RELATIONS BETWEEN HYDROLOGICAL VARIABLES AND YEAR-CLASS STRENGTH OF SPORTFISH IN EIGHT FLORIDA WATERBODIES

By

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This document is dedicated to to my parents, Robert and Constance.

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Abstract of Thesis Presented to the Graduate School
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Hydrological variables, such as water level (m) and flow rate (m^3/s), have influenced recruitment of sportfishes in lakes, reservoirs, and rivers. I evaluated how annual and seasonal flows and water levels were related to year-class strength of selected sportfishes across four rivers and four lakes in Florida. Species investigated included black crappie *Pomoxis nigromaculatus*, bluegill *Lepomis macrochirus*, largemouth bass *Micropterus salmoides*, redbreast sunfish, *L. auritus*, redear sunfish *L. microlophus*, and Suwannee bass *M. notius*. Hydrological data were obtained from the U.S. Geological Survey and the appropriate Florida Water Management Districts.

The residuals from catch-curve regressions developed from otoliths of fish caught by electrofishing were used to assess relationships between hydrological variables and year-class strength of sportfish. The multiple regression model computed for the Suwannee bass residuals combined from two rivers indicated that year-class strength was negatively related to spring median flow rates (r^2 = 0.38). Similarly, largemouth bass

residuals combined from four rivers indicated that year-class strength was negatively related to spring median flow rates and positively related to winter median flow rates ($r^2 = 0.24$). Conversely, bluegill residuals combined from two rivers indicated that year-class strength was positively related to the previous fall median flow rates ($r^2 = 0.38$). Redbreast sunfish residuals combined from three rivers indicated that year-class strength was positively related to the previous fall median flow rates before spawning ($r^2 = 0.31$). On a broader scale, *Micropterus* spp. (i.e., *notius* and *salmoides*) residuals were combined from four rivers and a multiple regression model indicated that year-class strength was negatively related to spring median flow rates and positively related to winter median flow rates ($r^2 = 0.22$). *Lepomis* spp. (i.e., *auritus* and *macrochirus*) residuals were combined from three rivers and the multiple regression equation indicated that year-class strength was positively related to fall median flow rates before spawning and negatively related to fall median flow rates ($r^2 = 0.47$). No significant regression models were detected between water level in lakes and year-class strength of sportfish.

Management implications of this work include regulation changes pertaining to minimum flows and levels (MFLs). Detecting impacts of flow on year-class strength of sportfish across lakes and rivers were variable but relationships were easier to detect in rivers. High flows, at least once every three years in the fall, may allow inundation of floodplain habitat, thus providing favorable environmental conditions for *Lepomis* spp. in rivers. Setting MFLs during periods of prolonged drought (i.e., three years or more) should consider impacts to short-lived species such as *Lepomis* spp. I contend that low flows for three or more consecutive years should be prevented and thus, MFLs should consider biological impacts to short-lived fishes.

INTRODUCTION

Water demand due to human population expansion in central Florida has increased ground-water removal, resulting in reduced ground water and surface water levels, particularly during periods of low rainfall. Reduced surface-water levels may have consequences for important sport fisheries in rivers and lakes. Previous studies have shown that low water levels may reduce habitat availability and substantially alter fish and invertebrate communities (Travnichek et al. 1995; Petts 1996).

Recruitment can be defined as the number of fish born in a given year that survive to reproductive or harvestable size (Willis and Murphy 1996). Recruitment into a fishery can be influenced by a number of density-dependent and independent factors (Everhart and Youngs 1981; Royce 1996). Possible density-dependent factors include cannibalism, disease, and predation (Houde 1987). Density-independent factors may include variations in temperature, turbidity, flow rate, or water level changes (Everhart and Youngs 1981; Sigler and Sigler 1990; Royce 1996). Increased water level may increase the amount of spawning habitat and food resources available to sportfish by inundating shoreline vegetation (Jenkins 1970; Aggus and Elliot 1975; Keith 1975; Timmons et al. 1980; Miranda et al. 1984; Meals and Miranda 1991). Alternately, above average flow rates in lotic systems have both positively and negatively influenced recruitment of fish, depending on the system and species (Filipek et al. 1991; Mason et al. 1991; Sallee et al. 1991; Kriksunov and Mamina 1995; Raibley et al. 1997). Thus, variations in flows and water levels may influence fish recruitment.

The extent of drought and flood periods will influence the magnitude, frequency, duration, and timing of changes in water flow (Grossman et al. 1990; Reice et al. 1990), which can influence fish community structure in rivers (Poff and Ward 1989; Walker et al. 1995; Richter et al. 1996; Poff et al. 1997). Stream flow is considered a major variable that affects the abundance and distribution of many riverine species (Resh et al. 1988; Power et al. 1995).

Catch-curve analysis has been used by fishery biologists to estimate total annual mortality (Ricker 1975). Residuals from catch curves can be used as an index of relative year-class strength, with positive residuals indicating relatively strong year classes and negative residuals indicating relatively weak year classes (Maceina and Bettoli 1998). Residuals can then be used to relate year-class strength to environmental variables (Wrenn et al. 1996; Maceina 1997). Wrenn et al. (1996) used a catch-curve multiple regression with environmental variables and determined that reservoir retention time over 16 days produced strong year classes of largemouth bass *Micropterus salmoides*. This technique was also used to relate recruitment of largemouth bass to flow conditions in two Alabama reservoirs (Maceina 1997). In addition, Sammons et al. (2002) used residuals to index crappie recruitment in several Tennessee reservoirs.

Minimum flows and levels (MFLs) for Florida lakes and rivers are set by the appropriate Florida Water Management District governing board to prevent significant ecological harm to waterbodies as a result of permitted water withdrawals (SJRWMD 2001). The state legislature requires the establishment of MFLs under Subsection 373.042(2), *Florida Statutes* (F.S.) (SJRWMD 2001). Based on previous evaluations of topography, soils, historical ground and surface water data, and vegetation data, MFLs are mandated to prevent harm to that ecological system (SJRWMD 2001). The MFLs are also reviewed periodically by the appropriate water management district and the Florida Department of Environmental Protection (SJRWMD 2001). However, criteria for establishing MFLs in Florida have not included biological factors such as ecological harm to fish recruitment. Knowledge of potential hydrological impacts on sportfishes could be used when MFLs are established and reviewed.

I evaluated the influence of water level and flow rate on year-class strength of six important sportfish species. My objectives were to (1) estimate the age frequency of selected sportfish species across eight Florida waterbodies; (2) use residuals around a catch curve to index relative year-class strength for each species and (3) relate relative year-class strength of each species to historic water-level fluctuations within each waterbody and among waterbodies for lakes and rivers.

METHODS

Site Selection

Waterbodies were chosen for sampling based on two requirements: 1) historical stream-flow (m^3/sec) or water-level (m) data dating back to at least 1992, which experienced significant changes in the flow or water level; and 2) historically low levels of aquatic vegetation. Water-level data back to 1992 were needed to have a minimum of nine years included for analyses with residuals. Aquatic vegetation can influence the amount of habitat that is gained or lost due to fluctuations in water level. High percentages of aquatic vegetation in waterbodies influence fish communities (Shireman et al. 1985; Smith and Orth 1990; Bettoli et al. 1993; Hoyer and Canfield 1996, Tate et al. 2003); thus fluctuating water levels may have a small impact on the amount of available habitat when abundant macrophytes are present. To reduce the confounding effect of aquatic plants on water level effects, I selected lakes that had historically low plant coverage (i.e., <20% coverage). Electrofishing transects were 20 minutes and included samples from all available habitat types. All sampling took place in the fall (September) through spring (March) due to potential sampling biases in the summer (Pope and Willis 1996).

Lakes Annie, Bonny, Crooked, and Disston were chosen because of their fluctuating water levels and low to moderate levels of aquatic vegetation (Figure 1). Lake characteristics are shown in Table 1. I performed electrofishing at Lake Annie from January to February 2002 and January 2003, at Lake Bonny in November 2001 and from

October to November 2002, at Crooked Lake from January to February 2002 and January 2003, and at Lake Disston in March 2002 and February 2003. The four rivers targeted for sampling were the Santa Fe, Ochlockonee, Withlacoochee North, and Withlacoochee South (Figure 1, Table 1). I performed electrofishing in the middle Santa Fe River in October 2001 and September 2002, at the upper Ochlockonee River in November 2001 and from September to October 2002, at the middle Withlacoochee River South in March 2002 and from February to March 2003, and at the middle Withlacoochee River North from November to December 2002.

Species Selected

The species chosen varied across systems but included black crappie *Pomoxis nigromaculatus*, bluegill *Lepomis macrochirus*, largemouth bass, redbreast sunfish *L. auritus*, redear sunfish *L. microlophus*, and Suwannee bass *M. notius*. All are sought by anglers as sportfishes. The species chosen for collection differed among lakes and rivers based on presence and abundance. Suwannee bass and redbreast sunfish are usually present only in rivers, whereas bluegill, black crappie, largemouth bass, and redear sunfish are present in both lakes and rivers.

Data Collection and Analyses

Three boats equipped for electrofishing were used in 2001 and 2002. I used two, 4.9-m jon boats with either a 50-hp or 60-hp outboard and a 4.3-m jon boat with a 15-hp outboard. Electrofishing equipment consisted of the same generator (5000-W AC) and either a Coffelt model VVP 15 or Smithroot model VI-A pulsator and similar cathode probes with electrical output ranging from 5-8 amps of DC current.

All large individuals of each species were kept for age analyses due to possible growth differences between male and females (e.g., largemouth bass; Carlander 1977).

The number of fish to be sacrificed was a concern, so all species were subsampled in smaller size groups where gender-specific growth was expected to be similar (Bettoli and Miranda 2001). Five largemouth bass per centimeter group < 35 cm total length (TL) and all largemouth bass ≥ 35 cm TL were kept. Five Suwannee bass per centimeter group < 25 cm TL and all Suwannee bass ≥ 25 cm TL were kept. For black crappie, bluegill, redear, and redbreast sunfish, five fish per centimeter group < 15 cm TL and all fish ≥ 15 cm TL were kept unless 20 fish were obtained per cm group ≥ 15 cm TL. Fish were placed on ice and returned to the laboratory where they were measured and weighed, gender determined, and sagittal otoliths removed.

Age and growth for all species was determined from annuli on the sagittal otoliths (Schramm and Doerzbacher 1982; Taubert and Tranquilli 1982; Hoyer et al. 1985; Maceina and Betsill 1987; Crawford et al. 1989; Schramm 1989; Hales and Belk 1992; Mantini et al. 1992; Buckmeier and Howells 2003). The annuli on otoliths from all fish were counted by observing the whole otolith under a microscope. Otoliths from fish ≥ age-1 were mounted on frosted glass microscope slides with super glue and then sectioned transversely along the dorsoventral plane into 0.5-mm sections using a South Bay Tech. Inc., Model 650, diamond wheel saw. Sections were mounted on glass microscope slides using Thermo Shandon synthetic mountant cement and the annuli were counted under a dissecting microscope. The total number of rings or annuli were recorded. The date of collection was considered when determining the age of the otolith (Hoyer et al. 1985; Crawford et al. 1989). Ages were determined by number of rings alone or the number of rings +1 for those fish caught before or after January 1st, respectively. Two independent readers were used, and in the instance a discrepancy occurred between the two readings, a third reader was used to resolve the age or the otolith was discarded. To remain consistent and potentially increase precision, the same three readers were used for the duration of the study.

An age-length key (Ricker 1975) was used to estimate the age frequency of subsampled fish below the specified length, and in some cases above the specified length (i.e., if $\geq$ 20 fish/cm group were collected above the specified length). The fraction of fish in the aged subsample (N = 5 fish/cm group) was extrapolated to the unaged fish below the specified length to assign fish age based on length. The age frequency of each species of fish below and above the specified length was combined to estimate the total number of fish at each age.

Sampling biases due to short-term weather events, flow conditions, or water level could cause a biased age structure. To assess the potential for sampling biases within a single year, I verified the age structure of fishes in three rivers and four lakes in the second sampling year. Fish were collected and aged as described above, and the age structure of each species was compared to data from the previous year for each waterbody. The Withlacoochee River North was not sampled in the second year.

Bathymetric maps were generated for lakes Annie, Bonny, Crooked, and Disston by Florida LAKEWATCH (2000, 2001, and 2003) personnel using differentially corrected global positioning equipment (GPS). A planimeter (Keuffel and Esser Co.) was used to trace the shoreline contour of each lake in planimeter units. The planimeter units were then compared to the scale of each map and converted into the actual surface area for each lake. Surface areas of different depths in each lake were plotted on hypsographic curves. A hypsographic curve indicates the change in lake surface area per change in water level. The hypsographic curves were generated to assess potential influence of water level on lake surface area and thus potential changes in inshore habitat availability.

Using the estimated age-frequency for each species and system, I performed catch-curve analyses:

$$\log_e(\text{NUMBER}) = b_0 - b_1(\text{AGE}) \tag{1}$$

where NUMBER is the estimated total number of fish of age x and AGE is fish age in years. Because sample size varied among species and waterbodies, the estimated total number of fish of each age was standardized into percent frequency at each age prior to the $\log_e$ transformation.

Catch-curve residuals (i.e., observed deviation from expected values from the regression line) display variation in recruitment among years, and therefore index relative-year class strength (Maceina 1997; Figure 2). Maceina (1997) defined strong and weak year classes as residuals greater than 0.50 and less than -0.50, respectively. I expected positive residuals to correspond to strong year classes and negative residuals to correspond to weak year classes. The magnitude of positive and negative residuals affect the amount of variation explained (r^2) in a simple linear regression model such as a catch curve. For example, I would expect relatively constant recruitment if the r^2 is high (i.e., > 0.95). Variability in recruitment of black crappie has been indexed with the recruitment variability index (RVI) (Guy and Willis 1995).

