NEST SURVIVAL, NESTING BEHAVIOR, AND BIOENERGETICS OF REDBREAST SUNFISH ON THE TALLAPOOSA RIVER, ALABAMA

Except where reference is made to the work of others, the work described in this thesis is my own or was done in collaboration with my advisory committee. This thesis does not include proprietary or classified information.

____
Benjamin Moore Martin

Certificate of Approval:

____
J. Barry Grand
Associate Professor
Forestry and Wildlife Sciences

____
Elise R. Irwin, Chair
Associate Professor
Fisheries and Allied Aquacultures

____
Russell Wright
Associate Professor
Fisheries and Allied Aquacultures

____
George T. Flowers
Dean
Graduate School

NEST SURVIVAL, NESTING BEHAVIOR, AND BIOENERGETICS OF REDBREAST SUNFISH ON THE TALLAPOOSA RIVER, ALABAMA

Benjamin Moore Martin

A Thesis

Submitted to

the Graduated Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Masters of Science

Auburn, Alabama
December 19, 2008

NEST SURVIVAL, NESTING BEHAVIOR, AND BIOENERGETICS OF

REDBREAST SUNFISH ON THE TALLAPOOSA RIVER, ALABAMA

Benjamin Moore Martin

____
Signature of Author

____
Date of Graduation

VITA

Benjamin Moore Martin, son of Donald Peter and Lisa Betts (Redell) Martin, was born on August 1, 1983 in Montgomery, Alabama. He attended Oneonta High School and graduate in 2001. He received a Bachelor of Science degree in August, 2005 from Auburn University in Fisheries Management. He worked as a Field/Laboratory technician for professors within the Department of Fisheries and Allied Aquacultures after gradation. A Graduate Research Assistant position was offered from the Alabama Cooperative Fish & Wildlife Research Unit under the supervision of Dr. Elise Irwin. He accepted the position and entered Graduate School at Auburn University in January 2006.

THESIS ABSTRACT

NEST SURVIVAL, NESTING BEHAVIOR, AND BIOENERGETICS OF REDBREAST SUNFISH ON THE TALLAPOOSA RIVER, ALABAMA

Benjamin Moore Martin

Masters of Science, December 19, 2008
(B.S., Auburn University, 2005)

91 Typed Pages

Directed by Elise R. Irwin

Adaptive management has been implemented in the Tallapoosa River, Alabama; one objective of the process is to determine how discharge and temperature affect redbreast sunfish reproductive success. Nesting male redbreast sunfish *Lepomis auritus* were monitored via snorkeling and video during 2006 and 2007 to estimate nest survival and quantify nesting behavior in a regulated reach of the Tallapoosa River (Alabama) below R.L. Harris Dam. In addition, males were collected during 2007 to determine if metabolic constraints were evident when caloric contents and bioenergetic models from the regulated Tallapoosa River and an unregulated tributary were compared.

A priori hypotheses were constructed relative to how biological and environmental factors might affect nest survival. Nest survival estimates were determined in Program MARK and competing environmental and biological models were evaluated using Akaike's information criterion (AIC). These data allowed for assessment of the functional response of daily survival rate of nests in relation to discharge. One year in

the study was an extreme drought year (2007) allowing for nest survival estimates during an atypical water management year. Findings from this study support use of spawning windows (e.g., low flow releases from dam) to increase reproductive success for redbreast sunfish. Spawning window timing could be as early as mid-May, which is earlier than previously suggested. Spawning flows provided earlier in the year could enhance reproductive success for other fish species.

Video of nesting behavior indicated that male redbreast sunfish primarily exhibited the *defend* and *leave* behavior during 'baseflow' (e.g., low flow conditions) observations. During higher discharge events (i.e., one-unit or turbine; ~ 200cms) spawning behaviors (e.g., *milt* and *court*) ceased and the *defend* behavior decreased; whereas, the *leave* and the *clean* behaviors increased. Behavior observations indicated that increased flow caused disruption of spawning and nest abandonment. Behavior during two-unit discharge events was only minimally observed because of drought conditions; however, data did indicate detrimental effects of two-unit discharge on nests (i.e., destruction).

Bioenergetic modeling predicted decreased growth, and weight for males during the spawning season at both the regulated and unregulated sites. At the unregulated site consumption rates increased as temperature increased; when the thermal maximum was reached (33°C), consumption decreased precipitously. In contrast, consumption rates at the regulated site were always positively related to temperature and did not decline when the thermal maxima was reached (28°C) suggesting that thermal mitigation occurred from hypolimnetic releases from the dam. Reducing uncertainty regarding how biota respond to management actions is a goal of adaptive management and results from this study are applicable to flow management and its subsequent effects on nesting centrarchids.

ACKNOWLEDGEMENTS

First and foremost the author thanks his parents Don and Lisa Martin for support throughout his education. Also, thanks to Dr. Irwin for guidance, friendship and the opportunity to be a part of Alabama Cooperative Fish and Wildlife Research Unit. Dr. Grand and Dr. Wright are also thanked for there help and expertise. Also, thanks are due to all members of the research unit for assistance in field and laboratory work. Special thanks are extended to his wife Molly for her continued support and friendship.

Style manual or journal used - North American Journal of Fisheries Management

Computer software used - Microsoft Word 2003, Microsoft Excel 2003, Sigma Plot 7.0, Program MARK, BEAST v2.01, SAS v9.1, Fish Bioenergetics 3.0, Nikon NIS-Elements

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The Tallapoosa River below R.L. Harris Dam (Randolph County, Alabama) is a regulated river currently subject to adaptive management (Irwin and Freeman 2002; www.rivermanagement.org). Adaptive management (Walters 1987) is the evaluation of system response to management with emphasis on reduction of uncertainty. In this system, manipulations of water releases at the dam have been implemented for various management objectives. One primary objective is to gain knowledge and reduce uncertainty related to effects of flows on native biota (Irwin and Freeman 2002). Irwin and Freeman (2002) hypothesized that increased base flow, decreased flow fluctuation, provision of "spawning windows", and mitigation for cold thermal releases would be beneficial to many fish species, including nesting centrarchids.

Manipulations of discharge regimes below hydroelectric dams may alleviate negative effects on reproduction and recruitment of fishes (Irwin et al. 1997; Freeman et al. 2001; Andress 2002; Irwin and Freeman 2002). Flow management could be implemented to provide periods of stable flow without significant generation events to allow time for spawning and larval development (Andress 2002; Irwin and Freeman 2002). Providing spawning windows would potentially allow for increased nest survival and ultimately may increase recruitment. Andress (2002) proposed a 10-11 day spawning window in mid-June for the regulated portion of Tallapoosa River to enhance redbreast sunfish *Lepomis auritus* nest survival; however, this management has been minimally evaluated.

Andress (2002) conducted research on nesting redbreast sunfish at regulated sites in the Tallapoosa and Coosa rivers and an unregulated site in the Tallapoosa River, and determined that nest success was negatively related to discharge and affected by thermal regime; however, his research was not conclusive regarding specific causal factors affecting nest success. In addition, Andress (2002) noted behavioral differences in nesting males inhabiting regulated versus unregulated sites, but these differences were not quantified. In support of objectives outlined for adaptive management of flow regimes below R.L. Harris Dam, quantification of effects of discharge on redbreast sunfish spawning success, reproductive behaviors, and bioenergetics could provide valuable data for reducing uncertainty regarding effects of management.

Redbreast sunfish - a model for nesting centrarchids in regulated systems.

The redbreast sunfish is an example of a nesting centrarchid that may be affected by generation of hydroelectric power and subsequent effects of river regulation on flow regimes (Lukas and Orth 1993). Redbreast sunfish are geographically widespread (throughout the east coast from Maine to Florida and along the Gulf of Mexico to Texas), and males build conspicuous nesting colonies in marginal habitats of streams and rivers (Lukas and Orth 1993). Building nests for egg development is a reproductive strategy of centrarchids that requires an increase in energy demand (Helfman et al. 1997). Nests are needed to attract females and for protection of eggs and larvae throughout development to larval swim-up and dispersion. Nests of redbreast sunfish are built by males in shallow water, are typically bowl shaped ranging in sizes from 0.25 - 1.0 m in diameter, and contain uniform gravel size (Andress 2002; Boschung and Mayden 2004). Andress (2002) reported that nests were often located near logs, stumps, or boulders near the margins of the Tallapoosa River. Given these characters, redbreast sunfish provide a model species for evaluation of effects of flow manipulations on nest success, nesting behavior, and bioenergetics.

Nesting survival

Effects of discharge on spawning success of redbreast sunfish below R.L. Harris dam was previously examined over two spawning seasons (1999 and 2000) at a regulated site in the Tallapoosa River, near Wadley, Alabama (Andress 2002). Discharge disturbances include rapidly rising water levels, increased flow rate, and temperature fluctuation due to hypolimnetic release (Andress 2002; Cushman 1985). Successful spawning of fishes is a management objective in the regulated Tallapoosa River. Nesting success of redbreast sunfish is a metric that can be measured and related to environmental variation due to flow regime.

Nesting behavior

Redbreast sunfish reproduction has been observed in previous studies (Lukas and Orth 1993; Andress 2002); however, specific attempts to quantify reproductive behavior have not been conducted. Cooke and Bunt (2004) indicated that underwater videography was an effective way to record visual observations of fish, and it can serve as a functional tool for obtaining information necessary in management decisions. Using underwater cameras, unobtrusive observations can be made to draw inference regarding reproductive biology, bioenergetics, and habitat use (Cooke and Bunt 2004). Recording behavioral responses to discharge events with underwater video cameras may help identify changes in reproductive behavior and allow quantification of behavioral patterns (Hinch and Collins 1991). In addition, behavioral variation can be determined in relation to changing flows and temperature fluctuations from hydropeaking, pulse power generation events, (Cooke and Schreer 2000) and may ultimately be related to nest success. Reproductive behavior such as nest guarding (i.e., chase and departure) have been recorded on video for other centrarchids (smallmouth bass *Micropterus dolomieu*; Steinhart et al. 2004), but other aspects of reproductive behavior are less well known (i.e., nest tending, and spawning). Videography could serve as a valuable method for monitoring potential effects of discharge on redbreast sunfish spawning behavior.

Bioenergetics

Quantifying variation in energy budgets of redbreast sunfish related to varying discharge and thermal regimes in rivers has not been attempted. Obtaining male redbreast sunfish for bioenergetic analysis could provide estimates of parental costs (Steinhart et al. 2004) related to spawning activity (i.e., nest building, nest maintenance, and courting) and environmental variation. Parental care is known to increase offspring survival, but may be a costly investment (Tolonen and Korpimaki 1996; Williams 1966). Forage consumption is likely reduced during parental care which can affect survival (parent and offspring) and future reproduction (Hinch and Collins 1991; Steinhart et al 2004). Because males rarely forage during parental care, activity costs of male redbreast sunfish during parental care could potentially be measured. Energy reserves are likely further compromised during discharge events by increasing nest maintenance and forcing increased swimming to maintain position over nests. Furthermore, discharge events could interrupt reproduction. Because discharge and temperature fluctuations could impact energy budgets, comparisons between nesting redbreast sunfish from the regulated portion of the Tallapoosa River and the unregulated portions of the basin should be conducted. Adaptive management of flows on the Tallapoosa River requires continued monitoring of biotic responses to flow management. Monitoring nest success, reproductive behaviors, and estimating bioenergetics of redbreast sunfish during spawning will provide vital information for reducing the uncertainty of response to flow regulation on the Tallapoosa River.

