determine the importance of inundation of terrestrial vegetation for producing strong year classes of black bass, although this has been shown to be critical (Aggus and Elliott 1975, Fisher and Zale 1991). Flooding of terrestrial vegetation in a year of average inflow for increasing largemouth and spotted bass growth and recruitment may not be as effective as inundation of vegetation in a year of naturally high inflow and nutrient loading (Strange et al. 1982, Miranda et al. 1984). Sporadic hydrologic fluctuations may have negative effects on spawning and hatching (Heisey et al. 1980, Bennett et al. 1985, Kohler et al. 1993), although not necessarily year-class strength (Gasaway 1970, Estes 1971, Kohler et al. 1993). Our analyses tended to average spring and summer hydrologic variables and ignore microvariation within seasons; hence, we can not evaluate the effect of these events on black bass reproductive success. Based on previous studies and this current one, maintaining high, stable water during spring and summer followed by a late summer/fall drawdown to allow revegetation and oxidation of organic and mineral matter, thus providing nutrients upon reflooding, may be the best management plan for black bass in southeast reservoirs.

Of the 25 major impoundments within the ACT and ACF drainage basins, only 7 had historical fisheries data sufficient for the types of analyses we performed. For the most part, the paucity of suitable data was due to a lack of consistent sampling with standardized procedures over a period of several consecutive years. We were not afforded the luxury of establishing and implementing an experimental protocol specifically designed to address the questions presented here. We had to rely upon existing data sets collected by state agencies and other parties. The data shortage should be remedied as state-sponsored standardized sampling programs mature.

Cove sampling with rotenone provided useful data for addressing our objectives despite its reputation for providing imprecise estimates of fish abundance (Timmons et al. 1978, Siler 1986, Van Den Avyle et al. 1995). Relative to rotenone samples, electrofishing estimates were not as frequently correlated with hydrologic variables even though the period of record for electrofishing samples often matched or exceeded that of available rotenone data (Table 1). It is possible that the data on young black bass abundance provided by electrofishing has higher variation than does that provided by rotenone sampling. March and April electrofishing, as conducted in Alabama and Georgia reservoirs (GDNR 1981, 1985; ADCNR 1988), can provide highly variable estimates of age-1 relative abundance among years (Van Horn et al. 1991) and cannot provide any data on age-0 fish. Houser and Rainwater (1975) observed that annual population estimates taken before late May underestimated numbers of age-1 largemouth bass because older bass moved toward shore earlier and dispersed earlier than younger bass. Also, variation in inshore and offshore movements in early spring (a function of variations in weather) may increase the variability of estimates among years. They concluded that the optimum time for sampling largemouth bass was when movement was least and all age groups reached their greatest density in coves, usually in early June. This may explain the lack of significant regressions for spring electrofishing data in Allatoona, Carter's, and West Point reservoirs. Electrofishing later in the spring may provide more precise data for assessing yearling abundance and electrofishing in the fall should enhance estimates of age-0 black bass abundance, thus strengthening models relating hydrology to black bass reproductive success.

Long-term data collection with consistent methods is important, provided details of possible sampling biases are understood. In this burgeoning era of ecosystem management, cooperation between states in establishing standardized sampling programs that are able to address the system-wide questions attempted here should be a high priority.

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