The RVI was calculated as described by Guy and Willis (1995):

$$\text{RVI} = [S_N/(N_m + N_p)] - N_m/N_p \tag{2}$$

where S_N is the summation of the cumulative relative frequency distribution based on the number of fish in each age-class, N_m is the number of age-groups missing from the sample that should be present (which does not include ages past the last age obtained), N_p is the number of age-groups present in the sample, and $N_p > N_m$. The RVI ranges from –1 to 1. Recruitment is more stable as RVI increases from –1 to 1. All assumptions described by Guy and Willis (1995) were met in order for estimates to be obtained. Thus, the recruitment coefficient of determination (RCD = r^2), RVI, and residual analysis are three options for assessing recruitment patterns of infrequently sampled populations (Isermann et al. 2002). I used all three indices to assess variability of recruitment for each species. The RVI has previously not been applied to sportfish populations other than black crappie.

Capture efficiency of boat electrofishing is size selective (Bayley and Austen 2002). Bayley and Austen (2002) determined catchability of largemouth bass and bluegill across a range of fish sizes. Based on their estimates, I used minimum catchable size groups to determine what age groups to include in the catch curves. Because electrofishing captures small fish at lower rates than their true abundance (Anderson 1995; Reynolds 1996), a catchable size was determined for each species across systems. *Lepomis* spp. and *Pomoxis* spp. were assigned a 100 mm-TL catchable size and *Micropterus* spp. were assigned a 200 mm-TL catchable size. Bayley and Austen (2002) found that fish above these sizes did not vary greatly in catchability. I assumed that *Lepomis* spp. and *Pomoxis* spp. catchabilities varied with fish size in a similar manner to bluegill in Bayley and Austen (2002) and that Suwannee bass catchability would be similar to largemouth bass. If at least 60% of the fish in an age group were assigned catchable size, that year class was kept in the catch curve. If less than 60% of the fish were above catchable size or there were less than three fish in the age group (Ricker

1975), then the year class was deleted from the catch curve. Due to variable growth rates across systems and species, the age range of catchable-sized fish used in the catch curves fluctuated across systems and species.

A sign test (Conover 1980) was performed on the residuals using the UNIVARIATE procedure (SAS 2000) to verify that similar strong and weak year classes in a subsequent year did occur and were not the result of sampling biases within a single year. Residuals for each year class sampled in consecutive years were scored as a "+" if both were above or below the regression line, which indicated agreement between the two sample years. Conversely, if a year- class residual was above the line in year one but below the line in year two, or vice versa, the year-class was scored as a "-". The sign test assessed whether "+" scores were significantly higher than "-" scores, which would indicate that residuals coincided between years across systems and species ($\alpha = 0.10$). To perform the sign test, the species were grouped according to rivers and lakes, and separate sign tests were performed on the two groups.

I selected the best catch-curve regression for each system and year to relate hydrological data using three criteria. First, the catch curve was selected to contain ages obtained during years when extreme water level or flow fluctuations occurred (i.e., minimum or maximum flow rates). Second, the catch curve that contained the most ages that were fully recruited to the gear was used, given the first criteria was met. If both catch curves incorporated extreme environmental conditions and contained the same number of ages, then the sample with the larger number of fish was chosen.

Correlation analyses was used to assess the relationship between residuals and environmental variables for the year the fish in each age were born for each system.

The water level (m) and flow data (m^3/sec) were separated into four periods: 1) January through March was considered winter: 2) April through June was considered spring; 3) July through September was considered summer; and 4) October through December was considered fall. Previous researchers (Maceina and Stimpert 1998; Sammons et al. 2002) have found hydrological conditions before spawning was related to crappie year-class strength, so the fall periods before the spawn were also evaluated in the correlation analyses for each sportfish species and were referred to as pre-spawn fall. Correlation analyses was performed on the residuals with the levels of minimum, maximum, and mean flow rates and/or stages for the annual, fall pre-spawn, winter, spring, summer, and fall periods.

To assess trends across systems, catch-curve residuals were standardized as percent frequencies and hydrological data (i.e., stream flow, m^3/sec, and water level, m) were also standardized as a percent of the median on a seasonal basis. Residuals were combined according to genus (e.g., *Lepomis*), species (e.g., *macrochirus*), and system type (i.e., river) for multiple regression with hydrological variables. I only obtained one black crappie catch curve on one lake, and thus black crappie were not included in the lake analyses of combined residuals. I used multiple linear regression models to determine if year-class strength (i.e., residuals) were related to the five seasonal variables (i.e., median flow or stage for all seasons) from the equation (Myers 1990).

$$Y = \beta_0 + \beta_1(x_1) + \beta_2(x_2) + \ldots + \beta_k(x_k) + \varepsilon_i \qquad (3)$$

Where Y is the year-class strength (residual), β_0 is the intercept value, β_k is parameter estimate, and x_k is the independent variable. Independent variables evaluated for flow and stage included pre-fall, winter, spring, summer, and fall percent of median values. To compare across systems, median values were used in the multiple liner regression models due to the influence of extreme values on the mean. Backward selection was used and the procedure terminated when the removal of no other independent variables could significantly ($P \leq 0.10$) improve the overall model. Multiple linear regression was performed on residuals across systems to provide some insight on regional responses of fish year-class strength in relation to flow or stage. The multiple regression models also allowed for multiple independent variables to be evaluated concurrently. Multicollinearity is a common problem in multiple regression models, and I checked for this problem by evaluating the Variance Inflation Factor (VIF) (Myers 1990). Regression models with a VIF ≥ 10 were not observed and as a result, multicollinearity was not considered a problem in the analyses.

To assess whether variation in flow or stage was related to overall recruitment variability, RVI values were correlated with the overall coefficient of variation (CV=SD/0.*100%) in flow or stage across systems for each species. All statistical analyses were conducted with SAS (2000) and statistical tests were considered significant when $P \leq 0.10$ and marginally significant relationships when $P = 0.11$. A P-value of 0.10 was chosen due to low power associated with most correlations (i.e., N = 5 age classes), and because I considered Type-II error to be important (Peterman 1990).

RESULTS

Hydrological Fluctuations

The overall historical range of water levels across the four lakes fluctuated from $\leq$ 1 to > 3 meters among years (Table 2). The overall range in water level was highest at Lake Crooked (3.8 m) and lowest at Lake Disston (1.2 m)(Table 2). For the four rivers, the overall historical range of flow rates varied from 0 to 1,062 m^3/sec among years (Table 3). Overall flow ranges were highest in the Withlacoochee North (2.2–1,062 m^3/sec) and lowest in the Withlacoochee South (0.9–150 m^3/sec) (Table 3). The bathymetric maps of Lakes Annie, Bonny, Crooked and Disston were generated at 97, 99, 96, and 97% of the maximum water level recorded, respectively (Figures 3, 4, 5, and 6). Bathymetric maps display the outermost contour line representing the shoreline of each lake at the time of map construction. These outermost contour lines were subject to change depending on the lake levels. Hypsographic curves revealed the potential influence of water level on lake surface area (Figure 7).

Sampling Effort and Age Distribution

A combined total of 576 electrofishing transects were conducted on the eight waterbodies. The Florida Fish and Wildlife Conservation Commission (FFWCC) contributed an additional 16 electrofishing transects on the Ochlockonee River in 2002, increasing the total electrofishing transects to 592. Most transects (> 97%) were sampled for 20 minutes in both years, but transects other than 20 minutes (10–17 min) were included in the analyses. To obtain an adequate age sample, electrofishing effort differed according to the system, species, and year (Table 4).

The number of fish collected and aged differed among systems, species and year (Table 4). A total of 19,301 sportfish were collected during the study: 8,298 bluegill; 5,558 redbreast sunfish; 3,675 largemouth bass; 733 Suwannee bass; 529 redear sunfish; and 508 black crappie (Table 4). For all populations combined, bluegill ranged from 22 to 263 mm TL, black crappie ranged from 109 to 350 mm TL, largemouth bass ranged from 48 to 635 mm TL, redbreast sunfish ranged from 33 to 244 mm TL, redear sunfish ranged from 56 to 312 mm TL, and Suwannee bass ranged from 67 to 406 mm TL (Table 4).

A total of 6,327 sportfish were aged during the study, which included 1,918 bluegill, 463 black crappie, 2,238 largemouth bass, 802 redbreast sunfish, 434 redear sunfish, and 472 Suwannee bass (Table 4). For all samples combined, there was 96% between-reader agreement resulting from 6,063 reader agreements out of 6,327 otoliths (Table 5). The 264 otolith disagreements were read by a third independent reader. A total of five otoliths were thrown out from the 264 disagreements because the third independent reader determined an age that was different than either of the first two readers. For all systems and sample years combined, between-reader agreement among species ranged from 91 to 98%. Ages ranged from 0 to 10 years for bluegill, 0 to 9 for black crappie, 0 to 12 for largemouth bass, 0 to 7 for redbreast sunfish, 1 to 10 for redear sunfish, and 0 to 12 for Suwannee bass.

Verification Analyses

A total of 36 usable catch-curves, 20 from lakes and 16 from rivers, were generated on sportfish population age samples obtained from seven systems. Depending on the species and the system, some samples of aged fish were smaller than catchable size and could not be verified with the coinciding age sample. These under represented age samples were not included in the sign test. The sign test on the residuals from the lakes and rivers revealed that similar strong and weak year classes in subsequent years, N = 43, P = 0.05, and N = 32, P = 0.02, respectively. Residuals matched 65% (28/43) of the time for lakes and matched 72% (23/32) of the time for rivers. Thus, strong and weak year classes were evident in both years in most cases. Changes in the age frequencies caused year classes with low residuals to change from positive to negative or vice versa (4/15 lake residual disagreements and 2/11 river residual disagreements) but fell within 0.20 of matching with each other. As a result, only 26% and 22% of lake and river residual disagreements were extreme values (i.e., > 0.2), respectively. These arbitrary residuals that fluctuated around zero were left in the two separate sign tests but did not significantly influence the results. Nevertheless, strong and weak year-classes were generally consistent between sample years.

The verification process determined which systems were adequately sampled for two years in a row and could then be included in the correlation and multiple regression analysis of residuals with the hydrological variables. A specific system and a species were included if at least 50% of the residuals matched in consecutive years (Table 6). I assumed samples that did not meet this criteria, were not related to water levels or flow rates and were not used in the analyses. Species samples that were not verified due to a small age sample during one year or the species was only sampled one time included Lake Annie bluegill, Lake Bonny largemouth bass, Crooked Lake redear sunfish, Lake Disston redear sunfish, and the Withlacoochee River North largemouth bass, redbreast sunfish, and Suwannee bass. These samples were used in the correlation and multiple regression analyses.

System-Specific Correlation Analyses of Residuals with Hydrological Variables

Lake Annie

No significant relationships between stage and relative year-class strength were found for Lake Annie, and most of the variation (r^2) was explained in the catch-curve regressions (Table 6). Bluegill and largemouth bass residuals were not correlated with any annual or seasonal water levels on a minimum, maximum or mean level (all $P \geq 0.27$). Thus, relatively constant recruitment of bluegill and largemouth bass residuals were found on Lake Annie and year-class strength was not related to water level.

Lake Bonny

Year-class strength of sportfish was variable in relation to water levels at Lake Bonny. Black crappie residuals from the catch curve indicated variable recruitment was present (i.e., low r^2 value, Table 6). Black crappie residuals from the catch curve were negatively correlated with maximum pre-spawn fall water levels (Table 7). Thus, low maxium water levels prior to the spawn may be an indicator of potentially strong year classes of black crappie in the following year. Largemouth bass residuals from the catch curve revealed relatively constant recruitment from 1995-1998. Although most of the variation (r^2) was explained in the catch curve regression (Table 6), largemouth bass residuals from the catch curve were positively correlated with minimum, maximum, and mean fall water levels (all $P \leq 0.06$; Table 7). As a result, higher water levels may provide young-of-year largemouth bass. Black crappie and largemouth bass residuals were not correlated with any other annual or any other seasonal water levels (all $P \geq 0.12$). Bluegill residuals from the catch curve were not correlated with any annual or seasonal water level variables (all $P \geq 0.15$). Thus, year class strength of bluegill was not related to water level, but high water level in the fall was positively related to largemouth bass and negatively related to black crappie in the pre-spawn fall season.

Crooked Lake

No significant relationships were found at Crooked Lake except for largemouth bass. Largemouth bass residuals from the catch curve indicated variable recruitment was not present (i.e., high r^2 value, Table 6). But, largemouth bass residuals were positively correlated with minimum, maximum, and mean fall water levels (all $P \leq 0.07$; Table 7). Largemouth bass residuals were not correlated with any other annual or seasonal water level on a minimum, maximum or mean level (all $P \geq 0.25$). Bluegill and redear sunfish residuals from the catch curve regressions revealed relatively constant recruitment from 1995–2001, and much of the variation (r^2) was explained (Table 6). Bluegill and redear sunfish residuals were not correlated with any annual or seasonal water level variables (all $P \geq 0.19$). Thus, year-class strength of bluegill and redear sunfish was not related to water level, but high water level in the fall was positively related to largemouth bass year-class strength.

Lake Disston

Relations between stage and residuals varied among species at Lake Disston. Most of the variation (r^2) was explained in the bluegill catch curve (Table 6), but residuals were negatively correlated with pre-spawn fall water levels ($P \leq 0.07$; Table 7). Most of the variation (r^2) was also explained in the largemouth bass catch curve (Table 6), but largemouth bass residuals were positively correlated with minimum annual water levels (Table 7). Most of the variation (r^2) was left unexplained in the redear sunfish catch curve (Table 6), and redear sunfish residuals were positively correlated with pre-spawn fall minimum and mean water levels (Table 7). Bluegill, largemouth bass, and redear sunfish residuals were not correlated with any other annual or seasonal water level variables (all $P \geq 0.13$). Results indicate an increase in water level during the fall before the spawn were positively related to year-class strength for redear sunfish and negatively related to for bluegill. Also, an increase in the minimum water level on an annual basis was positively related to largemouth bass year-class strength.