Hypotheses

In regards to nest survival, I hypothesize that environmental characteristics including discharge and temperature will have impacts on nest success. In particular I predict that daily maximum discharge will have a direct negative effect on daily survival rate (DSR) because maximum discharge could potentially destroy nests. I also predict that daily delta temperature (daily max – daily min temperature) will have an indirect negative effect on DSR because rapid drops in temperature could lead to male abandonment. Daily survival rate is predicted to decrease during the course of the spawning season (linear time trend) because males that spawn early are predicted to have greater success. As nest age increases I expect DSR to decrease because older nests will be susceptible to predation. Lastly, I will explore an idea that was proposed by Andress (2002) where later stages of development will have decreased survival rates. I expect Egg/YSF (early stage) will have greater survival rate than PUF/SUF (late stage) survival because later developmental stages will be subject to displacement during high flows.

Behavior of nesting males is expected to change in response to increased discharge. Specifically, spawning behaviors are expected to cease and behaviors related to increased nest maintenance and abandonment are expected to rise. Caloric contents for pre-spawn male redbreast sunfish from the regulated Tallapoosa River are expected to exhibit higher energy densities compared to those from unregulated sites in the basin because males will increase energetic content before spawning in anticipation of disturbance from Harris Dam; whereas post-spawn males from the Tallapoosa will have lower energy densities because an increase in parental care/energy expenditure will be required due to variable discharge and thermal regime.

Objectives

The overall goal of this project was to reduce uncertainty regarding how flow manipulation affects nesting centrarchids by monitoring redbreast sunfish during their spawning season in an adaptive management framework. Specific objectives were to: 1) Determine functional responses of nest survival to discharge and temperature; 2) determine functional spawning window timing and duration; 3) quantify nesting behaviors related to discharge; 4) and use bioenergetic models to examine differences in spawning male redbreast sunfish from the Tallapoosa River basin.

METHODS

Study Area

Two study areas were surveyed from the Tallapoosa River system, Alabama; the regulated study area was located near Wadley (Randolph County; 33º07'26.14"N, 085°33'33.15"W; Figure 1), 23 km below R.L. Harris Dam (hereafter Harris Dam) and unregulated sites were located on Saugahatchee Creek near the town of Notasulga, Lee County, Alabama (32°35'02.74"N, 085°40'33.43"W and 32°36'53.64"N, 085°43'36.74"W; Figure 2). The regulated reach was approximately 1 km in length and bounded by two shoals having characteristic mixed, coarse piedmont substrates. Harris Dam produces, pulse power generation used to meet peak demand of electricity; therefore, unnatural hydrologic and thermal regimes exist below the dam (Irwin and Freeman 2002) potentially affecting nest survival, nesting behavior and energetics of stream fishes. Saugahatchee Creek (unregulated) lies near the fall line and exhibits both piedmont and coastal plain characteristics. This site served as a "control" for portions of the research (bioenergetics modeling) because thermal regime was driven by environmental fluctuations rather than by hydroelectric generation. Approximately 3.5 km of this large tributary to the Tallapoosa River were surveyed.

Nest Survival

Environmental variables

Discharge data were collected from USGS gage 02414500 (Wadley) and used in nest survival analysis. Discharge (m^3/s) and temperature (°C) summary graphs for each spawning season were used to display yearly differences. Also, simple linear regression and simple correlations were performed on daily maximum discharge and daily delta temperature for each year to determine effects of power generation on temperature. Four water temperature loggers (HOBO Water Temp Pro v2; Onset Computer Corporation) were deployed on bank margins near nesting colonies to record temperature (°C) during each spawning season for use in degree-day calculations and nest survival analysis. Each was fixed with cable ties in a 250 mm PVC pipe (30 mm diameter) and attached to the substrate with eyebolts.

Nest observations

To determine nest survival for redbreast sunfish, nests were surveyed via snorkeling from May 26 through August 25, 2006 and May 4 through June 21, 2007. After nests were located, each was marked with a 76 x 76 mm brightly colored, numbered wooden disc fixed to the substrate with 75 mm wood screws (Figure 3).

Nests were observed every other day, when possible, and developmental stage was recorded [i.e., eggs, yolk-sac fry (YSF), pop-up fry (PUF), or swim-up fry (SUF); sensu; Andress 2002]. Nests were considered successful when development stage reached SUF. Total number of nest attempts was reported and successful attempts were expressed as a percentage of total attempts (nest success). Attempts with undetermined fate were not used in determination of nest success. Degree-days for each 24-hour period were used to calculate the heat energy necessary for eggs to develop to SUF for 2006 and 2007 using the following equation:

Equation 1. *Degree-days = [(maximum daily temperature + minimum daily temperature)/2)] – lower threshold temperature.*

Lower threshold temperature used was 17°C, the lower limit for bluegill egg development (Nakamura et al. 1971). Equation 1 allowed calculation of the number of degree-days for each 24-hour period and developmental time requirements (cumulative degree-days) of successful redbreast sunfish nests. Spawning window length was estimated by dividing mean cumulative degree-days for development by mean number of degree-days per day for each spawning season. Estimated timing of spawning window was then determined by observing peak swim-up dates from each season. Peak swim-up dates corresponded to days when numbers of successful nests were highest.

Nest survival

Nest histories were created from observations of individual nests during both spawning seasons (2006 and 2007) and input in Program MARK (White and Burnham 1997) to model daily survival of redbreast sunfish nests. Estimated survival rates from MARK are based on maximum likelihood theory and allow individual covariates to be incorporated with the use of the logit link or other link functions. For this study the logit link function was used. If several spawning attempts were observed on individual nests then each attempt was treated separately in nest survival analysis. Nesting histories consisted of six numeric values for each nest attempt as such:

/*1*/ 1 57 57 0 1;

The first number identified the nest, the second value was the day the nest was found, the third value was the last active day, the fourth was last day checked, the fifth was nest fate (0 = successful, 1 = failed), and the sixth value was number of identical nesting histories. Program MARK also allowed individual covariates to be entered after these values.

Daily discharge (m^3/s) variables and daily temperature (°C) variables were modeled as covariates to nest survival including: daily maximum discharge, daily minimum discharge, daily maximum temperature, daily minimum temperature, and daily delta temperature (daily max – daily min). In addition, nest age effect (Cooch and White 2005), nest stage effect, and a linear time trend effect were used as covariates. Nest age was simply the age of the nest when found (days), nest stage was determined by splitting nest age into two categories: nests less than or equal to 6 days old were considered to be Eggs/YSF (early stage) and those greater than 6 days old were PUF/SUF (late stage). Four potential models of nest stage were considered where the early stage or late stage could be modeled to follow a constant DSR or follow a time trend. Finally, the effect of linear time trend of DSR across the spawning season was modeled (Dinsmore et al. 2002).

Akaike Information Criterion (AIC) corrected for small sample size (AIC_c) was used to score competing models (Burnham and Anderson 2002). A hierarchical approach was used to determine top models explaining variation in daily survival. Two model sets were developed to separate environmental covariates (discharge and temperature) and biological covariates (nest age, nest stage, and linear time trend). The effect of the top model ($AIC_c \leq 3$) from the environmental model sets was graphically represented. Combination of the two model sets (top models only: $AIC_c \leq 3$) were used to build a final model set for each year. In the final model sets, a general rule of ΔAIC_c values < 2

(Burnham and Anderson 2002) was used to determine best model(s) for inference. Logistic regression equations were reported for each year's best model.

Nesting Behavior

Video recordings of nesting behavior were acquired during 2006 and 2007 for three experimental flows defined by release type from Harris Dam; base flow, one-unit or two-unit generations (Table 1). Nesting behavior was observed using ten waterproof video cameras (Sea-View® super mini B/W) for the 2006 and 2007 spawning season and variable cable length (50-200 ft) on cameras allowed nests to be observed by varying distance to a digital video recorder (DVR; CCTV Factory). Cameras were secured directly adjacent to nests with fabricated aluminum stands pointed toward the nest center at approximately a 45° angle. Camera cables were anchored to the substrate with plastic tent stakes so that they did not interfere with surrounding nests. Power was supplied to the cameras from a large deep-cycle battery by way of a 12-volt adapter with a ten-way splitter. A Black & Decker® 400 watt inverter attached to a separate large deep cycle battery supplied power to the DVR and television. All equipment and operators were secured near the shoreline on a 4.9 m jon boat anchored from the bow and stern (Figure 4). Once cameras were placed each feed was viewed on a television monitor to ensure proper field of view. After all cameras were set, a 15 minute acclimation period ensued before recording. Recordings were stored on the DVR internal hard drive automatically and allowed for simultaneous recordings. At the end of an experiment recording stopped and equipment was removed. When equipment was returned to the laboratory, recordings were converted to DVD for backup and analysis. A software program, BEAST™ (G. Losey, University of Hawaii), was used to analyze the data and allowed for real time video analysis of self defined behaviors: *defend*, *leave*, *clean*, *egg-stir*, *court*, and *milt*.

Behaviors during two of the experimental flows were analyzed: base flow and one-unit generation flow (Table 1). To define differences in the flow types base flow was defined as video recorded when discharge was <12 m^3/s; generation flow data were defined as video recorded for at least 14 min prior to a one-unit generation flow event reaching the study site and discharge >14 m^3/s. Use of hydrologic data from the USGS gage at Wadley allowed differentiation of the two flow types for behavioral analysis. Fourteen minute video segments (i.e., subsamples) were selected randomly from field recorded video for base flow. Ten subsamples were selected for behavioral analysis of each day of recorded video. Each of the behaviors was assigned a toggle key on a computer keyboard which allowed start and stop of each behavior observation. These data were analyzed by BEAST and frequencies of behaviors (durations and counts) were calculated. Proportions of the behavior were determined by further dividing fourteen minute video subsamples into one minute intervals. Observation of specific behaviors during one-unit generation events were not possible because of water clarity changes that occur during generation; therefore, analysis of behavior observed fourteen minutes prior and leading up to one-unit generation events was used. For these observations discharge could be included with behaviors because all recordings were from the same time. Because of drought conditions only one experimental two-unit generation was filmed (June 17, 2007) and was not included in behavior analysis because only two active nests existed during the experiment.

Bioenergetics

Collection and laboratory procedures

Male redbreast sunfish were collected for bioenergetic analysis from the Tallapoosa River at Wadley and Saugahatchee Creek (see Figure 1 and 2) at the beginning (Wadley: April 27, 2007 – May 17, 2007; Saugahatchee: May 10, 2007 – May 29, 2007) and end (Wadley: June 28, 2007; Saugahatchee: July 26, 2007) of the spawning season. Angling, backpack electrofishing (Model 12-A; Smith Root®, Inc., Vancouver, Washington), and boat electrofishing (Honda 2.5 GPP; Type VI-A Electrofisher; Smith Root®, Inc., Vancouver, Washington) were used for collection. Whole fish were euthanized in MS-222 (Tricaine Methane Sulphate), placed on ice, returned the laboratory, and subsequently frozen.