Ochlockonee River

The relationships between flow rates and year-class strength of sportfish at the Ochlockonee River were variable. Bluegill residuals from the catch curve were positively correlated with flow variables with the exception of pre-spawn minimum fall flow rates (all $P \leq 0.07$; Table 8). Variable bluegill relationships with flow rates may indicate the species ability to persist during multiple flow regimes. Largemouth bass residuals from the catch curve indicated variable recruitment was present (i.e., low r^2 value, Table 6), but no significant relationships were found between flow and relative largemouth bass year class strength in this system (all $P \geq 0.12$).

Redbreast sunfish residuals from the catch curve were positively related to flow variables at this system (all $P \leq 0.11$; Table 8). Redbreast sunfish year-class strength was positively associated with flow in several seasons including winter, summer, and fall seasons. Thus, high flow favored strong redbreast sunfish year classes. No other sportfish residuals were significantly correlated with any other annual or seasonal flow rate variables (all $P \geq 0.12$). Results indicate strong year classes of bluegill and redbreast sunfish were associated with higher flow rates but no significant relationships were detected for largemouth bass. Thus, relationships were variable across species and seasons in the Ochlockonee River.

Santa Fe River

Conversely, black bass year-class strength was negatively correlated to flow in the Santa Fe River (both $P \leq 0.09$; Table 8). Both largemouth bass and Suwannee bass year-class strength were negatively related to flow, particularly during the spring (Table 8). No other black bass residuals were correlated with any other annual or seasonal flow rate variables (all $P \geq 0.12$). Strong year classes of largemouth bass and Suwannee bass were associated with low flow rates, indicating potential persistence of these species in the event of a water withdrawal from the river.

Withlacoochee River North

Similarly, largemouth bass residuals from the catch curve were negatively correlated to flow variables at the Withlacoochee River North (all $P \leq 0.10$; Table 8) for several seasons, suggesting that high flow reduced largemouth bass year-class strength (Table 8). Largemouth bass residuals were not correlated with any other annual or seasonal flow rate variables (all $P \geq 0.12$). Redbreast sunfish and Suwannee bass residuals were not correlated with any annual or seasonal flow rate variables (all $P > 0.13$). Thus, low flow appeared to be favorable for strong largemouth bass year-class strength in the Withlacoochee River North and the Santa Fe River.

Withlacoochee River South

Generally, sunfish (*L. auritus* and *L. macrochirus*) year-class strength from the Withlacoochee River South was positively correlated with flow rates and no relationships were detected for largemouth bass. Bluegill residuals from the catch curve, when significant, were positively related to flow variables (all $P \leq 0.11$; Table 8). Largemouth bass residuals were not correlated with any annual or seasonal flow rate variables (all $P \geq 0.40$). No other sportfish residuals were correlated with any other annual or seasonal flow rates (all $P > 0.12$). Thus, high flow favored strong bluegill and redbreast sunfish year classes in this system.

Historical hydrological data for both lakes and rivers indicated high water levels and flow rates during 1997 and 1998 (i.e., high rainfall), whereas extremely low water levels and flow rates were observed in late 1999 through 2001 (i.e., drought conditions). The fluctuations in water level and/or flow rate data were related to year-class strength (i.e., residuals) among some of the systems. For example, largemouth bass from Crooked Lake displayed a relatively strong year-class in 1998 (i.e., high annual mean stage) (Table 2) and a weak year class in 2000 (i.e., lower annual mean stage) (Table 2), as indicated by positive and negative residuals (i.e., +0.58, -0.49). Also, largemouth bass from Lake Disston displayed a potential strong year-class in 1998 (i.e., high mean annual water level) (Table 2), as indicated by a positive residual (i.e., +0.55). Other positive residuals (i.e., strong year classes) $\geq$ +0.40 in 1998 included Lake Bonny largemouth bass; Ochlockonee River bluegill, largemouth bass, and redbreast sunfish; Withlacoochee River North redbreast sunfish and the Withlacoochee River South bluegill. Thus, I found evidence that high water in 1998 caused relatively strong year classes.

Multiple Regression Analysis of Combined Residuals

Lakes

Multiple regression models for each species combined across lakes revealed no significant relationships between seasonal stage values and year-class strength (all $P \geq 0.13$). The number of residuals included in the models ranged from ten for redear sunfish to 34 for *Lepomis* spp. combined. Thus, although within-lake relationships were found for several species at three of four lakes evaluated, I found no trends in year-class strength across the lakes using multiple regression, suggesting that regional trends were not evident.

Rivers

In general, multiple regression models combined across rivers indicated year-class strength of sunfish (i.e., redbreast sunfish and bluegill) was positively related to flow rates and black bass year-class strength was negatively related to flow rates (all $P \leq 0.10$; Table 9). The number of residuals included in the models ranged from eight for Suwannee bass to 32 for *Micropterus* spp. combined.

The best multiple regression equation for bluegill indicated that year-class strength was positively related with pre-spawn fall median flow rates and the model explained 38% of the variation (Table 9). Similar to bluegill, the best model for redbreast sunfish indicated that year-class strength was positively related with pre-spawn fall median flow rates and the model explained 31% of the variation (Table 9). Conversely, the best model for largemouth bass indicated that year-class strength was negatively related with spring median flow rates and positively related to winter median flow rates, and the model explained 24% of the variation (Table 9). Similar to largemouth bass, the best Suwannee bass model indicated that year-class strength was negatively related with spring median flow rates and the model explained 38% of the variation (Table 9).

The best multiple regression equation for sunfish (*L. auritus* and *L. macrochirus*) indicated that year-class strength was positively related to pre-spawn fall median flow rates and negatively related to fall median flow rates, and the model explained 47% of the variation (Table 9). The best model for black basses (*M. salmoides* and *M. notius*) indicated that year-class strength was negatively related to spring median flow rates and positively related to winter median flow rates and the model explained 22% of the variation (Table 9). Thus, regression equations revealed variable responses between sunfish and black bass populations and flow conditions across systems.

Correlation Analysis of Combined Recruitment Variability Indexes

Recruitment variability indexes were combined across system type (i.e., lakes or rivers) for each species. In order to perform a correlation analysis, a minimum of three data points were needed, so pooled RVI species samples that contained less than three data points were discarded from the analysis (i.e., black crappie were only obtained from one system). These discarded samples included black crappie and redear sunfish in lakes and bluegill and Suwannee bass in rivers. The coefficient of variation (CV) was obtained for the annual water level of each lake and the annual water level and flow rate from each river for correlation analysis with RVI.

Combined bluegill RVIs in four lakes were not correlated with the CV of water level ($P = 0.65$). Combined largemouth bass RVIs in four lakes were not correlated with the CV of water level ($P = 0.63$). Combined largemouth bass RVIs in four rivers were not correlated with any flow rate ($P = 0.41$). Combined redbreast sunfish RVIs in three rivers were not correlated with any flow rate ($P = 0.44$). Thus, overall recruitment variation indexed with the RVI was not significantly related to overall flow or stage variation among these systems.

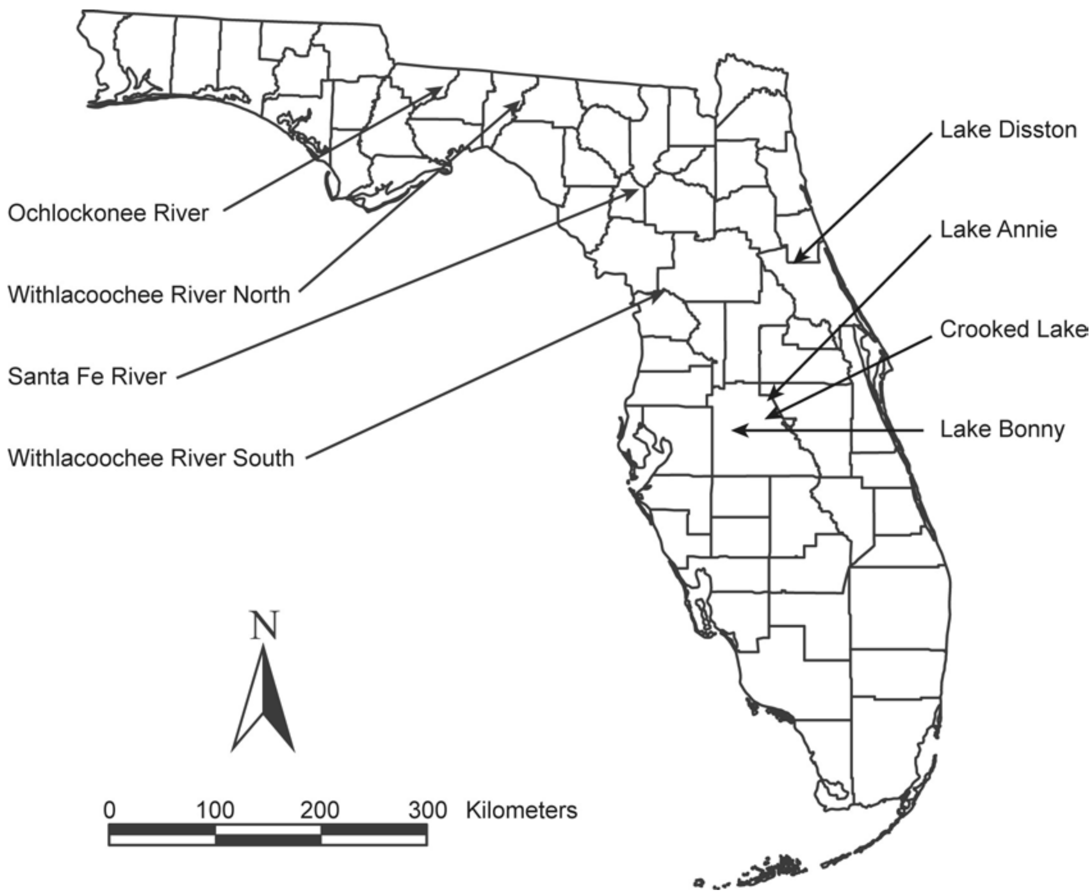

Figure 1. Location of eight sample sites. Arrows are pointing to approximate sample locations. All locations were sampled for two consecutive years during the same season (e.g., fall or winter), except the Withlacoochee River North which was only sampled in one year.

a)

b)

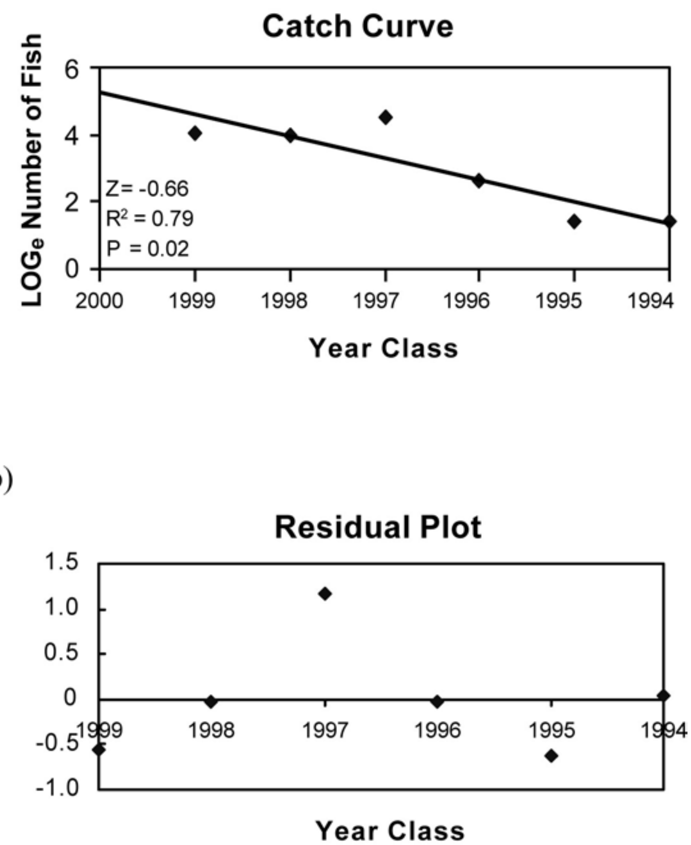

Figure 2. Determination of year-class strength displaying the hypothetical catch-curve (a) and the associated residual plot (b).

Annie (Polk County)
Florida LAKEWATCH Bathymetric Map

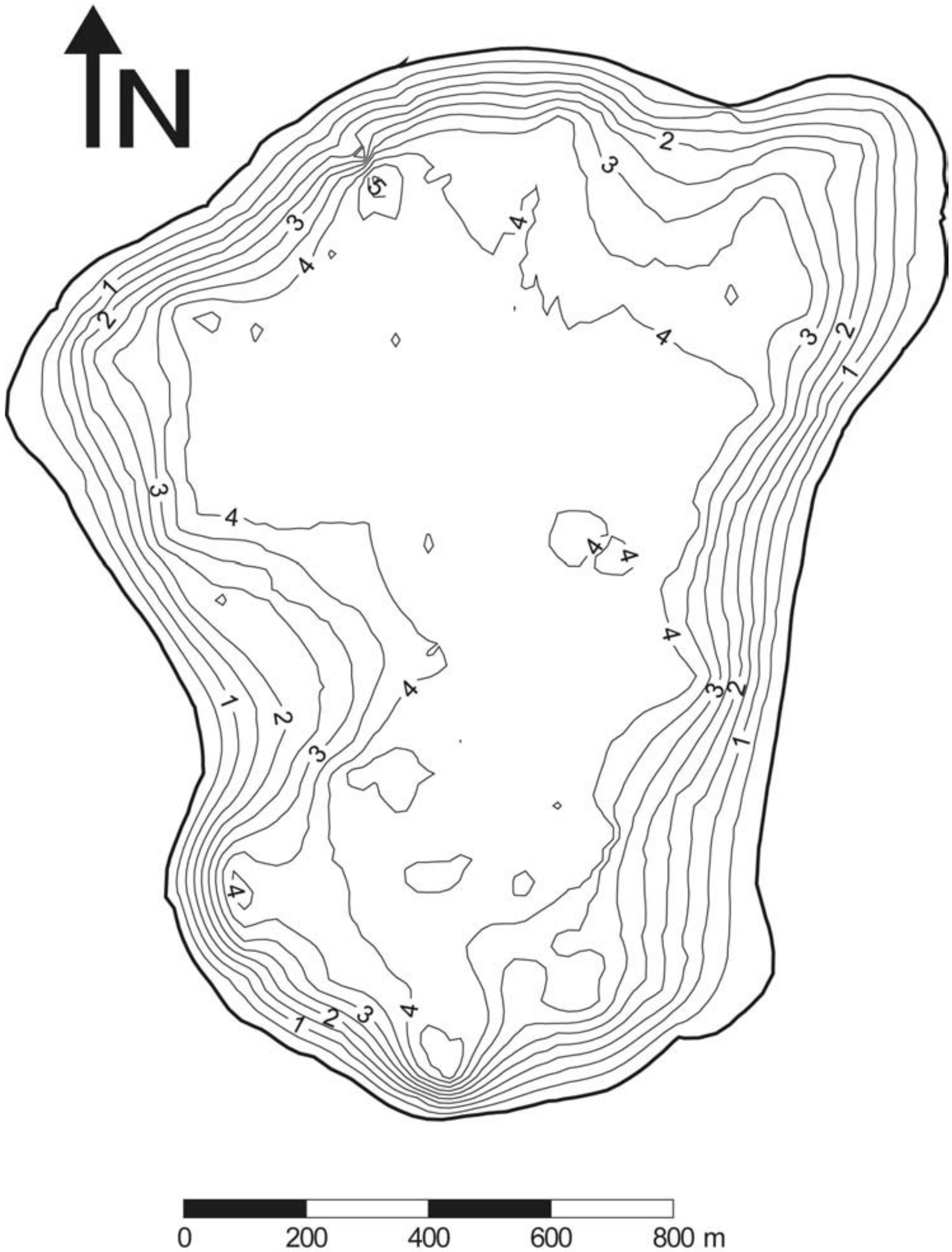

Figure 3. Florida LAKEWATCH personnel generated this map of Lake Annie by using differentially corrected global positioning equipment (GPS). Data were collected March 20, 2003. Scale and map contours are in meters and were generated using kriging technique in Surfer® software package (Golden, CO). The center of the lake is located at Latitude 27° 59' 32" and Longitude 81° 36' 25". On this date, the lake surface area was calculated at 180 hectares.

Bonny (Polk County)
Florida LAKEWATCH Bathymetric Map

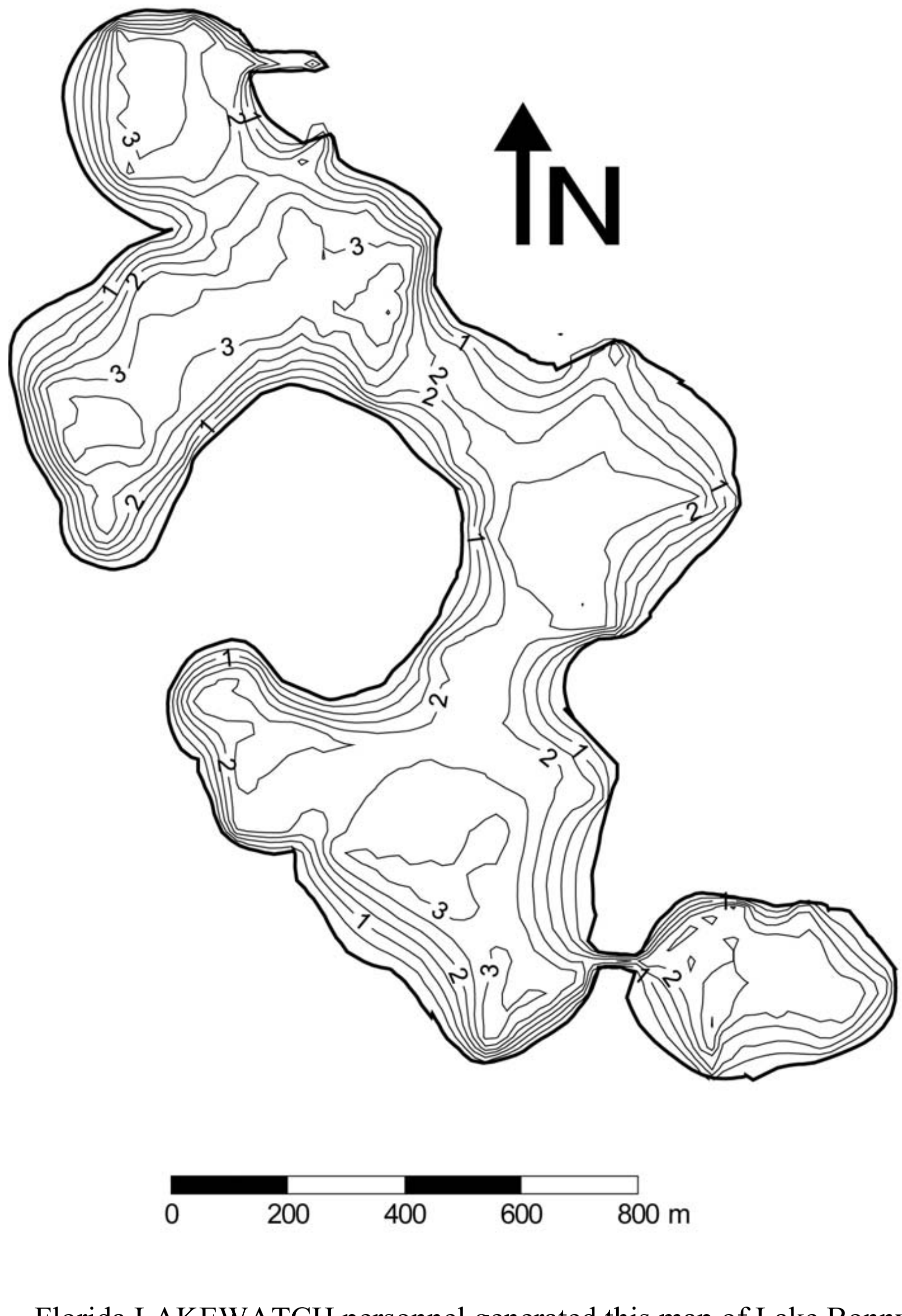

Figure 4. Florida LAKEWATCH personnel generated this map of Lake Bonny by using differentially corrected global positioning equipment (GPS). Data were collected March 20, 2003. Scale and map contours are in meters and were generated using kriging technique in Surfer® software package (Golden, CO). The center of the lake is located at Latitude 28° 02’ 16” and Longitude 81° 55’ 29”. On this date, the lake surface area was calculated at 108 hectares.

Crooked (Polk County)
Florida LAKEWATCH Bathymetric Map

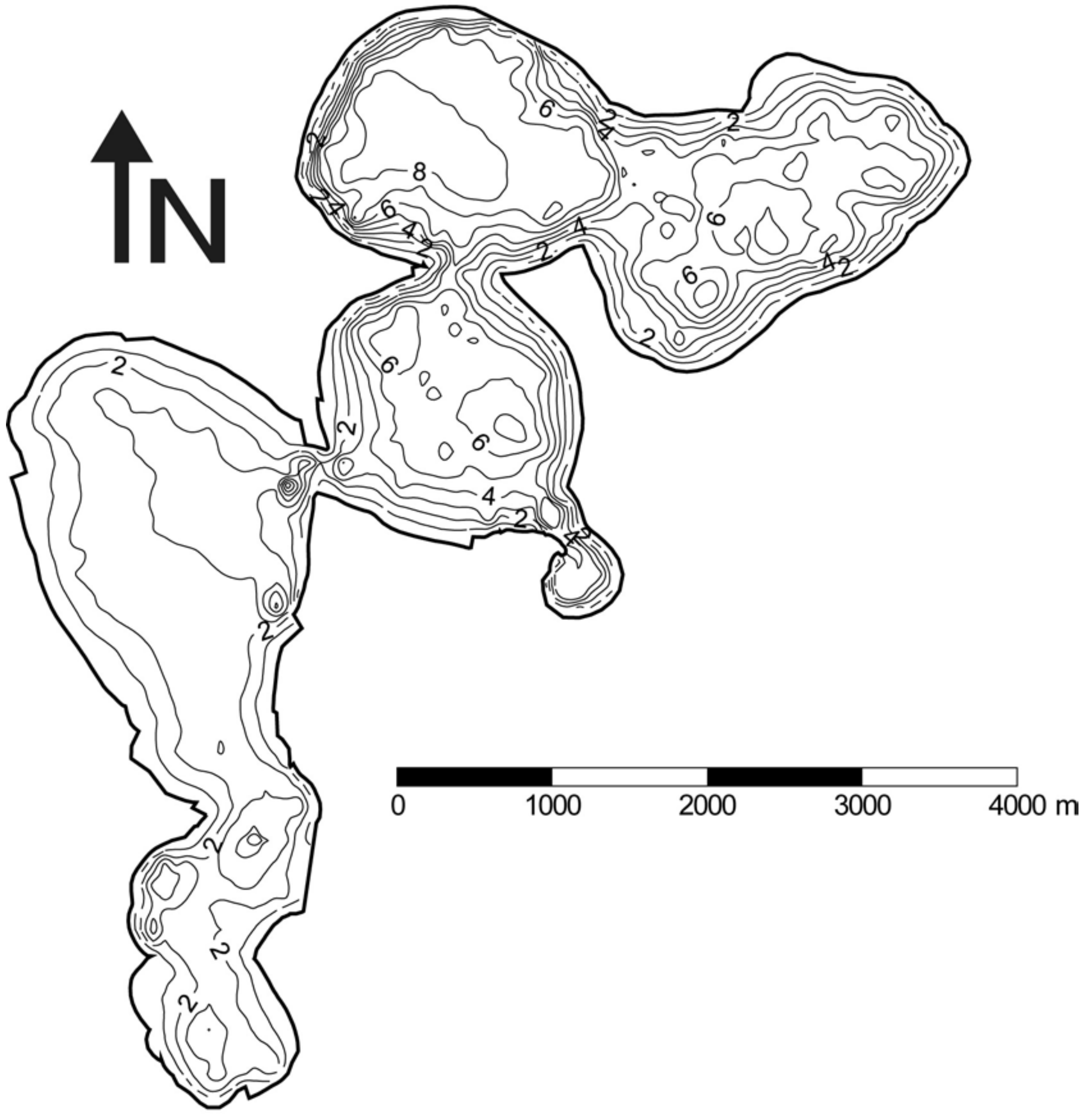

Figure 5. Florida LAKEWATCH personnel generated this map of Crooked Lake by using differentially corrected global positioning equipment (GPS). Data were collected August 8, 2001. Scale and map contours are in meters and were generated using kriging technique in Surfer® software package (Golden, CO). The center of the lake is located at Latitude 27° 48’ 27 and Longitude 81° 34’ 42. On this date, the lake surface area was calculated at 1356 hectares.

Disston (Flagler County)
Florida LAKEWATCH Bathymetric Map

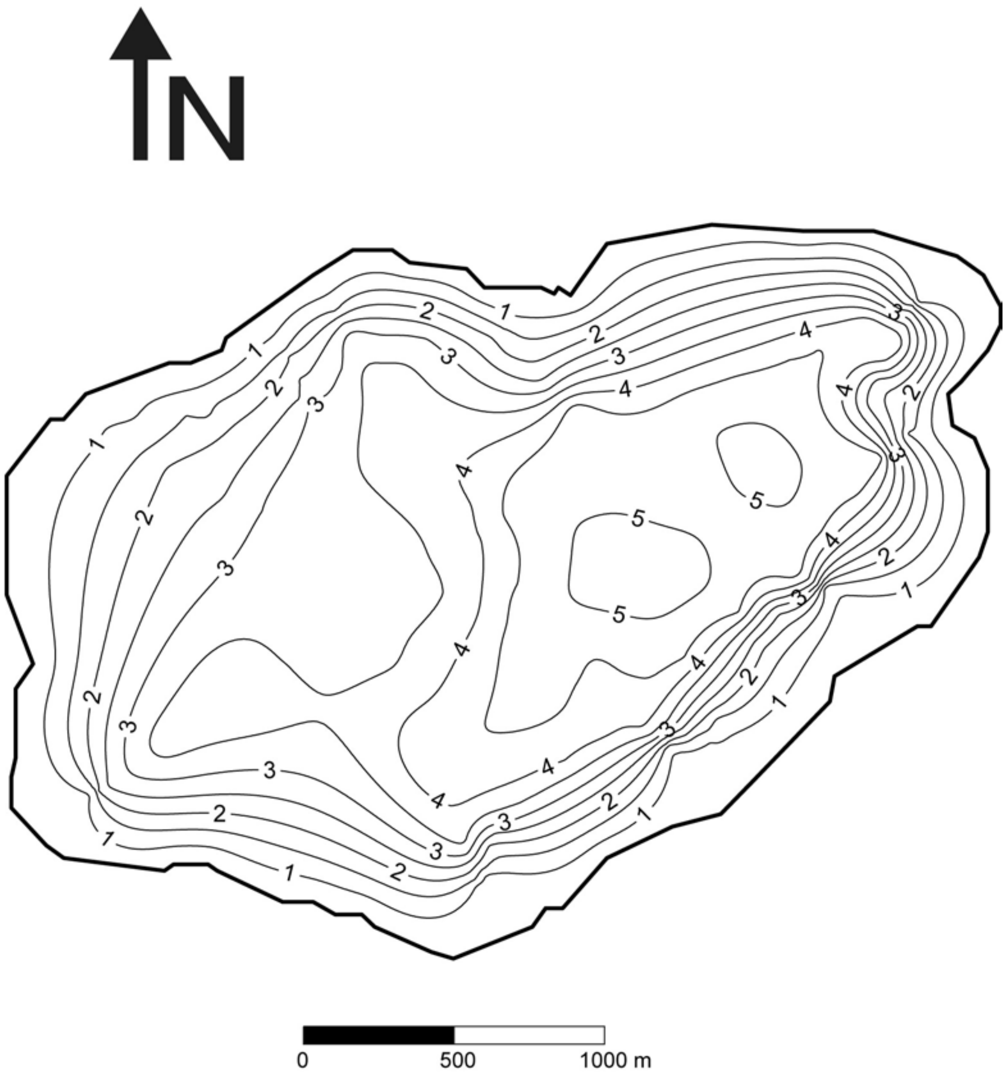

Figure 6. Florida LAKEWATCH personnel generated this map of Lake Disston by using differentially corrected global positioning equipment (GPS). Data were collected July 1, 1999. Scale and map contours are in meters and were generated using kriging technique in Surfer® software package (Golden, CO). The center of the lake is located at Latitude 29° 17’ 2" and Longitude 81° 23’ 31". On this date, the lake surface area was calculated at 1060 hectares.