Samples were thawed, and their wet weight (WW; nearest 0.01 g) and total length (TL; nearest 1 mm) recorded. Stomach contents were removed and preserved in 95% EtOH for later weight characterization and identification. Testes and the remaining body (hereafter referred to as body) were separated and oven-dried at 70°C until a constant weight (±0.01 g) was achieved for two consecutive days, and then final dry weight was recorded. Dried samples were blended to a homogenous mixture and then re-dried. At least two 0.1 g to 0.2 g pellets were formed and ignited in a semi-micro bomb calorimeter (Parr Instrument Co., Model 1425) to measure caloric content (cal/g). Additional pellets were analyzed until a difference between two caloric densities were less than or equal to two percent. Caloric values for all pellets were averaged to estimate caloric density ($cal \cdot g^{-1}$ dry weight) of the sample. The energetic density per WW of the sample was determined by multiplying the caloric density by the proportion of final dry weight to original WW for each body and testes. Bomb calibration was performed at 100-run intervals using a benzoic acid standard.

Caloric content analysis

Length-weight regressions were constructed and reported for males collected from Wadley and Saugahatchee Creek. Energy densities (J/g WW) of body and testes were compared using SAS v9.1 (SAS Institute Inc. Cary, NC) for pre and post-spawn males from both Wadley and Saugahatchee Creek using one-way ANOVA and Student's t-test ($\alpha = 0.10$). Residuals of WW, body caloric density, and testes caloric density for both pre- and post-spawn males were calculated, because energetic density can be influenced by fish size (Mackereth et al. 1999). Residuals were calculated from pooled samples of pre- and post-spawn males from each site. Observed values of WW and caloric densities were subtracting from predicted values from each WW, testes caloric density, and body caloric density from regressions of each against TL (Steinhart and Wurtsbaugh 2003; Sutton et al. 2000). Residuals of WW, body caloric density, and testes energy density were then regressed against TL for both pre and post-spawn males from both sites to test the effect of TL ($\alpha = 0.05$) on each variable.

Diet analysis

Analysis of diets was performed by reconstructing prey weights using literature regression equations that are based on total lengths and head widths of insects. Diet items were identified to Order or Family using a WILD dissecting microscope (Model M3C; Heerbrugg, Switzerland). Head capsule and/or total length (mm) of diet items were recorded using a Nikon Digital Sight (Model DS-Fi1) with Nikon NIS-Elements D 2.30 software. Wet weight and energy densities were calculated using regressions obtained from aquatic and terrestrial invertebrate literature. Estimated weights (mg) for aquatic invertebrates incorporated a power function equation of head width or body length (mm):

Equation 2. $$DW = aL^b$$

where DW is dry weight (mg), L is head width or body length (mm), and *a* and *b* are constants (Benke et al. 1999). Dry weights were converted to wet weight by using a general coefficient for invertebrates: 1 g dry weight = 6 g wet weight (Waters 1977). For terrestrial invertebrates predicted weights (g) incorporated the following equation:

Equation 3. $$\log_{10}WW = a + bL + b^1L^2$$

where WW is wet weight (g), L is body length (mm), and *a* and *b* are constants (Sage 1982). When diet items had no measureable parts, but Order or Family was known an average value of head width or body length of like taxa was assigned. Also, diet items with no measurable parts were given a count of one. Carapace length was used for decapods (crayfish) rather then total length and either shell length or shell width was used for gastropods and bivalves. Gastropods and bivalves within diets were not identified to family so the constants *a* and *b* within the Benke et al. (1999) paper were averaged to obtain values used in their DW determination.

Biomass of each taxa found in diets for the two sites and biomass of both pre- and post-spawn males was reported. Further analysis included splitting diet items into three categories: aquatic, terrestrial, and decapoda. Decapods were separated from the aquatic category to avoid bias in its biomass estimate. Both proportions of diets in terms of biomass and counts of the categories were calculated. Results from diet biomass and diet counts were contrasted between both sites for pre- and post-spawn males.

Bioenergetic modeling

Bioenergetic simulations for Wadley and Saugahatchee males were performed with Fish Bioenergetics 3.0 (Hanson et al. 1997) to estimate male redbreast sunfish specific growth rate (J/g/d) and specific consumption rate (J/g/d) across the spawning seasons. Male WW (g), caloric densities (J/g), water temperature (°C), prey proportions, and prey energy densities for pre- and post-spawn males from each site were used in simulations. Prey energy density that were used for simulations for aquatic invertebrates (3674 J/g), crayfish (3476 J/g), and terrestrial invertebrates (3719 J/g) were obtain from literature values (Irwin, B.J. Masters Thesis; Cummins and Wuycheck 1971). Water temperature values for Saugahatchee Creek were obtained from the Water Resource Management Department of Auburn, Alabama; whereas water temperatures for Wadley were taken from data loggers near nest colonies used in nest survival analysis. Base metabolic consumption, respiration, and egestion/excretion parameters for adult bluegill (Kitchell et al. 1974) were used for both sites during simulations. After simulations of base metabolic parameters and user input parameters were completed, specific growth rates (J/g/d), specific consumption rates (J/g/d), and weight (g), were compared between sites with respect to temperature.

RESULTS

Nest Survival

Environmental variables

Discharge and temperature regimes during the 2006 and 2007 study periods varied (Figures 5 and 6). During the 2006 spawning season a total of 34 one-unit generations and a single two-unit generation occurred; whereas, in 2007 two one-unit generations and a single two-unit generation occurred. In 2006, mean daily maximum discharge during the spawning season was 101.9 m^3/s; whereas, mean daily minimum discharge was 4.0 m^3/s with a range of 2.1 – 9.2 m^3/s (Table 2). Mean daily maximum temperature was 28.6°C, mean daily minimum temperature was 23.3 °C, and mean daily delta temperature was 5.4 °C (Table 2). Daily maximum discharge was correlated with daily delta temperature ($r = 0.55$), and simple regression indicated a significant relation ($r^2 = 0.31$, p = <0.001; Table 2) in 2006.

In 2007, mean daily maximum discharge was 31.2 m^3/s with a range of 281.9 m^3/s and mean daily minimum discharge was 3.2 m^3/s (Table 2). Mean daily maximum temperature was 25.7°C, mean daily minimum temperature was 21.6°C, and mean daily delta temperature was 4.2 °C (Table 2). Daily maximum discharge and daily delta temperature were highly correlated ($r = 0.75$), and simple linear regression indicated a significant relation ($r^2 = 0.56$, p = <0.001; Table 2) in 2007.

Nest observations

In 2006, a total of 409 nest attempts were observed in 151 redbreast sunfish where 183 attempts were successful (Table 3). In 2007, about half the number of nests and a quarter of nest attempts were observed in comparison to 2006 (Table 3). However, nest success was about equal in both years; 51% and 53% in 2006 and 2007, respectively. Mean cumulative degree-days (± SE) required for development from egg to SUF was greater in 2006 (67.1 ± 3.27) compared to 2007 (62.6 ± 3.90). Similarly, mean degree-days per 24-hour period (± SE) were greater for 2006 (8.9 ± 0.17) than 2007 (6.7 ± 0.31; Table 3). Peak swim-up dates for 2006 were observed during early to mid-June and during mid-May and early-June in 2007 (Table 3, Figure 7 and Figure 8).

Nest survival

In 2006, the environmental model set included six competing models (Table 4). The top model ($\Delta AIC_c \leq 3$) consisted of the single covariate, the effect of daily minimum discharge on DSR, and was included in the final model set. This model suggested that the odds of surviving increased by a factor of 0.33 (SE = 0.06; Table 5) as daily minimum discharge increased (Table 5). When minimum daily discharge (m^3/s) increased from the minimum observed to the maximum observed, daily survival rate increased by 14% (Figure 9). The 2006 biological model set included twelve competing models (Table 6). Three top models ($\Delta AIC_c \leq 3$) were included in the final model set. The top model was additive with the effect of nest age on DSR and the effect of DSR following a linear time trend across the spawning season. The second model was additive with the effect of early stage (Egg/YSF) held at a constant DSR, effect of late stage (PUF/SUF) allowed to follow a time trend in DSR, and the effect of DSR following a linear time trend across the spawning season. The third model was the additive effect of both early and late stage following a time trend in DSR, and the effect of DSR following a linear time trend across the spawning season.

The final model set for 2006 consisted of seven competing models (Table 7). Two models had $\Delta AIC_c \leq 2$; the best model included the additive effect of daily minimum discharge on DSR, nest age on DSR, and DSR following a linear time trend across the spawning season. The effect of daily minimum discharge in this model improved model fit by 1.83 ΔAIC_c units from the second model which was the additive effect of nest age and the effect of DSR following a linear time trend across the spawning season. Evidence ratio (w_i/w_j) for the best model was 2.5. The logistic regression equation for the best model was:

Equation 4. $$\text{logit}(S_i) = 1.184 + 0.205*(\text{daily minimum discharge}) + 0.123*(\text{nest age}) - 0.011*(\text{linear time trend})$$

Equation 4 suggests that as daily minimum discharge increased, the odds of survival increased by a factor of 0.205 (SE = 0.109) for each increase of 1 m^3/s. Likewise, as nest age increased the odds of survival increased by a factor of 0.123 (SE = 0.033) each day. However, across the nesting season the odds of nest survival decreased by a factor of 0.011 (SE = 0.006) each day. Thus, DSR was lower and decreased more rapidly through the nesting season for young nests when daily minimum discharge was low; however, nest age and date had relatively little effect on DSR at higher rates of discharge (Figure 10).

For 2007, the environmental model had six competing models (Table 8); the top model ($\Delta AIC_c \leq 3$) had a single covariate, the effect of daily maximum discharge on

DSR, and was included in the final model set. The odds of surviving decreased by a factor of 0.01 (SE = 0.002) as daily maximum discharge increased (Table 9). When maximum daily discharge (m^3/s) increased from the minimum observed to the maximum observed, daily survival rate decreased by 61% (Figure 11). The 2007 biological model set (Table 10) consisted of 12 competing models with five top models ($\Delta AIC_c \leq 3$). The first model was a single parameter model supporting the effect of nest age on DSR. The second top model was additive with effect of nest age on DSR and DSR following a linear time trend across the spawning season. The third top model was the additive effect of DSR following a time trend during the early stage, and the effect of DSR held constant during the late stage. The fourth top model was additive with both stage covariates held at a constant DSR. The final top model was additive with effect of DSR following a time trend during the early stage, effect of a DSR held constant during the late stage, and DSR following a linear time trend across the spawning season.