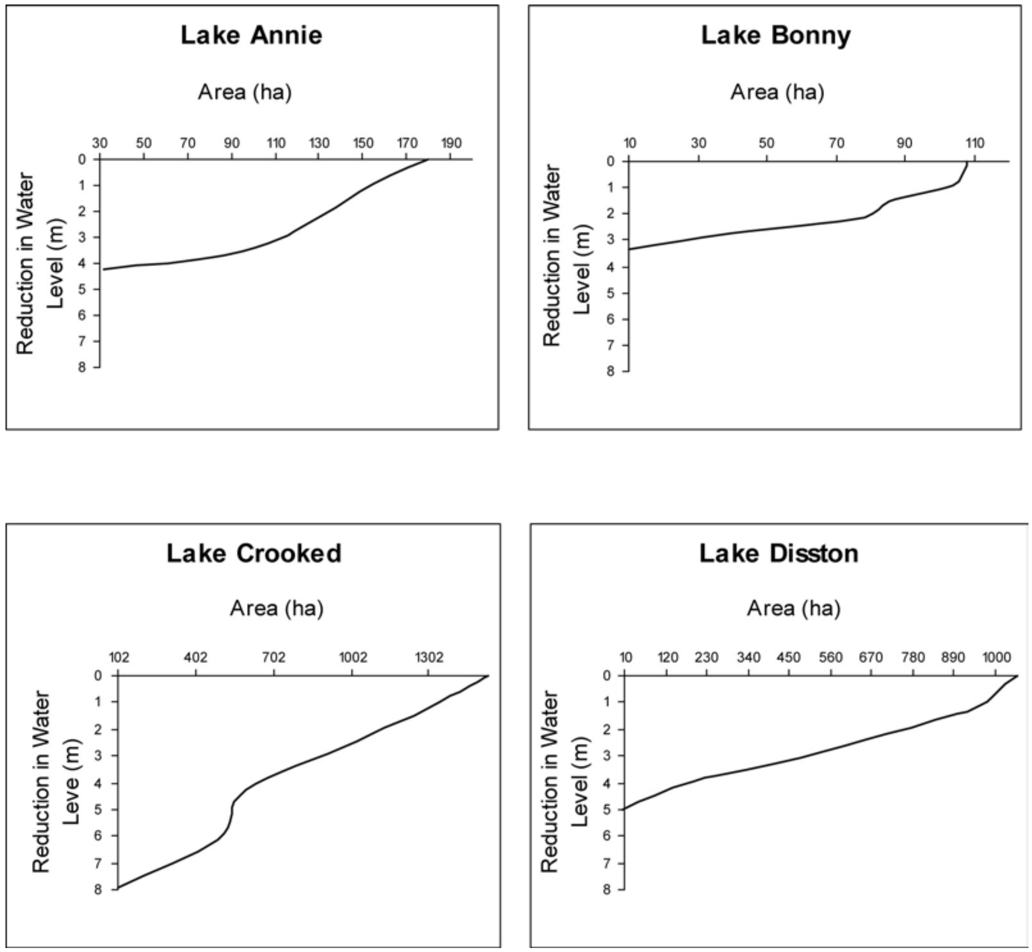

Figure 7. Hypsographic curves displaying the change in surface area with hypothetical declines in water level (m) for each of the four lakes. Florida LAKEWATCH bathymetric maps were traced using a planimeter to construct the curves.

Table 1. Characteristics of lakes and rivers sampled. Surface area (ha) was obtained from Florida LAKEWATCH (2000, 2001, and 2003). Trophic state was calculated according to criteria established by Forsberg and Ryding (1980). Species collected are abbreviated as follows: blc = black crappie; bg = bluegill; lmb = largemouth bass; rbsu = redbreast sunfish; resu = redear sunfish; swb = Suwannee bass. Water data sources are abbreviated as follows: SWFWMD = Southwest Florida Water Management District; SJRWMD = St. Johns River Water Management District. Sample location displays the furthest North and South GPS points sampled on the river. U.S.G.S. Gauge # indicates the United States Geological Survey's water monitoring station.

Lake	County	Surface Area (ha)	Trophic State	Species Collected	Water Data Source
Annie	Polk	180	Eutrophic	bg, lmb, resu	SWFWMD
Bonny	Polk	108	Hypereutrophic	blc, bg, lmb	SWFWMD
Crooked	Polk	1,356	Mesotrophic	blc, bg, lmb, resu	SWFWMD
Disston	Flagler	1,060	Mesotrophic	bg, lmb, resu	SJRWMD

River	County	Sample Location		Species Collected	U.S.G.S. Gauge #
		North	South		
Ochlockonee	Gadsden/Leon	30.59°N, 84.36°W	30.49°N, 84.40°W	bg, lmb, rbsu, swb	02339000
Santa Fe	Alachua/Columbia/ Gilchrist	29.83°N, 82.65°W	29.85°N, 82.63°W	lmb, rbsu, swb	02321975
Withlacoochee (North)	Hamilton/Madison	30.62°N, 83.27°W	30.50°N, 83.24°W	lmb, rbsu, swb	02319000
Withlacoochee (South)	Citrus/Marion	29.01°N, 82.39°W	28.98°N, 82.33°W	bg, lmb, rbsu	02313000

Table 2. Historical lake elevation (m) means, the coefficient of variation (CV = SD/0*100%), number of water level observations (N), and ranges of each year for the four study lakes.

Lake	Year	N	Mean Elevation (m)	CV	Overall Range (m)
Annie	1990	11	33.2	0.28	33.0–33.3
	1991	9	33.3	0.51	33.1–33.5
	1992	0	.	.	.
	1993	12	34.2	0.19	34.1–34.3
	1994	12	34.4	0.69	34.1–34.8
	1995	12	35.0	0.84	34.7–35.4
	1996	12	35.5	0.17	35.3–35.5
	1997	12	35.1	0.27	35.0–35.3
	1998	12	35.5	0.44	35.3–35.8
	1999	12	35.0	0.37	34.8–35.2
	2000	12	34.3	0.77	34.0–34.8
	2001	10	33.7	0.77	33.4–34.1
Bonny	1988	4	40.0	0.13	40.0–40.1
	1989	12	39.6	0.58	39.3–39.9
	1990	12	39.3	0.63	38.8–39.6
	1991	12	39.1	1.14	38.6–39.7
	1992	12	39.6	0.76	39.2–40.0
	1993	11	40.0	0.35	39.7–40.1
	1994	12	39.8	0.57	39.5–40.1
	1995	12	39.9	0.53	39.6–40.3
	1996	12	39.7	0.23	39.6–39.9
	1997	12	39.6	0.91	39.1–40.2
	1998	12	40.0	0.67	39.6–40.4
	1999	12	39.6	0.46	39.2–39.8
	2000	12	38.8	0.93	38.4 – 39.5
	2001	10	38.1	1.14	37.5–38.9
Crooked	1990	12	32.7	0.35	32.6–32.9
	1991	12	32.8	1.21	32.4–33.3
	1992	12	33.5	1.53	32.9–34.1
	1993	12	34.1	0.36	33.9–34.3
	1994	12	34.1	1.04	33.7–34.8
	1995	12	35.0	1.06	34.5–35.5
	1996	12	35.3	0.27	35.2–35.5
	1997	12	35.1	0.50	34.8–35.4
	1998	12	35.9	0.42	35.6–36.2
	1999	12	35.8	0.70	35.4–36.2
	2000	12	35.6	0.68	35.3–36.1
	2001	10	34.9	0.67	34.6–35.2

Table 2. Continued.

Lake	Year	N	Mean Elevation (m)	CV	Overall Range (m)
Disston	1992	271	4.03	2.96	3.74–4.31
	1993	307	3.95	3.40	3.72–4.24
	1994	330	4.06	3.66	3.76–4.55
	1995	330	3.98	4.56	3.67–4.43
	1996	321	4.08	2.55	3.87–4.32
	1997	273	4.06	2.76	3.81–4.40
	1998	273	3.97	5.56	3.58–4.36
	1999	272	3.88	4.70	3.60–4.23
	2000	293	3.87	3.56	3.65–4.14
	2001	291	4.01	5.60	3.68–4.93
	2002	47	4.05	0.53	4.01–4.08

Table 3. Historical river flow rate (m^3/sec) means, coefficient of variation (CV = SD/0*100%), number of flow rate observations (N), and ranges of each year for the four study rivers.

River	Year	N	Mean Flow Rate (m^3/sec)	CV	Overall Range (m^3/sec)
Ochlockonee	1990	365	18.7	162	0.57–151
	1991	365	58.9	142	1.67–634
	1992	366	28.9	113	2.61–229
	1993	365	30.1	169	0.62–289
	1994	365	65.5	129	4.79–770
	1995	365	25.1	146	1.67–286
	1996	366	23.6	111	2.55–145
	1997	365	32.7	104	1.39–174
	1998	365	41.5	158	0.57–504
	1999	365	10.5	102	1.27–44.2
	2000	366	7.00	111	0.54–39.4
	2001	365	17.8	142	1.22–174
	2002	273	8.50	130	0.96–59.8
Santa Fe	1992	92	50.3	103	18.8–239
	1993	365	17.2	78.2	2.80–49.8
	1994	365	16.6	66.9	4.13–62.6
	1995	365	15.9	49.6	4.98–43.6
	1996	366	17.6	123	5.52–195
	1997	365	18.5	66.7	6.54–87.2
	1998	365	37.8	112	14.7–259
	1999	365	8.22	48.1	3.74–18.7
	2000	366	2.95	48.2	1.16–9.06
	2001	365	1.27	115	0.02–7.53
	2002	15	0.14	21.6	0.10–0.19
Withlacoochee North	1990	365	29.3	150	2.80–188
	1991	365	124	150	4.56–1062
	1992	366	49.4	126	4.76–388
	1993	365	54.1	176	2.38–538
	1994	365	99.6	93.7	8.24–530
	1995	365	47.6	173	3.74–535
	1996	366	30.0	139	3.74–238
	1997	365	71.3	108	3.94–351
	1998	365	89.4	152	4.59–974
	1999	365	13.5	118	2.15–80.4
	2000	366	16.8	133	2.58–154
	2001	273	42.7	132	3.51–283

Table 3. Continued.

River	Year	N	Mean Flow Rate (m^3/sec)	CV	Overall Range (m^3/sec)
Withlacoochee South	1990	365	8.90	39.4	3.70–21.9
	1991	365	15.0	85.2	3.70–49.6
	1992	366	6.50	71.2	1.70–37.1
	1993	365	10.3	37.8	5.60–21.4
	1994	365	21.1	75.3	4.60–62.0
	1995	365	31.6	77.9	8.30–97.1
	1996	366	24.8	39.9	11.6–44.7
	1997	365	11.6	104	3.10–84.1
	1998	365	54.6	87.5	9.40–150
	1999	365	10.3	41.6	4.20–27.8
	2000	366	3.10	49.2	1.10–7.30
	2001	273	4.10	96.8	0.90–24.9

Table 4. Waterbody, species, season and year of sampling. Number of fish aged, total fish collected (Total), electrofishing effort in minutes (Effort), and minimum total length collected (Min TL, mm), and maximum total length collected (Max TL, mm).

Waterbody	Species	Season	Year	Aged	Total	Effort	Min TL	Max TL
Lake Annie	Bluegill	Winter	2002	73	73	400	35	207
			2003	55	84	360	54	200
	Largemouth Bass		2002	232	376	400	90	585
			2003	176	370	360	105	635
	Redear Sunfish		2002	125	151	400	85	312
			2003	82	141	360	65	234
Lake Bonny	Black Crappie	Fall	2001	227	254	940	111	350
			2002	188	206	810	109	346
	Bluegill		2001	236	1,721	940	26	263
			2002	200	2,722	810	22	226
	Largemouth Bass		2001	72	72	940	236	567
			2002	71	82	810	142	579
Crooked Lake	Black Crappie	Winter	2002	27	27	520	180	341
			2003	21	21	580	131	253
	Bluegill		2002	153	499	520	37	249
			2003	142	198	580	45	253
	Largemouth Bass		2002	211	408	520	106	635
			2003	133	221	580	107	562
	Redear Sunfish		2002	30	30	520	56	223
			2003	115	125	580	57	272
Lake Disston	Bluegill	Winter	2002	215	573	820	38	263
			2003	233	317	900	49	256
	Largemouth Bass		2002	133	169	820	148	589
			2003	107	108	900	153	596
	Redear Sunfish		2002	52	52	820	72	244
			2003	30	30	900	119	246
Ochlockonee River	Bluegill	Fall	2001	209	688	760	37	218
			2002	150	914	1,228	66	242
	Largemouth Bass		2001	137	206	760	75	597
			2002	182	335	1,228	57	556
	Redbreast Sunfish		2001	169	923	760	48	228
			2002	128	2,653	1,228	33	222
	Suwannee Bass		2001	24	24	760	80	406
			2002	37	38	1,228	67	392
Santa Fe River	Largemouth Bass	Fall	2001	149	254	810	74	535
			2002	165	256	710	48	501
	Redbreast Sunfish		2001	69	403	810	62	244
			2002	57	162	710	90	190
	Suwannee Bass		2001	151	275	810	75	383
			2002	175	305	710	72	383

Table 4. Continued.