In 2007 the final model set was comprised of 12 competing models (Table 11). Two models with $\Delta AIC_c \leq 2$ were present. The best model explaining variation in daily nest survival was the additive effects of daily maximum discharge on DSR, nest age on DSR, and DSR following a linear time trend across the spawning season. The second model was similar, but did not have the additive effect of DSR following a linear time trend across the spawning season. The inclusion of the linear time trend in the top model increased ΔAIC_c by 0.29 units. An evidence ratio of the best model and second model was 1.14. The logistic regression equation for the best model was:

Equation 5. $$\text{logit}(S_i) = 2.114 - 0.012*(\text{daily maximum discharge}) + 0.197*(\text{nest age}) - 0.020*(\text{linear time trend})$$

Equation 5 suggests that as daily maximum discharge increased, the odds of survival decreased by a factor of 0.012 (SE = 0.003) for each increase of 1 m^3/s. However, as nest age increased the odds of survival increased by a factor of 0.197 (SE = 0.051) each day. Across the nesting season the odds of nest survival decreased by a factor of 0.02 (SE = 0.013) each day. Thus, DSR was much lower for young nests when daily maximum discharge was high; however, nest age and date had relatively minute effect on DSR at lower rates of discharge (Figure 12).

Nesting Behavior

The majority of behavioral data were collected during base flow conditions (Figure 13). Six behaviors were observed and proportion of time spent exhibiting behavior was quantified during one-minute video segments (Figure 13). During base flow conditions the primary behaviors were *defend* (average time spent = 36%) or *leave* (average time spent = 46%; Figure 13). No trends were apparent, but when either of these behaviors were depressed the other behaviors becomes proportionally greater. Both the *egg-stir* and *court* behaviors were the next most frequent and averaged up to almost 20% of their activity per minute interval. The *clean* and *milt* behavior were less common in relation to other behaviors each averaging about 5% per minute interval.

Behaviors recorded leading up to one-unit flow were different in comparison to base flow conditions (Figure 14). Within the first two minutes of a one-unit generation event, both *defend* and *leave* behaviors decreased (15% and 10% respectively) and the clean behavior increased to 20%. After the initial increase in discharge, the *leave* behavior became much more frequent; a 24% increase in the proportion of this behavior was observed between the fourth and fifth minute interval. After the fifth minute interval, the *defend* behavior steadily declined and the *clean* behavior became more prevalent. The spawning behaviors of *court* and *milt* were never observed during one-unit observations.

Bioenergetics

A total of 22 pre-spawn males and 18 post-spawn males were collected from Wadley. Pre-spawn males had a mean total length of 183 mm and mean wet weight of 124 g; whereas, post-spawn males averaged 171 mm TL and 102 g. At Saugahatchee Creek a total of 20 pre-spawn males and 21 post-spawn males were collected. Mean total length for pre-spawn males was 155 mm and mean wet weight was 66 g; whereas post-spawn averaged 151 mm TL and 59 g. Male length:weight regressions for both sites were best fit with a power function (Figure 15 and 16) and both regressions indicated a strong relation (Wadley $r^2 = 0.986$; Saugahatchee $r^2 = 0.976$).

Caloric content analysis

Mean body energy density (J/g) was higher at Wadley for both pre- and post-spawn males, but mean testes energy density (J/g) for pre-spawn males from Wadley was lower (Table 12). Body and testes energy densities (J/g) were not different between pre- and post-spawn males at Wadley ($p > 0.10$). Saugahatchee males showed no significant differences between pre- and post-spawn body energy densities ($p > 0.10$), but significant differences were detected for testes energy densities ($F_{1,39}= -1.81$, $p = 0.08$). Body energy densities between pre-spawn males for both sites showed no significant differences ($p > 0.10$), but significant differences were observed for post-spawn males ($F_{1,37}= 10.22$, $p = 0.003$; $t = -3.20$, $p = 0.003$). Testes energy densities differences were detected between pre-spawn males from both sites ($F_{1,35}= 3.97$, $p = 0.05$; $t = 2.09$, $p = 0.05$) but not between post-spawn males ($p > 0.10$). Regression of residuals of WW and energy densities (body and testes) against TL for both pre- and post-spawn males showed no significant relations at either of the sites (Figures 17 and Figure 18).

Diet analysis

Diets of redbreast sunfish males consisted of invertebrates. A total of 19 insect orders were identified in diets of males collected from Wadley; 17 orders were identified in diets from fish collected in Saugahatchee Creek (Table 13). At the Wadley site, total diet biomass was 60.3 g; pre-spawn diet biomass was 42.6 g (N=22, 2 empty), and post-spawn diet biomass was 17.7 g (N=18, 2 empty). Total diet biomass from fish collected in Saugahatchee Creek was 24.2 g; pre-spawn diet biomass was 7.2 g (N=20, 4 empty), and post-spawn diet biomass was 17.0 g (N=21, 7 empty). Diet biomass of pre-spawn redbreast sunfish males from Wadley was proportionally greater in decapods (62%) followed by aquatic macroinvertebrates (32%) and terrestrial invertebrates (6%) respectively; whereas diet biomass for post-spawn was spread evenly across the three diet types (Figure 19). In contrast, when looking at post-spawn diet counts for Wadley (Figure 20) decapods proportionally were the least important (2%) and aquatic macroinvertebrates were the dominant prey (87%) followed by terrestrial invertebrates (11%). Decapods were not present in diets of pre-spawn males from Saugahatchee Creek and aquatic macroinvertebrates comprised 65% of the diet biomass, however 76% of the post-spawn diet biomass was decapods followed by 19% terrestrial invertebrates and 5% aquatic macroinvertebrates (Figure 21). In Saugahatchee Creek, count data for pre-spawn male redbreast sunfish diets were not different from biomass results; however, count data from post-spawn male diets were different from biomass results (terrestrial invertebrates, 61%; aquatic macroinvertebrates, 34%; and decapods, 5%; Figure 22).

Bioenergetic modeling

Model parameters used in the bioenergetic models for male redbreast sunfish collected from Wadley and Saugahatchee are listed in Table 14. Initial models estimated a p-value (proportion of maximal consumption) of 0.491 for males from Saugahatchee and 0.285 for males from Wadley. Consumption by males was estimated at 129 g and 89 g for Saugahatchee and Wadley, respectively. Males from Saugahatchee had the lowest estimated specific growth rate of -50 J/g/day during day 34 of the simulation, when temperature peaked at its highest value of 33 °C (Figure 23). Positive specific growth rates were estimated during early and late portions of the simulation when temperatures decreased. Positive specific growth rates were never predicted at Wadley during its simulation and reached their lowest on day 46 of the simulation at -26 J/g/day; however, during most days specific growth rate was predicted to be under -15 J/g/day (Figure 24). Predicted specific consumption rate (J/g/day) was considerably higher for males from Saugahatchee and reached its lowest value on day 34 during the highest temperature observed during the simulation; whereas, specific consumption rate closely followed temperature across the entire simulation for fish from Wadley (Figure 23 and Figure 24). Predicted weight (g) remained constant during the first 17 days of the simulation at Saugahatchee then began to decline through day 37 during high temperatures and then leveled out for the remainder of the simulation (Figure 24). Predicted weight of fish from Wadley exhibited a decreasing trend throughout the simulation (Figure 24).

DISCUSSION

Adaptive resource management provides a framework for decision making relative to management of socio-ecological systems where uncertainty is recognized (Williams et al. 2007). Monitoring of resources in response to management activities, application of knowledge gained during monitoring, and reduction of uncertainty related to effects of management on resources ultimately provide inference for prescription of future management (Walters 1986). This study was conducted in support of the "monitor-compare-adjust" process of adaptive management of the Tallapoosa River below R.L. Harris Dam (Kennedy et al. 2006). Specifically, monitoring of nest survival of redbreast sunfish has increased our knowledge relative to the functional responses of nest survival to discharge. Consequently, findings are directly transferable to support the structured decision making tool (Bayesian Belief Network; BBN) described by Kennedy et al. (2006) for adaptive management of the Tallapoosa River below Harris Dam. In addition, the unexpected occurrence of a severe drought during the 2007 spawning season allowed for quantification of nest survival in responses to water management in an extreme dry water year.

High flow events have been implicated as an important variable for explaining variation in nest success for centrarchids (Lukas and Orth 1995; Andress 2002). Andress (2002) reported that increased discharge was detrimental to nest success of redbreast sunfish in the Tallapoosa River. His study years included an extreme wet year (1999) and a moderately wet year (2000); nest success was 7% and 51% in the study years, respectively. Nest success for both years observed in the present study (2006 = 51%; 2007 = 53%) was similar to Andress' (2002) findings in 2000, although the number of nest attempts and length of observational period varied between years. Nest success was likely low in 1999 due to shorter periods of stable flow and higher magnitude disturbances (Andress, 2002). In 2000 and 2006, Harris Dam had a similar generation schedule with few two-unit generations, and long periods of stable flows. Very few generations and extremely long periods of stable flows during 2007 likely led to a similar nest success rate.

Andress (2002) used known-fate analysis in Program MARK for nest survival estimation and although nest survival was negatively related to discharge for both of his study years, definition of functional relations was limited with his approach. Since 2002, a nest survival model is now available in Program MARK that allowed for incorporation of individual, group, and time-specific covariates to estimate nest survival (White and Burnham 1999; Dinsmore et al. 2002). This approach allowed for development and analysis (using AIC_c, Burnham and Anderson 2002) of detailed competing models.

Findings from the current study support the use of spawning windows (Irwin and Freeman 2002) to increase recruitment potential of redbreast sunfish. Developmental time requirements for nests suggest that spawning window duration of 10-11 days would be sufficient for production of redbreast sunfish swim-up larvae (present study, Andress 2002). However, during the drought year peak swim-up dates were earlier than observed in other years, indicating that spawning windows could be provided earlier (mid-May) than previous suggested (mid-June; Andress 2002) during drought years. May spawning windows could enhance recruitment of both game and non-game fishes in the regulated Tallapoosa River (Irwin et al. 1997; Freeman et al. 2001). Recruitment is an important goal of the adaptive management project to support healthy fish communities and sport fisheries (Irwin and Freeman 2002; Kennedy et al. 2006). This increased flexibility is beneficial to the adaptive management of the Tallapoosa River.

Results from nest survival modeling did not indicate that temperature was related to daily survival of nests; however, because discharge and temperature were correlated, power to detect specific effects of temperature on nest survival was likely low. More specific testing to separate the potential effects of temperature on nest survival may be warranted particularly in light of the influence of temperature on metabolic constraints (Diana 1984). Laboratory experiments could separate the effects of temperature from discharge and allow for examination of parameters that might be influenced differentially by the two abiotic factors (Weyers et al. 2003). A concurrent study is being conducted to define the effects of temperature on larval survival and growth of young-of-the-year channel catfish (*Ictalurus punctatus*) and spotted bass (*Micropterus punctulatus*) (T. Goar, personal communication), and these data may be valuable in quantifying uncertainty related to survival of larvae after they leave nests.

Direct observation of behavior changes during discharge disturbances allowed for quantification of nesting behaviors in relation to increased discharge. Other studies concerning nesting centrarchids have observed nest abandonment or failure in relation to abiotic factors (Goff 1986; Lukas and Orth 1995, Steinhart et al.2005). Results from observations of nesting male redbreast sunfish during flow experiments supported my hypotheses that behaviors related to spawning (e.g., *milt* and *court* behaviors) ceased during one-unit generations and the *leave* behavior (i.e., displacement) increased. Also, nest tending behaviors (e.g., *clean* behavior) increased when compared to base flow *clean* behavior. As discharge increased during one-unit flow recordings, removal of debris deposited into nests accounted for the increase in the *clean* behavior (Appendix B). Examples of behaviors (i.e., video clips) during both base flow and one-unit flow experiments can be observed on the CD included in Appendix B. In addition, detrimental effects of two-unit generation were suggested by Andress (2002) and corroborated by this study (Appendix A).

A significant difference of energetic content was detected between post-spawn males, but contrary to prediction, males from Saugahatchee Creek had lower body caloric content. Lower caloric content observed in post-spawn males from Saugahatchee Creek may have been related to increased metabolic costs associated with elevated temperatures observed at the Saugahatchee Creek. Water temperatures at Wadley were lower and relatively constant because of water regulation from Harris Dam compared to Saugahatchee Creek which was subject to extremely low water levels and elevated temperatures due to the 2007 drought. Both bioenergetic models illustrated the importance of temperature related effects on specific growth rate; decreased growth was predicted at higher temperatures. Negative specific growth rates were not unexpected as spawning and parental investment could have accounted for this observation; males can lose up to 10% of body weight during parental care (Coleman and Fischer 1991). Results from the bioenergetic models suggested that male redbreast sunfish from Saugahatchee Creek experienced more drastic metabolic costs due to drought conditions because of higher temperatures. High temperatures were mitigated by flow management, thus similar metabolic costs were not experienced by spawning redbreast sunfish during 2007. Although temperature did not appear to influence nest survival, it had important effects on metabolism, and therefore may indirectly affect nest survival.

Sampling design for the bioenergetic portion of this project did not allow for maximum contrast between pre- and post-spawn males because fish were collected over a range of dates during pre-spawn, and post-spawn males were collected on two dates separated by nearly a month. Another potential sampling design flaw included using fish collected from two sampling techniques, both angling (pre-spawn males) and electrofishing (post-spawn males) which could have introduced bias related to either size or condition of male fish.

Behaviors recorded and quantified during experimental flows allowed observation of differences between base flow and one-unit flows; however observations of two-unit flows were limited and further observations are needed to describe differences between experimental flow types. Quantification of true activity cost differences could be acquired from videos and incorporated into bioenergetic modeling, but would require the use of two cameras simultaneously recording each fish. Methods used by Bosclair (1992) could be implemented to allow activity cost differences to be calculated by positioning two cameras in an *x*, *y*, *z* Cartesian co-ordinate plane (Trudel and Boisclair 1996) and determining fish co-ordinates at 1-s intervals. Also, electromyogram (EMG) telemetry could record immediate responses to environmental stessors (Cooke et al. 2001; Cooke and Schreer 2003; Murchie and Smokorowski 2004). These methods would allow for better estimation of how behavior and bioenergetics are coupled and related to reproductive success during adverse environmental conditions.

Because specific hydrology was different between years of the present study, testing of my *a priori* hypotheses on nest success in relation to specific flow patterns was possible. Nest survival models from 2006 identified a minimum flow requirement while 2007 revealed a different peak swim-up time. These results led to recommendations for timing of spawning windows during drought years and allowed updating of the decision support model related to redbreast sunfish spawning success. Although extreme drought conditions did not negatively affect overall nest survival in the regulated Tallapoosa River, lower flows similar to what might be provided in a drought contingency plan could reduce survival.

LITERATURE CITED

Anderson, R.O., and R.M. Neumann. 1996. Length, weight, and associated structural indices. Pages 457-463 *in* B.R. Murphy and D.W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Andress, R.O. 2001. Nest survival of *Lepomis* species in regulated and unregulated rivers. Masters Thesis. Auburn University, Alabama.

Benke, A.C., A.D. Huryn, L.A. Smock, and J.B. Wallace. 1999. Length-mass relationships for freshwater macroinvertebrates in North America with particular reference to the southeastern United States. Journal of the North American Benthological Society 18:308-343.

Boisclair, D. 1992. An evaluation of the sterocinematographic method to estimate fish swimming speed. Candian Journal of Fisheries and Aquatic Sciences 49:523-531.

Boschung, Jr. H.T, and R.L. Mayden. 2004. Fishes of Alabama. Smithsonian Institution. 449-450.

Burnham, K.P., and D.R. Anderson. 2002. Model Selection and multimodel inference: A practical information-theoretic approach. 2nd Edition. Springer-Verlag New York, Inc.

Coleman, R.M., and R.U. Fischer 1991. Brood size, male fanning effort and the energetics of a non-sharable parental investment in bluegill sunfish, *Lepomis macrochirus* (Teleostei:Centrarchidae). Ethology 87:177-188.

Cooch, G., and G.C. White. 2008. Program MARK: A gentle introduction. Chapter 17. Retrieved September 29, 2008, from Colorado State University, Department of Fishery and Wildlife Biology Website: http://www.phidot.org/software/mark/docs/book

Cooke, S.J., and C.M. Bunt. 2004. Construction of a junction box for use with an inexpensive, commercially available underwater video camera suitable for aquatic research. North American Journal of Fisheries Management. 24:253-257.

Cooke, S.J., R.S. McKinley, and D.P. Philipp. 2001. Physical activity and behavior of a centrarchid fish, *Micropterus salmoides* (Lacepede), during spawning. Ecology of Freshwater Fish 10:227-237.

Cooke, S.J., and J.F. Schreer, D.P. Philipp, P.J. Weatherhead. 2003. Nesting activity, parental care behavior, and reproductive success of smallmouth bass, *Micropterus dolomieu*, in an unstable thermal environment. Journal of Thermal Biology 28:445-456.

Cooke, S.J., and J.F. Scheer. 2003. Environmental monitoring using physiological telemetry: a case study examining common carp responses to thermal pollution in a coal-fired generating station effluent. Water, Air, and Soil Pollution 142:113-136.

Cummins K.W., and J.C. Wuycheck. 1971. Caloric equivalents for investigations in ecological energetics. International Association of Theoretical and Applied Limnology. No.18. 15:12.

Cushman, R.M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American Journal of Fisheries Management. 5:330-339.

Diana, J.S. 1995. Biology and ecology of fishes. Cooper Publishing Group LLC, Carmel, IN 34-44.

Dinsmore, S.J., G.C. White, and F.L. Knopf. 2002. Advanced techniques for modeling avian nest survival. Ecology 83:3476-3488.

Freeman, M.C., Z.H. Bowen, K.D. Bovee, and E.R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications. 11(1):179-190.

Goff, G.P. 1986. Reproductive success of male smallmouth bass in Long Point Bay, Lake Erie. Transactions of the American Fisheries Society 115:415-423.

Hanson, P.C., T.B. Johnson, D.E. Schindler, and J.F. Kitchell. 1997. Fish Bioenergetics 3.0. Madison, Wisconsin: University of Wisconsin Sea Grant Institute.

Helfman, G.S., B.B Collette., and D.E Facey. 1997. The diversity of fishes. Blackwell Publishing. 355-365.

Hinch, S.G., and N.C. Collins. 1991. Importance of diurnal and nocturnal nest defense in the energy budget of male smallmouth bass; insights from direct video observations. Transactions of the American Fisheries Society. 120:657-663.

Irwin, E.R., and M.C. Freeman. 2002. Proposal for adaptive management to conserve biotic integrity in a regulated segment of the Tallapoosa River, Alabama, U.S.A. Conservation Biology. 16(5):1212-1222.

Irwin, E.R., M.C. Freeman, and J.J. Isley. 1997. Effects of low regime on recruitment and growth of juvenile basses (*Micropterus* spp.) in flow-regulated rivers. Final Report. Fish and Wildlife Service. Arlington, Virginia.

Irwin, B.J. 2001. Manipulating gizzard shad *Dorosoma Cepedianum* populations to manage for their sport fish predators: Potential of selective poisoning and predatory control. Masters Thesis. Auburn University, Alabama.

Kennedy, K. M., E. R. Irwin, M. C. Freeman, and J. Peterson. 2006. Development of a decision support tool and procedures for evaluating dam operation in the Southeastern United States. Science Support Partnership Program Project Final Report to USGS and USFWS.

Kitchell, J.F., J.F. Koonce, R.V. O'Neill, H.H. Shugart, J.J. Magnuson, and R.S. Booth. 1974. Transactions of the American Fisheries Society 4:786-798.

Lukas, J.A., and D.J Orth. 1993. Reproductive ecology of redbreast sunfish *Lepomis auritus* in a Virginia stream. Journal of Freshwater Ecology. 8(3):235-244.

Lukas, J.A., and D.J. Orth. 1995. Factors affecting nesting success of smallmouth bass in a regulated Virginia stream. Transactions of the American Fisheries Society 124:726-735.

Mackereth R.W., D.G. Noakes, and M.S. Ridgway. 1999. Size based variation in somatic energy reserves and parental care expenditure by male smallmouth bass, *Micropterus dolomieu*. Envionmental Biology of Fishes 56:263-275.

Murchie K.J., and K.E. Smokorowski. 2004. Relative activity of brook trout and walleyes in response to flow in a regulated river. North American Journal of Fisheries Management 24:1050-1057.

Nakamura, N., S. Kasahare, and T. Yada. 1971. Studies on the usefulness of the bluegill sunfish, *Lepomis macrochirus* Refinesque, as an experiment standard animal. II. One the development stages and developmental stages and growth from egg through one year. Journal of the Faculty of Fisheries and Animal Husbandry, Hiroshima University 10(2): 139-151.

Sage, R.D. 1982. Wet and dry-weight estimates of insects and spiders based on length. The American Midland Naturalists 108:407-411.

Sammons, S.M., and M.J. Maceina. 2008. Evaluating the potential effectiveness of harvest restrictions on riverine sunfish populations in Georgia, USA. Fisheries Management and Ecology 15(3):167-178.

Steinhart, G.B., N.J. Leonard, R.A. Stein, and E.A. Marschall. 2005. Effects of storms, angling, and nest predation on smallmouth bass (*Micropterus dolomieu*) nest success. Canadian Journal of Fisheries and Aquatic Sciences 62:2649-2660.

Steinhart, G.B., M.E. Sandrene, S. Weaver, R.A. Stein, and E.A. Marschall. 2004. Increased parental care cost for nest-guarding fish in a lake with hyperabundant nest predators. Behavioral Ecology 16(2):427-343.

Steinhart G.B., and W.A. Wurtsbaugh. 2003. Winter ecology of kokanee: Implications for salmon management. Transactions of the American Fisheries Society 132:1076-1088.

Sutton, S.G., T.P. Bult, and R.L. Haedrich. 2000. Relationships among fat weight, body weight, water weight, and condition factors in wild Atlantic salmon parr. Transactions of the American Fisheries Society 129:527-538.

Tolonen, P., and E. Korpimaki. 1996. Do kestrels adjust their parental effort to current or future benefit in a temporally varying environment? Ecoscience 3:165-172.