Waterbody	Species	Season	Year	Aged	Total	Effort	Min TL	Max TL
Withlacoochee River North	Largemouth Bass	Fall	2002	137	203	1,220	52	588
	Redbreast Sunfish		2002	198	1,061	420	45	241
	Suwannee Bass		2002	85	91	1,220	67	386
Withlacoochee River South	Bluegill	Winter	2002	143	353	620	52	230
			2003	109	156	997	66	242
	Largemouth Bass		2002	158	350	620	109	546
			2003	175	265	997	97	629
	Redbreast Sunfish		2002	102	252	620	57	212
			2003	79	97	997	40	201
Sum				6,327	19,301			

Table 5. Description of otolith reader agreement across system, species, season, and year. Discrepancies indicate the number of discrepancies between two readers, and % Agreement indicates the percent agreement between two readers for each sample.

Waterbody	Species	Season	Year	Number Aged	Discrepancies	% Agreement
Lake Annie	Bluegill	Winter	2002	73	0	100
			2003	55	2	96
	Largemouth Bass		2002	232	0	100
			2003	176	1	99
	Redear Sunfish		2002	125	1	99
			2003	82	9	89
Lake Bonny	Black Crappie	Fall	2001	227	30	87
			2002	188	11	94
	Bluegill		2001	236	5	98
			2002	200	17	92
	Largemouth Bass		2001	72	4	94
			2002	71	3	96
Crooked Lake	Black Crappie	Winter	2002	27	0	100
			2003	21	1	95
	Bluegill		2002	153	5	97
			2003	142	8	94
	Largemouth Bass		2002	211	0	100
			2003	133	0	100
	Redear Sunfish		2002	30	0	100
			2003	115	11	90
Lake Disston	Bluegill	Winter	2002	215	20	91
			2003	233	7	97
	Largemouth Bass		2002	133	7	95
			2003	107	0	100
	Redear Sunfish		2002	52	3	94
			2003	30	1	97
Ochlockonee River	Bluegill	Fall	2001	209	2	99
			2002	150	5	97
	Largemouth Bass		2001	137	6	96
			2002	182	1	99
	Redbreast Sunfish		2001	169	1	99
			2002	128	4	97
	Suwannee Bass		2001	24	0	100
			2002	37	1	97
Santa Fe River	Largemouth Bass	Fall	2001	149	18	88
			2002	165	6	96
	Redbreast Sunfish		2001	69	4	94
			2002	57	9	84
	Suwannee Bass		2001	151	6	96
			2002	175	15	91

Table 5. Continued.

Waterbody	Species	Season	Year	Number Aged	Discrepancies	% Agreement
Withlacoochee River North	Largemouth Bass	Fall	2002	137	0	100
	Redbreast Sunfish		2002	198	20	90
	Suwannee Bass		2002	85	0	100
Withlacoochee River South	Bluegill	Winter	2002	143	4	97
			2003	109	3	97
	Largemouth Bass		2002	158	4	98
			2003	175	0	100
	Redbreast Sunfish		2002	102	8	92
			2003	79	1	99
Sum				6,327	264	
Mean				129	5.4	96

Table 6. Catch-curve linear regression equations for each waterbody and species with r^2, P, ages, and N. Ages is the number of fish ages used in each catch curve analysis used to generate residuals for correlation analyses with hydrological variables. N is the total number of fish collected by electrofishing used to generate residuals.

Waterbody	Species	Year	Equation	r^2	*P*	Ages	N
Lake Annie	Bluegill	2002	Log (% Freq) = 4.39 – 0.36 × age	0.94	0.03	4	66
	Largemouth Bass	2002	Log (% Freq) = 5.36 – 0.70 × age	0.97	0.00	6	270
Lake Bonny	Black Crappie	2001	Log (% Freq) = 5.15 – 0.66 × age	0.79	0.02	6	222
	Bluegill	2001	Log (% Freq) = 4.97 – 0.84 × age	0.82	0.01	6	790
	Largemouth Bass	2001	Log (% Freq) = 5.74 – 0.61 × age	0.98	0.01	4	47
Crooked Lake	Bluegill	2003	Log (% Freq) = 4.39 – 0.42 × age	0.91	0.00	7	144
	Largemouth Bass	2002	Log (% Freq) = 5.17 – 0.65 × age	0.88	0.01	6	314
	Redear Sunfish	2003	Log (% Freq) = 4.07 – 0.32 × age	0.83	0.01	7	111
Lake Disston	Bluegill	2002	Log (% Freq) = 5.32 – 0.72 × age	0.91	0.00	7	371
	Largemouth Bass	2002	Log (% Freq) = 4.63 – 0.48 × age	0.87	0.01	6	113
	Redear Sunfish	2002	Log (% Freq) = 2.94 – 0.07 × age	0.20	0.56	4	39
Ochlockonee River	Bluegill	2001	Log (% Freq) = 6.39 – 1.10 × age	0.88	0.06	4	225
	Largemouth Bass	2001	Log (% Freq) = 4.58 – 0.46 × age	0.79	0.04	5	59
	Redbreast Sunfish	2001	Log (% Freq) = 7.15 – 1.40 × age	0.86	0.07	4	434
Santa Fe River	Largemouth Bass	2001	Log (% Freq) = 4.68 – 0.52 × age	0.83	0.03	5	166
	Suwannee Bass	2001	Log (% Freq) = 4.79 – 0.55 × age	0.91	0.01	5	193
Withlacoochee River North	Largemouth Bass	2002	Log (% Freq) = 3.44 – 0.16 × age	0.50	0.12	6	46
	Redbreast Sunfish	2002	Log (% Freq) = 6.53 – 1.14 × age	0.94	0.04	5	613
	Suwannee Bass	2002	Log (% Freq) = 4.37 – 0.31 × age	0.46	0.52	3	37
Withlacoochee River South	Bluegill	2003	Log (% Freq) = 5.48 – 0.74 × age	0.95	0.01	5	125
	Largemouth Bass	2003	Log (% Freq) = 4.06 – 0.33 × age	0.79	0.01	7	137
	Redbreast Sunfish	2002	Log (% Freq) = 7.13 – 1.38 × age	0.95	0.14	3	211

Table 7. Significant correlation relationships between measures of bluegill, black crappie, largemouth bass, and redear sunfish year-class strength and stage for four lakes. Minimum, maximum, and mean stages were measured for the annual, pre-spawn fall, fall, winter, spring, and summer periods. N indicates the number of residuals obtained from the catch curve. R indicates whether the relationship was positively or negatively correlated. r^2 indicates the percent variation explained in the model. No significant relationships were detected for Lake Annie.

Water Body	Species	Water Variable	Period	Level	N	R	***P***	r^2
Bonny	Black Crappie	Stage	Pre-Spawn Fall	Max	6	-0.74	0.09	0.47
	Largemouth Bass	Stage	Fall	Min	4	0.94	0.06	0.88
	Largemouth Bass	Stage	Fall	Max	4	0.99	0.01	0.98
	Largemouth Bass	Stage	Fall	Mean	4	0.99	0.01	0.99
Crooked	Largemouth Bass	Stage	Fall	Min	6	0.81	0.05	0.08
	Largemouth Bass	Stage	Fall	Max	6	0.77	0.07	0.23
	Largemouth Bass	Stage	Fall	Mean	6	0.79	0.06	0.17
Disston	Bluegill	Stage	Pre-Spawn Fall	Min	7	-0.72	0.07	0.51
	Bluegill	Stage	Pre-Spawn Fall	Max	7	-0.88	0.01	0.77
	Bluegill	Stage	Pre-Spawn Fall	Mean	7	-0.75	0.05	0.56
	Largemouth Bass	Stage	Annual	Min	6	0.74	0.10	0.54
	Redear Sunfish	Stage	Pre-Spawn Fall	Mean	4	0.98	0.02	0.96
	Redear Sunfish	Stage	Pre-Spawn Fall	Min	4	0.99	0.02	0.97

Table 8. Significant correlations between measures of bluegill, largemouth bass, redbreast sunfish, and Suwannee bass year-class strength and flow rate for the four rivers. Levels of minimum, maximum, and mean flow rates were measured for the annual, pre-spawn fall, fall, winter, spring, and summer periods. N indicates the number of residuals obtained from the catch curve. R indicates whether the correlation was positive or negative. P* indicates a marginally significant relationship.

Waterbody	Species	Water Variable	Period	Level	N	R	*P*	r^2
Ochlockonee River	Bluegill	Flow	Pre-Spawn Fall	Min	4	-0.93	0.07	0.87
	Bluegill	Flow	Summer	Max	4	0.99	0.02	0.97
	Bluegill	Flow	Fall	Min	4	0.94	0.07	0.88
	Redbreast Sunfish	Flow	Annual	Max	4	0.99	0.00	0.99
	Redbreast Sunfish	Flow	Annual	Mean	4	0.89	0.11*	0.79
	Redbreast Sunfish	Flow	Winter	Max	4	0.99	0.00	0.99
	Redbreast Sunfish	Flow	Winter	Min	4	0.95	0.05	0.91
	Redbreast Sunfish	Flow	Winter	Mean	4	0.99	0.01	0.98
	Redbreast Sunfish	Flow	Summer	Min	4	0.92	0.08	0.85
	Redbreast Sunfish	Flow	Summer	Max	4	0.92	0.08	0.85
	Redbreast Sunfish	Flow	Pre-Spawn Fall	Max	4	0.98	0.02	0.96
Santa Fe River	Largemouth Bass	Flow	Spring	Max	5	-0.94	0.02	0.89
	Largemouth Bass	Flow	Spring	Mean	5	-0.84	0.08	0.71
	Suwannee Bass	Flow	Annual	Mean	5	-0.83	0.08	0.69
	Suwannee Bass	Flow	Spring	Min	5	-0.82	0.09	0.68
	Suwannee Bass	Flow	Spring	Max	5	-0.86	0.06	0.75
	Suwannee Bass	Flow	Spring	Mean	5	-0.96	0.01	0.92
Withlacoochee River North	Largemouth Bass	Flow	Annual	Min	6	-0.75	0.09	0.56
	Largemouth Bass	Flow	Fall	Max	6	-0.88	0.02	0.78
	Largemouth Bass	Flow	Fall	Mean	6	-0.78	0.07	0.61
	Largemouth Bass	Flow	Summer	Mean	6	-0.83	0.04	0.69
	Largemouth Bass	Flow	Summer	Min	6	-0.74	0.10	0.55
Withlacoochee River South	Bluegill	Flow	Spring	Max	5	0.82	0.09	0.67
	Bluegill	Flow	Winter	Min	5	0.79	0.11*	0.63
	Bluegill	Flow	Winter	Mean	5	0.80	0.11*	0.64
	Redbreast Sunfish	Flow	Pre-Spawn Fall	Min	3	0.99	0.03	0.99

Table 9. Significant multiple regression equations predicting year-class strength (i.e., residual) from flow rates for the four rivers.

Model	r^2	DF	P-value
Bluegill residual = -0.2142 + 0.0009 × pre-spawn fall median flow	0.38	7	0.10
Largemouth bass residual = 0.2438 – 0.0028 × spring median flow + 0.0009 × winter median flow	0.24	21	0.08
Redbreast sunfish residual = -0.1967 + 0.0006 × pre-spawn fall median flow	0.31	11	0.06
Suwannee bass residual = 0.3656 – 0.0032 × spring median flow	0.38	7	0.10
Lepomis spp. residual = 0.0570 + 0.0006 × pre-spawn fall median flow – 0.0004 × fall median flow	0.47	19	0.00
Micropterus spp. residual = 0.2502 – 0.0028 × spring median flow + 0.0008 × winter median flow	0.22	29	0.03

DISCUSSION

In general, year-class strength was more strongly related to system hydrology in rivers than in lakes. Changes in water flow and stage influence fish community structure in rivers (Poff and Ward 1989; Grossman et al. 1990; Walker et al. 1995; Richter et al. 1996; Poff et al. 1997). According to Resh et al. (1988) and Power et al. (1995), stream flow is considered a major variable that affects the abundance and distribution of many riverine species. Variation in flow/stage was much higher for rivers than for lakes in this study, and I found stronger relationships between year-class strength and flow/stage in rivers than in lakes. Thus, rapid and extreme changes in flow/stage in rivers may more strongly influence fish populations than the relatively minor and less variable stage changes in lakes. Relationships between year-class strength and hydrology in rivers appear to be stronger and easier to detect than in lakes.

Results indicated that black bass year-class strength was often negatively related to spring median flow rates in rivers. For example, combined Suwannee bass residuals revealed year-class strength was negatively related with spring median flow rates in rivers. Largemouth bass year-class strength was also negatively related with spring median flow rates and positively related to winter median flow rates in rivers. Similarly, combined black bass (*M. salmoides* and *M. notius*) residuals were negatively related with spring median flow rates and positively related to winter median flow rates in rivers. Mason et al. (1991) and Sallee et al. (1991) found that smallmouth bass *M. dolomieu*, year-class strength was negatively correlated with flow rates. Mason et al. (1991)

surmised that high flow events caused low dissolved oxygen concentrations which may have negatively influenced smallmouth bass year class strength. High flow during spring may reduce nest success due to turbulence or increased juvenile smallmouth bass mortality due to displacement (Sallee et al. 1991; Filipek et al. 1991). Filipek et al. (1991) found that largemouth bass and spotted bass *M. punctulatus* year-class strength was negatively correlated with flow rates in rivers. Similarly, largemouth bass and Suwannee bass exhibited strong year classes in the Santa Fe River during low flow periods in the spring, similar to smallmouth bass year-class strength in three Virginia rivers (Scott Smith, VDGIF, Personal Communication). In Florida rivers, periods of low flow often result in clear water conditions which may increase aquatic macrophyte abundance, potentially improving habitat for young black basses and providing increased survival.

Conversely, largemouth bass relative year-class strength was positively correlated with water levels in three of four lakes. Specifically, fall water levels after the spawn were positively correlated with largemouth bass residuals from Lakes Bonny and Crooked, and residuals were positively correlated with annual water levels at Lake Disston. Lake Bonny electrofishing samples in November 2001 yielded no age-0 and six age-1 fish (i.e., low mean annual water level in 2000 and 2001). Electrofishing samples in November 2002 indicated a strong 2002 year class, with 52 out of 71 fish being age-0 (i.e., high summer and fall water level) and no age-1 or age-2 fish were obtained, suggesting potential year class failure during low water years (2000 and 2001). Personal observation during electrofishing at Lake Bonny in the fall of 2001 revealed growth of terrestrial vegetation due to two consecutive years of low water. I surmise that, as a result of increased rainfall, terrestrial vegetation became inundated in 2002, producing a strong year-class of largemouth bass. Potential mechanisms for a strong year class could include increased food resources, increased available spawning habitat and decreased predation (Bross 1969; Jenkins 1970; Aggus and Elliot 1975; Keith 1975; Shirley and Andrews 1977; Aggus 1979; Timmons et al. 1980; Miranda et al. 1984; Ploskey 1986; Meals and Miranda 1991). Thus, I found evidence that largemouth bass year-class strength was positively related to stage in lakes but negatively related to flow in rivers. Trends were more evident in rivers as multiple regression models for combined systems were significant in rivers but no trends were found among lakes.

Recruitment variability among black crappie populations has been characterized as a "boom or bust" fishery, with a strong year class forming every 3-5 years (Hooe 1991; Guy and Willis 1995; Allen and Miranda 1998; Maceina and Stimpert 1998). Black crappie residuals were negatively correlated with pre-spawn fall maximum water levels at Lake Bonny. The results dispute what has been found with stronger year classes of crappie *Pomoxis* spp. being positively correlated with higher water levels in the winter or spring (Beam 1983; Willis 1986; Miller et al. 1990; Maceina 2003). However, my results were similar to Maceina and Stimpert (1998), who also found that crappie year-class strength was influenced by hydrological variables prior to the spawn. Lower water levels prior to the spawning period concentrates prey items (i.e., higher food availability) (Jenkins 1970; Aggus 1979) which may provide more favorable conditions for a successful spawn (Liston and Chubb 1985) due to increased growth (Aggus 1979) and potentially higher fecundity of adults (Crim and Glebe 1990). Springate et al. (1985) found that food deprivation reduced the rate of maturation and the total fecundity of rainbow trout *Oncorhynchus mykiss*. Furthermore, Ploskey (1986) surmised that spawning success of largemouth bass did not necessarily insure a strong year class but increased the likelihood of producing one if environmental conditions were favorable. Thus, low water levels prior to the spawn may be an indicator of potentially strong year classes of black crappie in the following spring. However, I caution that this relation was found only in one lake where I obtained enough black crappie for assessment.

Unlike black bass, combined bluegill and redbreast sunfish residuals were positively related with pre-fall median flow rates in rivers. Combined *Lepomis* spp. (*auritus* and *macrochirus*) residuals were positively related with pre-fall median flow rates and negatively related with fall median flow rates in rivers. Fish yield and production are strongly related to the extent of accessible floodplain (Junk et al. 1989). Aggus (1979) indicated that under conditions of an expanding physical environment, opportunistic species may increase greatly in abundance and biomass. High flow in the fall before a spawn could increase *Lepomis* spp. year-class strength in rivers through increased food availability and possible increases in fecundity (Springate et al. 1985; Crim and Glebe 1990). Access to the floodplain before the spawn may provide higher fecundity due to higher densities of invertebrate prey in floodplain habitats (Neckles et al. 1990), which may influence *Lepomis* spp. year-class strength in rivers. My results were variable among species and system types, but I detected a positive relationship between *Lepomis* spp. (*auritus* and *macrochirus*) year-class strength and fall median flow rates in three rivers combined. Redbreast sunfish may serve as indicator species for setting MFLs, because I found redbreast sunfish to be positively correlated with high flow rates in two rivers. In general, high flow rates in the fall prior to spawning was related to strong-year classes of *Lepomis* spp. in Florida rivers.

Much is known about reservoirs and the relations of hydrology to sportfish year-class strength (Bross 1969; Jenkins 1970; Aggus and Elliot 1975; Keith 1975; Shirley and Andrews 1977; Aggus 1979; Timmons et al. 1980; Miranda et al. 1984; Ploskey 1986; Meals and Miranda 1991; Ozen and Noble 2002), but little is known about natural lakes (Tate et al. 2003). Few studies have assessed effects of flow on year-class strength of *Lepomis* spp. Meals and Miranda (1991) found that age-0 centrarchid abundance generally increased with water levels in Mississippi reservoirs. Bluegill and redear sunfish year-class strength were negatively and positively correlated with fall water level before the spawn and in spring and summer at Lake Disston, respectively. The lack of relationships between sunfish species and stage in lakes may result because of protracted spawning periods (Mettee et al. 1996), which could allow year-class success if environmental conditions become favorable for some period during the spring or summer. My sample sizes for redear sunfish may have been too low in lakes, which could have precluded detecting differences. Thus, no general trends were evident across lakes for *Lepomis* spp.

Catch-curve regressions for sportfish revealed relatively constant recruitment (r^2) for many of the lakes. Due to relatively stable recruitment, correlations of residuals with hydrological variables were often not found. Despite fluctuations in water level, sportfish populations may have experienced constant recruitment due to lake morphometry (Figure 7). Guy and Willis (1995) suggested that recruitment patterns of black crappie may be influenced by the morphometry of the system. Lakes with shallow sloping shorelines can encounter drastic reductions of lake surface area during drought conditions (Hutchinson 1957). Conversely, lakes with steep sloping shorelines can encounter less than significant reductions of lake surface area during drought conditions (Hutchinson 1957). For example, a 1 m (meter) water level decrease at Lake Annie results in 17% less surface area (hectares) (Figure 2). In contrast, surface areas (hectares) of Lakes Bonny, Crooked, and Disston decrease 6, 9, and 8 % with a 1-m drop in water level. Lake Annie's surface area varied the most of any lake but no significant correlations were found between year class strength of sportfish and water levels. Alternately, significant correlations were found with year-class strength of sportfish and water levels for Lakes Bonny, Crooked, and Disston despite smaller percent surface area decreases. The hypsographic curves were generated at stages below the maximum observed water level during this study, and as a result, surface area (hectares) estimates were up to 4% less than the actual maximum water level for the four lakes. Nevertheless, I expected year-class strength of sportfish to vary in lakes with large changes in surface area per change in water level. This did not occur possibly due to relatively few relationships found between stage and year-class strength at lakes.

Differences in river morphology may explain why largemouth bass were not correlated with flow rates on the upper Ochlockonee River but negatively correlated with flow at the Santa Fe and Withlacoochee North Rivers. Bain et al. (1988) found that stream species respond differently to variable water levels and have specific microhabitat preferences. In addition, Talmage et al. (2002) used the habitat variables of percent overhanging vegetation, percent woody debris, and substrate characteristics to explain up to 50% of the variability in warmwater stream-fish abundance and species richness.

Although measuring changes in riverine habitat and the extent of floodplain connection with changes in stage was not an objective of this study, effects of flow and stage on available habitat should be considered in future studies in Florida rivers.

I found no relation between overall recruitment variability of sportfish indexed with the RVI and variation in stage or flow for either lakes or rivers. The main limitation in determining RVI is the proportion of missing year classes within an age-structure sample (Isermann et al. 2002). Furthermore, as the proportion of missing year classes in a sample increases, RVI decreases (Isermann et al. 2002). This limitation has proved to be problematic in our study because most of the sportfish populations had no missing year classes. The RVI may not be useful in assessing sportfish populations if missing year classes do not occur, potentially limiting the value of the RVI for these species.

As with any scientific study, violation of assumptions during analysis can be a problem. I performed multiple catch curve analyses, assuming mortality was constant (Ricker 1975). In all likelihood, fishing mortality (*F*) differed among species and systems. Systems incurring high fishing mortality may demonstrate reduced age groups in the catch curve analysis (i.e., residuals). Also, *F* may have been variable among different ages within catch-curve regressions, which could have influenced my residuals. Use of residuals from catch-curve regressions to assess year-class strength in fish is best suited for longer-lived fishes (Maceina 1997). This may explain the low number of significant relationships, because my sample size and statistical power were low due to relatively short-lived fish, such as bluegill and redear sunfish.

Previous studies (Schramm and Doerzbacher 1982; Hoyer et al. 1985; Maceina and Betsill 1987; Crawford et al. 1989; Schramm 1989; Hales and Belk 1992; Mantini et al.

1992; Buckmeier and Howells 2003) have validated the formulation of one annulus per year for otoliths on all sportfish that I examined, except Suwannee bass. I assumed that rings on Suwannee bass otoliths were annuli, similar to largemouth bass in the Southeast.

Although I found relations between sportfish year-class strength and hydrological variables in lakes and rivers, these correlations may not indicate a causal relationship. Spurious correlations could have resulted in my study, because a relatively large number of comparisons were made (Jackson and Somers 1991). Similar to other studies (Beam 1983; Willis 1986; Wrenn et al. 1996, Maceina and Stimpert 1998; Maceina 2003), my results indicated relations between flow/stage and fish year-class strength. Nevertheless, I caution that some of the relationships may not have been cause and effect. Future studies should quantitatively assess habitat changes with flow and stage changes to better elucidate mechanisms between system hydrology and fish recruitment.

There are many factors that can affect electrofishing catch rates including fish behavior, fish size, fish species, population density, sampling crew, water clarity, water conductivity, water level, water temperature, and weather conditions (Hardin and Connor 1992; Hilborn and Walters 1992; Reynolds 1996; Bayley and Austen 2002). Electrofishing for this project took place during two separate hydrological regimes. Electrofishing in the fall of 2001 and spring of 2002 occurred when water levels and flow rates were near extreme minimum lows (i.e., drought conditions). Conversely, samples in the fall of 2002 and spring of 2003 occurred when water levels and flow rates were near mean or above historic mean values. Electrofishing catch rates of sportfish in the first year of sampling were much higher than in the second year of sampling for the same system. As a result, more ages (i.e., year classes) were generally obtained for the catch curves in the first year of sampling. The results may be due to sampling biases because my electrofishing equipment was not able to reach deeper areas in both the lakes and rivers during the second year of sampling (i.e., reduced catchability). Conversely, under low water conditions (i.e., low stage) sportfish became more concentrated and may not have been able to avoid the electric field, hence catch rates increased (Pierce et. al 1985). Nevertheless, strong and weak year-classes were usually corroborated in the catch curves.

Substantial difficulty and disagreement was observed during the aging process of redbreast sunfish. I surmise that the input of water from natural springs in rivers coupled with a potential protracted spawning period (Davis 1972; Bass and Hitt 1974; Lukas and Orth 1993) occasionally produced false annuli (i.e., opaque bands) in redbreast sunfish otoliths. Hales and Belk (1992) encountered a similar problem with bluegill in a South Carolina cooling reservoir. However, after discussion with experienced otolith readers from the FFWCC (i.e., Steve Crawford and Eric Nagid, personal communication), the faintness and incompleteness of these false annuli distinguished them from true annuli. Therefore, I believe that redbreast sunfish were aged with adequate accuracy.

Periodic natural fluctuations of water levels and flow rates occur on a regular basis due to rainfall. Despite these fluctuations, fish assemblages persist over time (Bass 1990; Paller 1997). Aumen and Gray (1995) supported a more natural hydrologic variability because they found that sustained high water levels may cause a decline in vegetated habitats resulting in lower sportfish abundance. Fish species that persist over time may be long-lived or may produce multiple cohorts within a year (Chesson and Warner 1981). As a result, once environmental and hydrological conditions are favorable (i.e., the ideal water level or flow rate), a strong year class is produced (Warner and Chesson 1985).

Factors influencing year-class strength of sportfish can be ambiguous to fisheries biologists. Fish recruitment is a complex process that involves both density-dependent and independent factors (Everhart and Youngs 1981; Royce 1984), so I did not expect all the variation to be explained by hydrological variables. Studies have examined fish assemblage changes after the impoundment of a river (Quinn and Kwak 2003) or the institution of a minimum flow (Travnichek et al. 1995; Bowen et al. 1998), but I attempted to relate year-class strength of six recreationally important sportfish to hydrology in some of Florida's rivers and lakes. By examining the relationships of sportfish populations to hydrological influences, I related year-class strength of some sportfishes in Florida to the water levels and stream flow rates. Although it is easier from an agency perspective to manage multiple systems with the same hydrological regime, the variability in results indicate the need for system-specific management, particularly in lakes (Guy and Willis 1995; Isermann et al. 2002; Sammons et al. 2002) where I found few among-system trends. These results will possibly help natural resource managers develop effective MFLs to protect against damage to sportfish populations.

MANAGEMENT IMPLICATIONS FOR SETTING MINIMUM FLOWS AND LEVELS

Minimum Flows and Levels (MFLs) have been implemented by various methods and models including the 'Montana Method' (Tennant 1976), the 'Instream Flow Incremental Methodology' (IFIM) (Bovee 1982), the 'Physical Habitat Simulation' (PHABISM) (Milhous et al. 1989), and the 'Range Variability Approach' (RVA) (Richter et al. 1996). The 'Montana Method' simulates flow regimes based on the average daily discharge or the mean annual flow. The IFIM predicts curves based on habitat preferences at different flow levels, such that these curves are based on field sampling of fish locations with associated measurements of habitat conditions (i.e., depth, velocity). The PHABISM is an intricate component of the IFIM that analyzes habitat availability for fishes. The RVA approach uses hydrologic variability such as timing, frequency, duration, and rates of change to sustain and protect natural ecosystem functions. All models have their advantages and shortcomings, but no particular model has become the norm for identifying the correct method for setting a MFL.