Trudel, M., and D. Boisclair. 1996. Estimation of fish activity costs using underwater video cameras. Journal of Fish Biology 48:40-53.

Walters, C. J. 1986. Adaptive management of renewable resources. Macmillan Publishing, New York, New York.

Walters, C.J. 1997. Challenges in adaptive management of riparian and coastal ecosytems. Conservation Ecology 1(2):1 http://www.consecol.org/vol1/iss2/art1/

Waters, T.F. 1977. Secondary production in inland waters. Advances in Ecological Research 10:115.

White, G.C., and K.P. Burnham. 1997. Program MARK: Survival estimation from populations of marked animals. Retrieved January 23, 2006, from Colorado State University, Department of Fishery and Wildlife Biology Website: http://www.cnr.colostate.edu/~gwhite/mark/mark.html

Williams, G.C. 1996. Natural selection, costs of reproduction, and a refinement of Lack's principle. American Naturalist 687-690.

Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2007. Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, DC.

Weyers, R.S., C.A. Jennings, and M.C. Freeman. 2003. Effects of pulsed, high-velocity water flow on larval robust redhorse and v-lip redhorse. Transactions of the American Fisheries Society 132:84-91.

Table 1. Definition of experimental flows released from R. L. Harris Dam during the study (May - August of 2006 and May - June 2007). Discharge data from the USGS gage near Wadley, Alabama (#02414500) were evaluated to determine the number of occurrences for each experimental flow type. Video data of nesting behavior of redbreast sunfish were collected during different experimental flow events. The number of video observations equates to the number of nests observed for the behavioral study during different experimental flows.

Experimental flow	Definition and duration of release	Number of occurrences	Number of video observations
Base Flow	One turbine, 0-30 minutes	98	29
One-unit	One turbine, >30 minutes	36	10
Two-unit	Two turbines, > 30 minutes	2	2

Table 2. Summary of environmental variables from the Wadley site (2006 and 2007) used in nest survival modeling. Mean daily maximum and mean daily minimum discharge (m^3/s) and range (in parentheses) are reported for each year. Mean daily maximum, mean daily minimum, and mean daily delta temperature (°C; Δ= maximum daily temperature- minimum daily temperature) and range (in parentheses) are also reported for both years. Simple correlation and regression statistics are reported for the relation between daily maximum discharge and daily delta temperature for the periods of record (24 May – 25 August 2006 and 4 May – 21 June 2007).

	Mean Discharge		Mean Temperature			Daily maximum discharge versus daily Δ temperature		
Wadley	Maximum m^3/s (Range)	Minimum m^3/s (Range)	Maximum °C	Minimum °C	Delta °C	r	r^2	P-value
2006	101.9 (5.7 - 274.2)	4.0 (2.1 - 9.2)	28.6 (24.2 - 33.2)	23.2 (19.2 - 27.4)	5.4 (2.3 - 9.4)	0.55	0.31	<0.0001
2007	31.2 (6.0 - 287.9)	3.2 (2.3 -4.7)	25.7 (2.3 - 4.7)	21.6 (15.7 - 26.3)	4.2 (2.1 - 11.5)	0.75	0.57	<0.0001

Table 3. Total number of nest attempts, successful attempts, failed attempts, and attempts with unknown fate for the Wadley site (2006 and 2007). Mean cumulative degree days (MCDD) required for development of eggs through swim-up fry, mean degree-days (MDD) per 24 hour period, and peak swim-up date(s) for the Wadley site (2006 and 2007).

	Number						
Year	**Nest Attempts**	**Successful**	**Failed**	**Unknown**	**MCDD**	**MDD**	**Peak swim-up date(s)**
2006	409	183	174	52	67.1 (N=43; SE=3.27)	8.9 (N=92; SE=0.17)	5 June; 12-14 June
2007	114	59	52	3	62.6 (N=20, SE=3.90)	6.7 (N=49; SE=0.31)	14-17 May; 4-7 June

Table 4. Results of the 2006 nest survival environmental model set. These models were developed from nesting histories created using observations of nesting redbreast sunfish from the Tallapoosa River, Wadley, Alabama (26 May - 25 August 2006). Models are ranked by ascending ΔAIC_c, w_i is the model weight and K is the number of parameters.

Model	Deviance	K	AIC_c	ΔAIC_c	w_i
{Daily Min Discharge}	866.85	2	870.85	0.00	0.98
{Daily Max Temp}	874.78	2	878.79	7.93	0.02
{Daily Max Discharge}	877.09	2	881.09	10.24	0.01
{Daily Delta Temp}	884.96	2	888.97	18.11	0.00
{Daily Min Temp}	890.72	2	894.72	23.87	0.00
{S(.) Design Matrix}	897.71	1	899.71	28.85	0.00

Table 5. Parameter estimates (β), standard errors, and 95% confidence limits (LCL = lower confidence level, UCL = upper confidence level) for the environmental model set of covariates used to determine influence on redbreast sunfish nest success in 2006 (Tallapoosa River near Wadley, Alabama).

Parameter	Estimate	SE	LCL	UCL
Intercept	3.113	0.173	2.774	3.452
Daily Maximum Discharge	-0.006	0.001	-0.008	-0.003
Intercept	0.999	0.273	0.465	1.534
Daily Minimum Discharge	0.331	0.062	0.210	0.452
Intercept	8.964	1.351	6.316	11.611
Daily Maximum Temperature	-0.231	0.048	-0.325	-0.318
Intercept	5.487	1.127	3.277	7.697
Daily Minimum Temperature	-0.133	0.050	-0.231	-0.036
Intercept	3.988	0.422	3.161	4.814
Daily Delta Temperature	-0.266	0.071	-0.404	-0.127

Table 6. Results of the 2006 nest survival biological model set. These models were developed from nesting histories created using observations of nesting redbreast sunfish from the Tallapoosa River, Wadley, Alabama (26 May - 25 August 2006). Models are ranked by ascending ΔAIC_c, w_i is the model weight and K is the number of parameters. Within the models TT is abbreviated for linear time trend.

Model	Deviance	K	AIC_c	ΔAIC_c	w_i
{Nest Age + TT}	853.97	3	859.98	0.00	0.44
{Early Stage Constant + Late Stage Trend + TT}	852.80	4	860.82	0.84	0.29
{Early Stage Trend + Late Stage Trend + TT}	851.82	5	861.85	1.87	0.17
{Early Stage Constant + Late Stage Constant + TT}	857.77	3	863.78	3.80	0.07
{Early Stage Trend + Late Stage Constant + TT}	857.06	4	865.08	5.10	0.03
{TT}	869.15	2	873.16	13.18	0.00
{Early Stage Constant + Late Stage Trend}	886.18	3	892.19	32.21	0.00
{Nest Age}	889.85	2	893.86	33.88	0.00
{Early Stage Constant + Late Stage Constant}	889.95	2	893.95	33.97	0.00
{Early Stage Trend + Late Stage Trend}	886.17	4	894.19	34.21	0.00
{Early Stage Trend + Late Stage Constant}	889.90	3	895.91	35.93	0.00
{S(.) Design Matrix}	897.71	1	899.71	39.73	0.00

Table 7. Results of the 2006 nest survival final model set. These models were developed from nesting histories created using observations of nesting redbreast sunfish from the Tallapoosa River, Wadley, Alabama (26 May - 25 August 2006). Models are ranked by ascending ΔAIC_c, w_i is the model weight and K is the number of parameters. Within the models TT is abbreviated for linear time trend.

Model	Deviance	K	AIC_c	ΔAIC_c	w_i
{Daily Min Discharge + Nest Age + TT}	850.13	4	858.15	0.00	0.45
{Nest Age + TT}	853.97	3	859.98	1.83	0.18
{Early Stage Constant + Late Stage Trend + TT}	852.80	4	860.82	2.67	0.12
{Daily Min Discharge + Early Stage Constant + Late Stage Trend + TT}	849.06	6	861.10	2.95	0.10
{Early Stage Trend + Late Stage Trend + TT}	851.82	5	861.85	3.69	0.07
{Daily Min Discharge + Early Stage Trend + Late Stage Trend + TT}	847.86	7	861.91	3.76	0.07
{Daily Min Discharge}	866.85	2	870.85	12.70	0.00
{S(.) Design Matrix}	897.71	1	899.71	41.55	0.00

Table 8. Results of the 2007 nest survival environmental model set. These models were developed from nesting histories created using observations of nesting redbreast sunfish from the Tallapoosa River, Wadley, Alabama (4 May - 21 June 2007). Models are ranked by ascending ΔAIC_c, w_i is the model weight and K is the number of parameters.

Model	Deviance	K	AIC_c	ΔAIC_c	w_i
{Daily Max Discharge}	260.19	2	264.20	0.00	1.00
{Daily Delta Temp}	276.33	2	280.34	16.14	0.00
{Daily Min Temp}	280.64	2	284.65	20.45	0.00
{S(.) Design Matrix}	283.25	1	285.25	21.05	0.00
{Daily Max Temp}	282.48	2	286.50	22.29	0.00
{Daily Min Discharge}	283.11	2	287.13	22.92	0.00

Table 9. Parameter estimates (β), standard errors, and 95% confidence limits (LCL = lower confidence level, UCL = upper confidence level) for the environmental model set of covariates used to determine influence on redbreast sunfish nest success in 2007 (Tallapoosa River near Wadley, Alabama).

Parameter	Estimate	SE	LCL	UCL
Intercept	3.087	0.186	2.722	3.451
Daily Maximum Discharge	-0.013	0.002	-0.018	-0.008
Intercept	2.893	0.778	1.369	4.417
Daily Minimum Discharge	-0.081	0.217	-0.507	0.346
Intercept	0.425	2.506	-4.488	5.337
Daily Maximum Temperature	0.087	0.100	-0.109	0.282
Intercept	0.231	1.451	-2.612	3.075
Daily Minimum Temperature	0.113	0.069	-0.023	0.248
Intercept	4.427	0.690	3.075	5.779
Daily Delta Temperature	-0.438	0.155	-0.742	-0.133

Table 10. Results of the 2007 nest survival biological model set. These models were developed from nesting histories created using observations of nesting redbreast sunfish from the Tallapoosa River, Wadley, Alabama (4 May - 21 June 2007). Models are ranked by ascending ΔAIC_c, w_i is the model weight and K is the number of parameters. Within the models TT is abbreviated for linear time trend.

Model	Deviance	K	AIC_c	ΔAIC_c	w_i
{Nest Age}	264.96	2	268.98	0.00	0.31
{Nest Age + TT}	263.29	3	269.33	0.35	0.26
{Early Stage Trend + Late Stage Constant}	265.22	3	271.25	2.27	0.10
{Early Stage Constant + Late Stage Constant}	267.94	2	271.96	2.98	0.07
{Early Stage Trend + Late Stage Constant + TT}	263.93	4	271.99	3.01	0.07
{Early Stage Trend + Late Stage Trend}	264.49	4	272.54	3.56	0.05
{Early Stage Trend + Late Stage Trend + TT}	262.86	5	272.95	3.97	0.04
{Early Stage Constant + Late Stage Constant + TT}	266.97	3	273.00	4.02	0.04
{Early Stage Constant + Late Stage Trend}	267.56	3	273.60	4.61	0.03
{Early Stage Constant + Late Stage Trend + TT}	266.40	4	274.46	5.48	0.02
{S(.) Design Matrix}	283.25	1	285.25	16.27	0.00
{TT}	283.04	2	287.05	18.07	0.00

Table 11. Results of the 2007 nest survival final model set. These models were developed from nesting histories created using observations of nesting redbreast sunfish from the Tallapoosa River, Wadley, Alabama (4 May - 21 June 2007). Models are ranked by ascending ΔAIC_c, w_i is the model weight and K is the number of parameters. Within the models TT is abbreviated for linear time trend.

Model	Deviance	K	AIC_c	ΔAIC_c	w_i
{Daily Max Discharge + Nest Age + TT}	243.93	4	251.99	0.00	0.48
{Daily Max Discharge + Nest Age}	246.24	3	252.27	0.29	0.42
{Daily Max Discharge + Early Stage Trend + Late Stage Constant}	246.95	5	257.04	5.05	0.04
{Daily Max Discharge + Early Stage Trend + Late Stage Constant + TT}	245.14	6	257.25	5.27	0.03
{Daily Max Discharge + Early Stage Constant + Late Stage Constant}	249.87	4	257.93	5.94	0.02
{Daily Max Discharge}	260.19	2	264.20	12.22	0.00
{Nest Age}	264.96	2	268.98	16.99	0.00
{Nest Age + TT}	263.29	3	269.33	17.34	0.00
{Early Stage Trend + Late Stage Constant}	265.22	3	271.25	19.26	0.00
{Early Stage Constant + Late Stage Constant}	267.94	2	271.96	19.97	0.00
{Early Stage Trend + Late Stage Constant + TT}	263.93	4	271.99	20.00	0.00
{S(.) Design Matrix}	283.25	1	285.25	33.27	0.00

Table 12. Mean male body and testes energy densities (J/g) for both pre- and post-spawn males with their respective sample size (N) collected from Saugahatchee Creek, near Notasulga, Alabama (May 10 – May 29, 2007 and July 26, 2007) and the Tallapoosa River, near Wadley, Alabama (April 27, 2007 – May 17, 2007 and June 28, 2007).

Site	Spawn	Mean body energy density (N)	Mean testes energy density (N)
Wadley	Pre	4605 (22)	3414 (17)
	Post	4729 (18)	3976 (18)
Saugahatchee	Pre	4435 (20)	4265 (20)
	Post	4202 (21)	3475 (21)

Table 13. Total biomass (g) and biomass (g) for each taxa found in pre- and post-spawn male redbreast sunfish diets collected from Saugahatchee Creek, near Notasulga, Alabama (May 10 – May 29, 2007 and July 26, 2007) and the Tallapoosa River, near Wadley, Alabama (April 27, 2007 – May 17, 2007 and June 28, 2007).

TYPE ORDER Family	Site	
	Saugahatchee	Wadley
AQUATIC		
ODONATA	4,279	1,534
EPHEMEROPTERA	586	2,584
PLECOPTERA	290	365
TRICHOPTERA	133	958
MEGALOPTERA	.	14,017
COLEOPTERA	106	323
DIPTERA	17	39
DECAPODA	13,005	33,026
BIVALVIA	.	2
GASTROPODA	5	8
TERRESTRIAL		
HYMENOPTERA		
Vespidae	32	.
Formicidae	32	31
DIPTERA	384	42
COLEOPTERA	804	2,698
ARACNIDA	30	5
CHILOPODA	719	3,838
ORTHOPTERA	2,455	563
HEMIPTERA	13	5
LEPIDOPTERA (larva)	1,293	.
ODONATA	4	212
PLECOPTERA	.	30
Total Biomass (mg)	24,187	60,278
Total Biomass (g)	24.2	60.3
Pre-Spawn Biomass (g)	7.2	42.6
Post-Spawn Biomass (g)	17.0	17.7

Table 14. Model parameters used in the bioenergetic model (Hanson et al., 1997) to determine specific growth rate (J/g/d), specific consumption rate (J/g/d), and weight across the simulation period for redbreast sunfish males collected from Saugahatchee Creek near Notasulga, Alabama during (May 10 – May 29, 2007 and July 26, 2007) and from the Tallapoosa River near Wadley, Alabama during (April 27, 2007 – May 17, 2007 and June 28, 2007).

Model parameter	Saugahatchee	Wadley
Simulation length (Day)	78	63
Percent aquatic invertebrates in diet (pre; post)	65; 5	32; 36
Percent terrestrial invertebrates in diet (pre; post)	35; 19	6; 27
Percent crayfish in diet (pre; post)	0; 76	62; 37
Redbreast sunfish starting WW (g)	66	124
Redbreast sunfish ending WW (g)	59	102
Redbreast sunfish starting energy density (kJ/g)	4431	4598
Redbreast sunfish ending energy density (kJ/g)	4197	4726

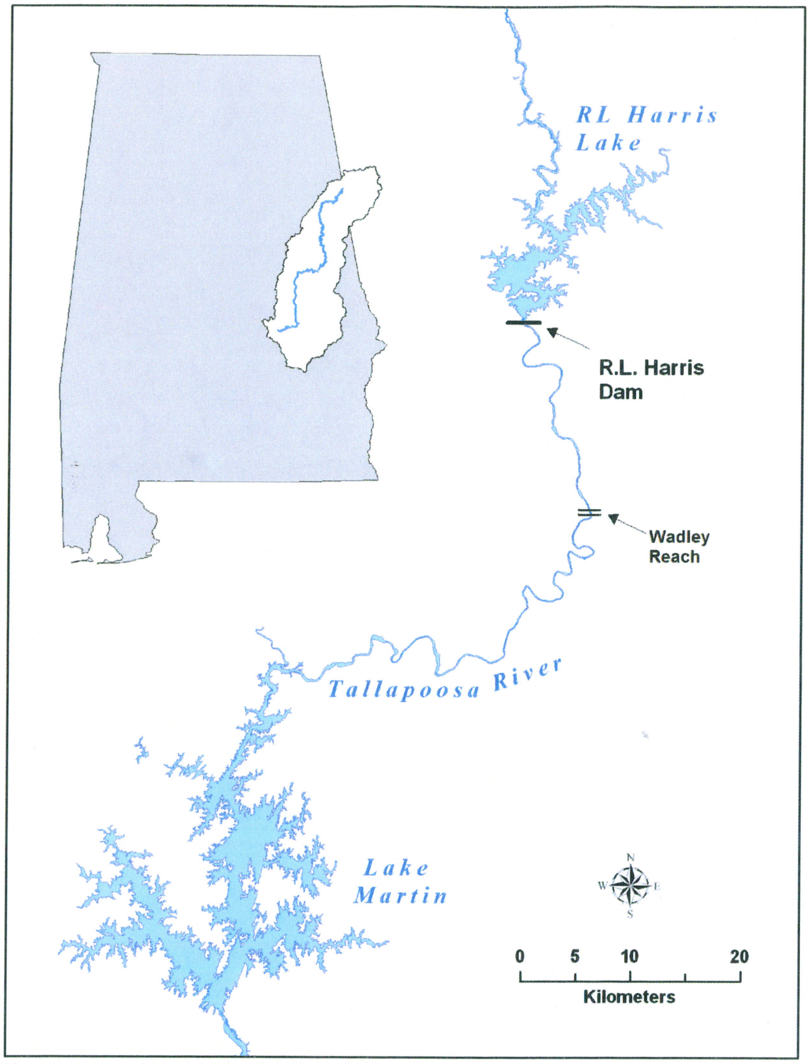


Figure 1. Location of R.L. Harris Dam and Wadley reach (site location for portions of the study) on the Tallapoosa River, Randolph County, Alabama. The inset indicates the location of the Tallapoosa River basin within the state of Alabama. The headwaters are located within the state of Georgia.

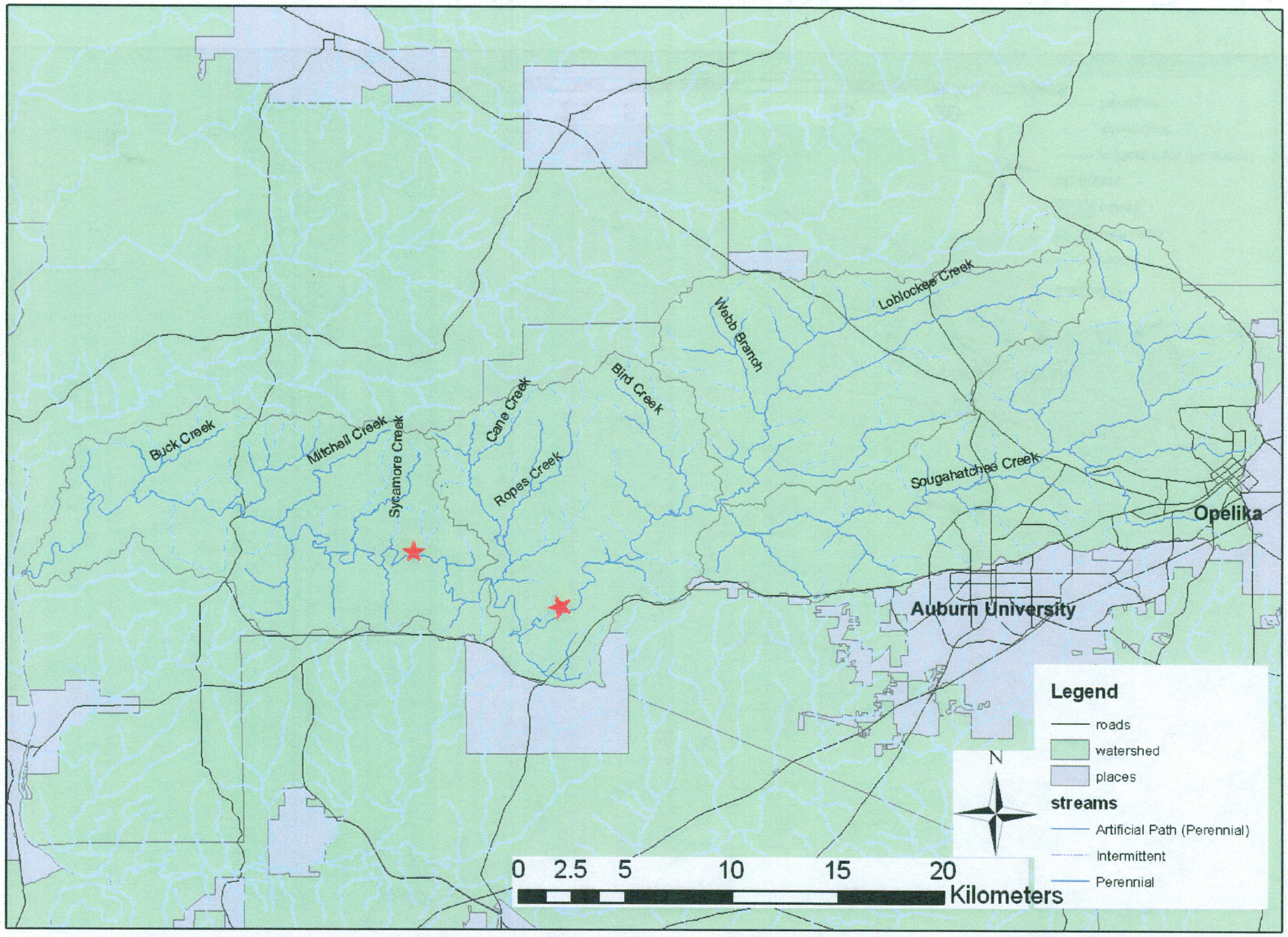


Figure 2. Saugahatchee Creek watershed located in both Lee and Macon Counties, Alabama. The red stars indicate location of sample sites (East star – 32°35'02.74"N, 085°40'33.43"W; West star – 32°36'53.64"N, 085°43'36.74"W) where male redbreast sunfish were collected for bioenergetic assessment.