The methods described above relate specific habitat changes to fish assemblages. Rather than making predictions of specific habitat changes and their influences on fish assemblages, I evaluated broad-scale relations between water level/flow and sport fish year-class strength in both lakes and rivers. My results suggest that among-system relationships are common for rivers but not for lakes. Thus, MFLs would be more likely to be regionally applicable in Florida rivers than in lakes. Although I evaluated impacts to sportfish populations, other portions of the fish assemblage (e.g., threatened or endangered fishes) were not evaluated and should be considered as part of biological criteria in setting MFLs.

Currently, MFLs are set by the appropriate Florida Water Management District and the Florida Department of Environmental Protection according to previous evaluations of topography, soils, historical ground and surface water data, and vegetation data. Thus far, biological factors have not been considered when MFLs are set. Criteria used by establishing MFLs in Florida should include biological factors that prevent ecological harm. This study provided fish recruitment data that can be used for setting MFLs. Fish recruitment is one biological factor that should be taken into account when MFLs are set because freshwater sportfishing in Florida is a one billion dollar industry in Florida (USFWS 1996). Thus, MFLs should consider impacts to sportfish populations.

Missing year classes occur naturally in fish populations due to adverse environmental conditions, but sportfish populations seem to be resilient and persist in multiple system types (Bass 1990; Bayley and Osborne 1993; Paller 1997). Despite reductions in number and abundance of species, Paller (1997) found the persistence of multiple species, including bluegill and largemouth bass, following 3.5 years of low water in a South Carolina reservoir. According to Lowe et al. (1994) and Neubauer et al. (2003), adverse environmental conditions (e.g., low flow) will not cause significant harm unless these conditions persist for more than five years. My results indicated that *Lepomis* spp. year-class strength was positively related to flow rate, and five years of low flow rates is probably too much time for these species to persist in a riverine ecosystem due to their life history. *Lepomis* spp. are short lived and mortality could eliminate species if complete year-class failure occurred for five years. Maximum age for redbreast sunfish collected in this study was age seven, but the majority of the individuals collected did not exceed age four. Conversely, life history strategies for *Micropterus* spp. include being longer lived, with a maximum age of 12 in this study. Thus, low flows for five or more years may cause weak year classes and reduced abundances of *Lepomis* spp. in rivers; potentially impacting sport fisheries. High flows at least once every three years in the fall may allow inundation of floodplain habitat, producing favorable environmental conditions for *Lepomis* spp. Setting MFLs during periods of prolonged drought (i.e., three years or more) should consider impacts to short lived species such as *Lepomis* spp. I contend that low flows for three or more consecutive years should be prevented, and thus, MFLs should consider biological impacts to short-lived fishes.

Detecting impacts of flow on year-class strength of sportfish across lakes and rivers were variable but relationships were easier to detect in rivers. For example, in rivers, redbreast sunfish year-class strength was positively related to pre-fall median flow rates, whereas largemouth bass were negatively related to spring median flow rates and positively related to winter median flow rates. Thus, setting low flows could have detrimental effects on some fishes but positive on others. Nevertheless, fish have high fecundity and have adapted to highly variable conditions, particularly in rivers, where fish tend to persist through short periods of unfavorable conditions (Bayley and Osborne 1993). Thus, extreme high or low flow/stage events occur naturally, but minimum flows and levels should be set to prevent substantial alteration of this natural variability such as three or more consecutive years of low levels in lakes and rivers.

APPENDIX A
INADEQUATE CATCH CURVES

Catch-curve linear regression equations that were not used in correlation analyses with hydrological variables. A ^ next to the species (i.e., redear sunfish ^) denotes < 50% agreement in residuals or inadequate sample size collected. Age is the number of fish ages used in each catch curve analysis. N is the total number of fish collected by electrofishing used to generate residuals and the associated r^2 and P values.

Waterbody	Species	Year	Equation	r^2	P	Ages	N
Lake Annie	Bluegill	2003	Log (% Freq) = 7.24 – 1.45*age	0.99	0.01	3	70
	Largemouth Bass	2003	Log (% Freq) = 5.20 – 0.64*age	0.95	0.01	5	270
	Redear Sunfish ^	2002	Log (% Freq) = 3.45 – 0.13*age	0.01	0.96	3	128
		2003	Log (% Freq) = 5.82 – 0.86*age	0.94	0.03	4	118
Lake Bonny	Black Crappie	2002	Log (% Freq) = 6.87 – 0.92*age	0.73	0.15	4	96
	Bluegill	2002	Log (% Freq) = 4.17 – 0.61*age	0.65	0.10	5	520
	Largemouth Bass	2002	Low Sample Size	-	-	-	-
Crooked Lake	Black Crappie ^	2002	Low Sample Size	-	-	-	-
		2003	Low Sample Size	-	-	-	-
	Bluegill	2002	Log (% Freq) = 5.83 – 0.91*age	0.97	0.00	6	428
	Largemouth Bass	2003	Log (% Freq) = 4.76 – 0.52*age	0.72	0.03	6	166
	Redear Sunfish	2002	Low Sample Size	-	-	-	-
Lake Disston	Bluegill	2003	Log (% Freq) = 4.82 – 0.52*age	0.90	0.00	7	258
	Largemouth Bass	2003	Log (% Freq) = 4.62 – 0.48*age	0.93	0.00	6	93
	Redear Sunfish	2003	Low Sample Size	-	-	-	-
Ochlockonee River	Bluegill	2002	Log (% Freq) = 7.77 – 1.66*age	0.99	0.00	3	401
	Largemouth Bass	2002	Log (% Freq) = 5.02 – 0.62*age	0.87	0.00	4	119
	Redbreast Sunfish	2002	Log (% Freq) = 7.20 – 1.52*age	0.88	0.22	3	1486
	Suwannee Bass ^	2001	Low sample size	-	-	-	-
		2002	Low sample size	-	-	-	-
Santa Fe River	Largemouth Bass	2002	Log (% Freq) = 4.38 – 0.43*age	0.57	0.14	5	115
	Redbreast Sunfish ^	2001	Log (% Freq) = 7.31 – 1.47*age	0.99	0.00	4	330
		2002	Log (% Freq) = 6.33 – 1.06*age	0.93	0.04	4	155
	Suwannee Bass	2002	Log (% Freq) = 5.16 – 0.63*age	0.93	0.01	5	213
Withlacoochee River (South)	Bluegill	2002	Log (% Freq) = 6.70 – 1.18*age	0.91	0.05	4	281
	Largemouth Bass	2002	Log (% Freq) = 5.68 –0.81*age	0.83	0.03	5	243
	Redbreast Sunfish	2003	Log (% Freq) = 4.91 – 0.53*age	0.46	0.53	3	59

APPENDIX B
AGE FREQUENCIES

Age-frequency distributions and recruitment variability index (RVI) values for each species, system, and year. An asterisk next to the year (i.e., 2001*) denotes the sample used for relation to the hydrological variables. A ^ next to the species (i.e., rbsu^) denotes < 50% agreement in residuals or inadequate sample size, therefore the sample was not used in any correlation analyses. Samples with less than 3 fish obtained of a particular age were used to index RVI values but were not included in catch-curve analyses. In addition, year-classes were removed from the catch-curves and RVI index, if they were below the assigned catchable size. Species abbreviations are as follows: bg = bluegill; blc = black crappie; lmb = largemouth bass; rbsu = redbreast sunfish; resu = redear sunfish; swb = Suwannee bass.

Water Body	Species	Year	RVI	Age												
				0	1	2	3	4	5	6	7	8	9	10	11	12
Lake Annie	bg	2002*	0.73	.	9	25	18	15	8	.	.	.	.	.	.	.
	bg	2003	0.91	.	12	54	13	3	.	.	.	.	.	.	.	.
	lmb	2002*	0.86	.	101	119	83	32	25	7	4	1	.	.	.	.
	lmb	2003	0.85	.	92	120	75	39	28	8	1	1	.	.	.	.
	resu^	2002	0.73	.	0	37	53	38	2	2	2	0	1	.	.	.
	resu	2003	0.72	.	5	56	45	12	5	2	.	.	.	.	.	.
Lake Bonny	blc	2001*	0.77	19	11	59	52	89	14	4	4	.	.	.	.	.
	blc	2002	0.75	57	29	23	48	19	27	2	1	.	.	.	.	.
	bg	2001*	0.86	763	327	130	206	113	9	5	.	.	.	.	.	.
	bg	2002	0.87	2398	369	31	64	41	15	.	.	.	.	.	.	.
	lmb	2001*	0.77	0	6	12	23	14	6	4	1	1	.	.	.	.
	lmb	2002	0.43	52	0	0	3	4	3	3	4	1	1	.	.	.
Crooked Lake	blc^	2002	0.61	.	1	3	8	10	1	1	3	0	1	.	.	.
	blc	2003	0.29	.	2	0	4	6	4	0	2	3	.	.	.	.
	bg	2002	0.70	.	48	53	35	17	13	17	5	4	0	1	.	.
	bg	2003*	0.91	.	52	240	140	23	16	6	3	1	.	.	.	
	lmb	2002*	0.82	.	86	93	114	74	19	7	7	2	.	.	.	.
	lmb	2003	0.77	.	50	31	52	46	27	7	3	1	.	.	.	.
	resu	2002	0.78	.	4	8	10	5	1	1	.	.	.	.	.	.
	resu	2003*	0.65	.	19	26	29	16	14	17	5	4	0	1	.	.
Lake Disston	bg	2002*	0.87	.	88	173	114	46	25	5	3	5	.	.	.	.
	bg	2003	0.81	.	25	68	67	59	37	17	6	4	2	1	.	.
	lmb	2002*	0.81	.	54	46	31	10	12	10	3	1	.	.	.	.
	lmb	2003	0.83	.	5	32	27	19	6	5	4	1	1	1	.	.
	resu	2002*	0.66	.	11	10	7	11	11	2	.	.	.	.	.	.
	resu	2003	0.53	.	2	6	8	5	1	6	1	.	.	.	.	.

Appendix B. Continued.

Water Body	Species	Year	RVI	Age												
				0	1	2	3	4	5	6	7	8	9	10	11	12
Ochlockonee River	bg	2001*	0.68	0	447	109	100	10	6	.	.	.	.	.	.	.
	bg	2002	0.94	167	287	325	63	16	2	.	.	.	.	.	.	.
	lmb	2001*	0.30	87	54	19	25	9	3	2	3	0	0	0	0	1
	lmb	2002	0.86	122	85	57	20	31	11	2	2	2	2	1	.	.
	rbsu	2001*	0.89	0	468	179	233	18	4	1	1	.	.	.	.	.
	rbsu	2002	0.72	456	623	1313	110	63	0	2	.	.	.	.	.	.
	swb^	2001	0.36	4	4	2	2	1	2	1	2	0	0	0	0	1
	swb	2002	0.48	9	10	6	3	3	2	3	0	0	2	.	.	.
Santa Fe River	lmb	2001*	0.88	29	53	100	31	10	22	1	1	3	.	.	.	.
	lmb	2002	0.80	84	55	40	48	7	9	11	2	.	.	.	.	.
	rbsu^	2001	0.91	0	70	249	63	15	31	1	1	.	.	.	.	.
	rbsu	2002	0.93	6	76	64	11	4	1	.	.	.	.	.	.	.
	swb	2001*	0.70	25	49	123	28	19	20	1	2	3	1	0	1	.
	swb	2002	0.85	27	61	82	75	36	11	9	1	2	.	.	.	.
Withlacoochee River (North)	lmb	2002*	0.55	108	28	11	15	5	4	7	2	1	4	0	0	1
	rbsu	2002*	0.90	205	149	369	163	68	7	6	2	.	.	.	.	.
	swb	2002*	0.33	31	18	13	17	7	0	0	2	.	.	.	.	.
Withlacoochee River (South)	bg	2002	0.88	.	67	164	74	39	4	2	.	.	.	.	.	.
	bg	2003*	0.83	.	17	66	41	14	12	3	.	.	.	.	.	.
	lmb	2002	0.88	.	104	116	69	23	32	3	1	1	1	.	.	.
	lmb	2003*	0.55	.	123	24	45	24	21	12	5	6	0	0	1	.
	rbsu	2002*	0.90	.	34	141	61	9	2	.	.	.	.	.	.	.
	rbsu	2003	0.74	.	37	20	32	7	.	.	.	.	.	.	.	.

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BIOGRAPHICAL SKETCH

Timothy Frederick Bonvechio was born October 29, 1977, in West Palm Beach, Florida, the son of Robert Bonvechio, Jr. and Constance Bonvechio. He graduated from Palm Beach Gardens Community High School in 1996. He received his Associate of Arts degree in Biology from Palm Beach Community College in May of 1998. He received his Bachelor of Science degree in Forest Resources and Conservation from the University of Florida in December of 2000. While finishing undergraduate studies, he gained part-time employment in May of 2000, as a freshwater fisheries technician under the direction of Dr. Mike Allen. The day after Tim received his Bachelor of Science degree, Dr. Allen recruited him on as a full-time technician. During his tenure as technician, he gained valuable experience in fisheries management. As a result, he began his graduate work at the University of Florida in the spring of 2002 to pursue a Master of Science degree in fisheries management. After graduation in December 2003, he plans on pursuing a career in fisheries management as a state freshwater fisheries biologist.

Upon departure, he leaves an old saying which has no author, “When God created the earth, He made it two-thirds water and one-third land, surely he meant for man to spend more time fishing than plowing.”