Figure 3. Redbreast sunfish nest marked with a 76 x 76 mm brightly colored, numbered wooden disc. The male fish is located near the top of the bowl shaped nest.

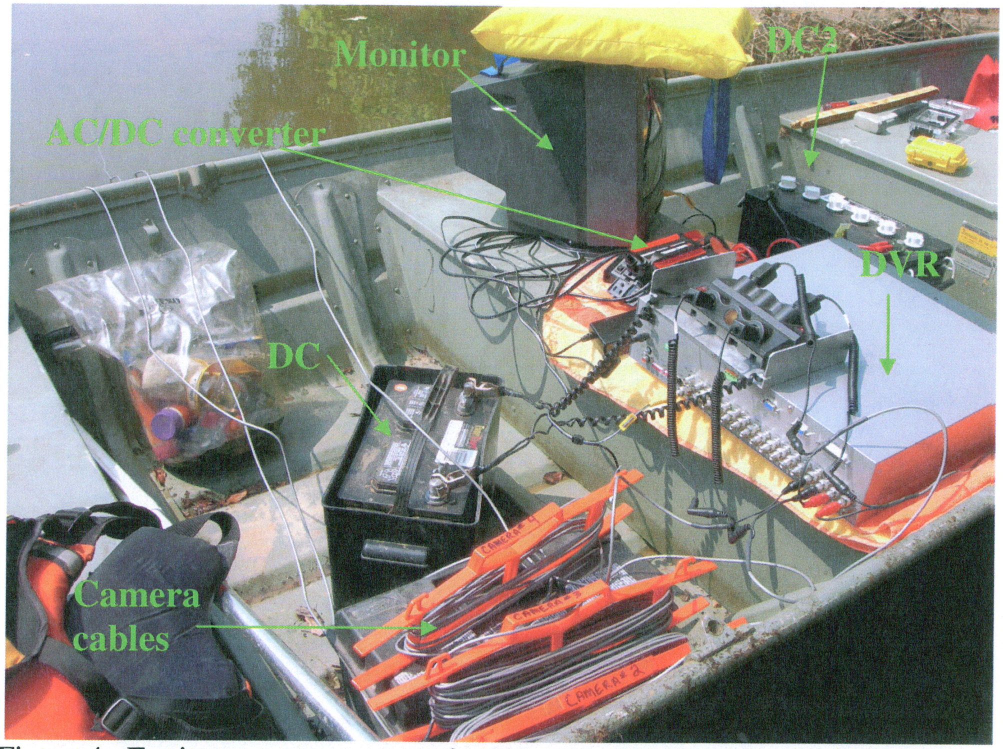


Figure 4. Equipment arrangement for videography of nesting behavior. Individual components are labeled on the photograph and include, monitor (top, near center), digital video recorder (DVR, left center), camera cables (bottom center), direct current power source for cameras (DC, above cables), direct current power source for DVR and monitor (DC, above DVR) and alternate current/DC converter (AC/DC converter, between monitor and DVR). All equipment was located in a 4.9 m jon boat that was secured to the bank of the river.

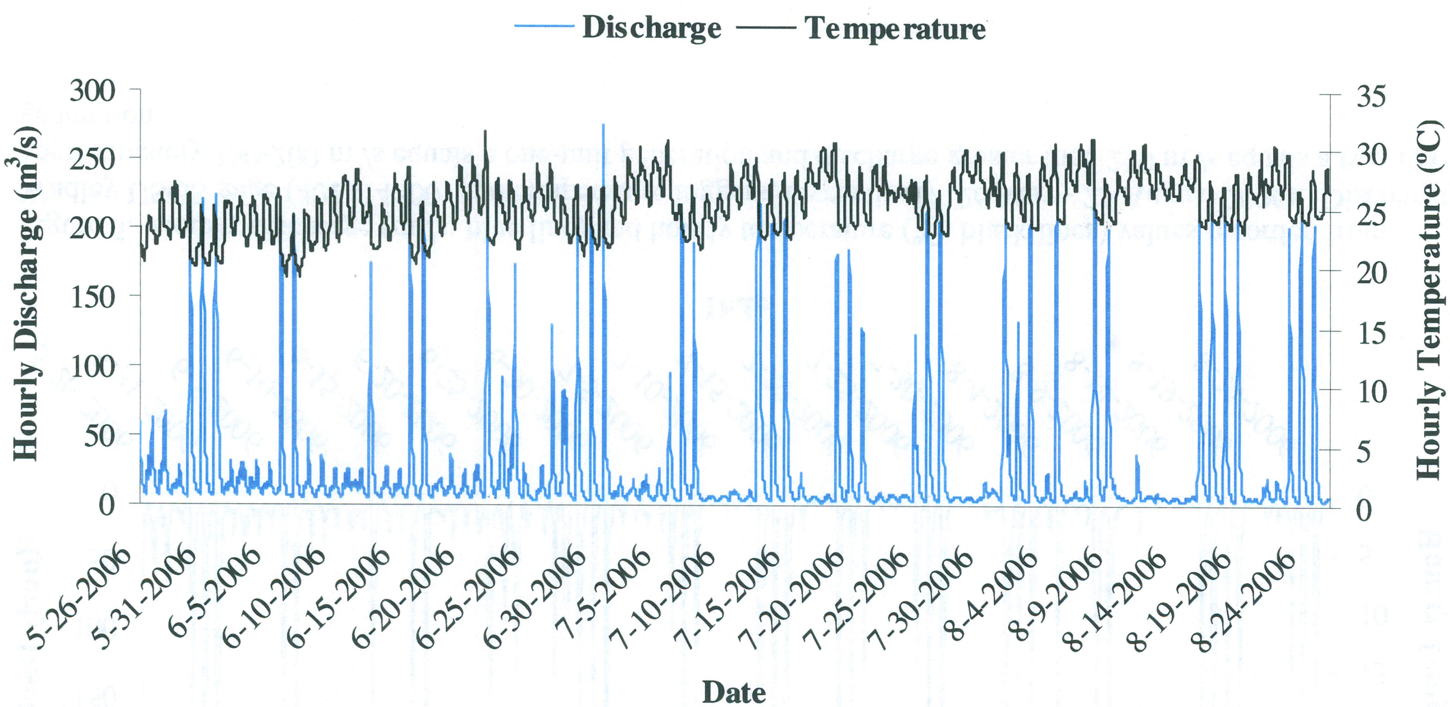


Figure 5. Hourly discharge (m^3/s; blue line) and hourly temperature (ºC; black lines) values recorded from Wadley USGS gage (#02414500) and temperature loggers, respectively (26 May - 25 August 2006). Discharge approximately 150-200 m^3/s equals a one-unit generation and discharge greater than 250 m^3/s equals a two-unit generation.

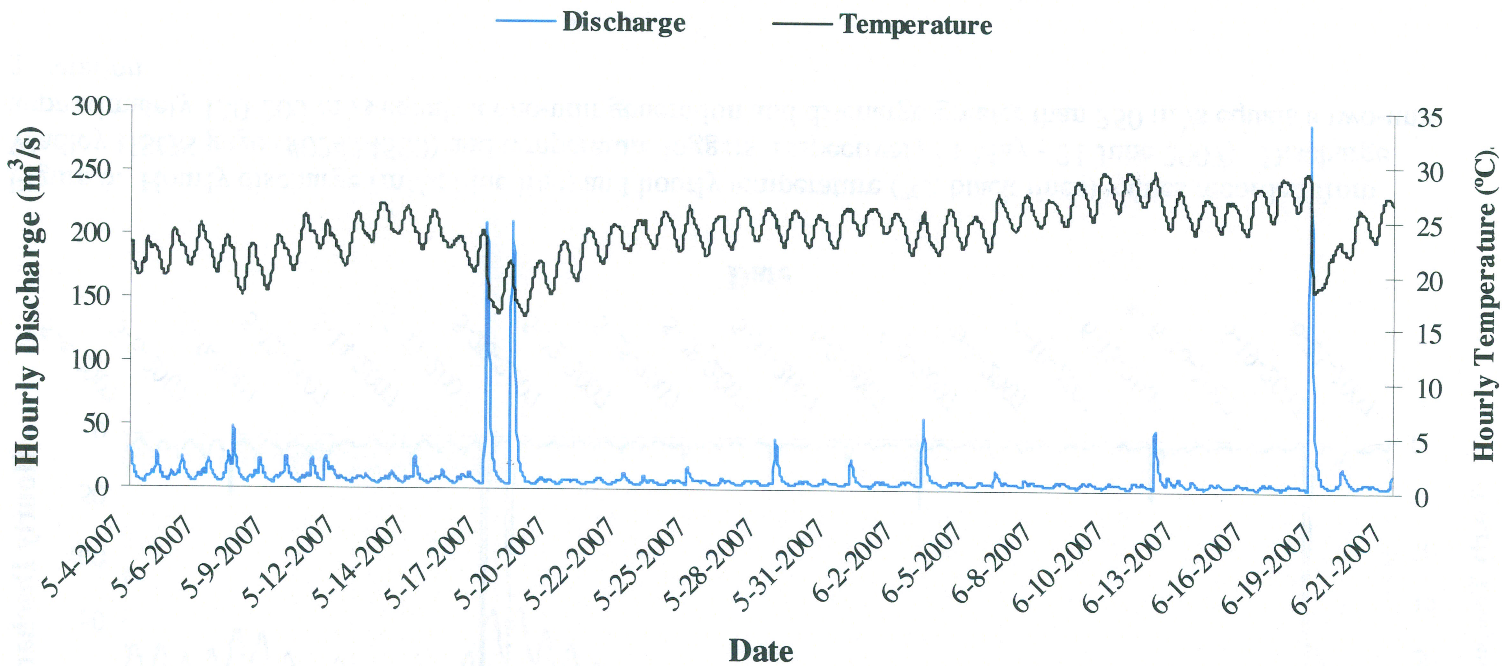


Figure 6. Hourly discharge (m^3/s; blue line) and hourly temperature (°C; black lines) values recorded from Wadley USGS gage (#02414500) and temperature loggers, respectively (4 May - 21 June 2007). Discharge approximately 150-200 m^3/s equals a one-unit generation and discharge greater than 250 m^3/s equals a two-unit generation.

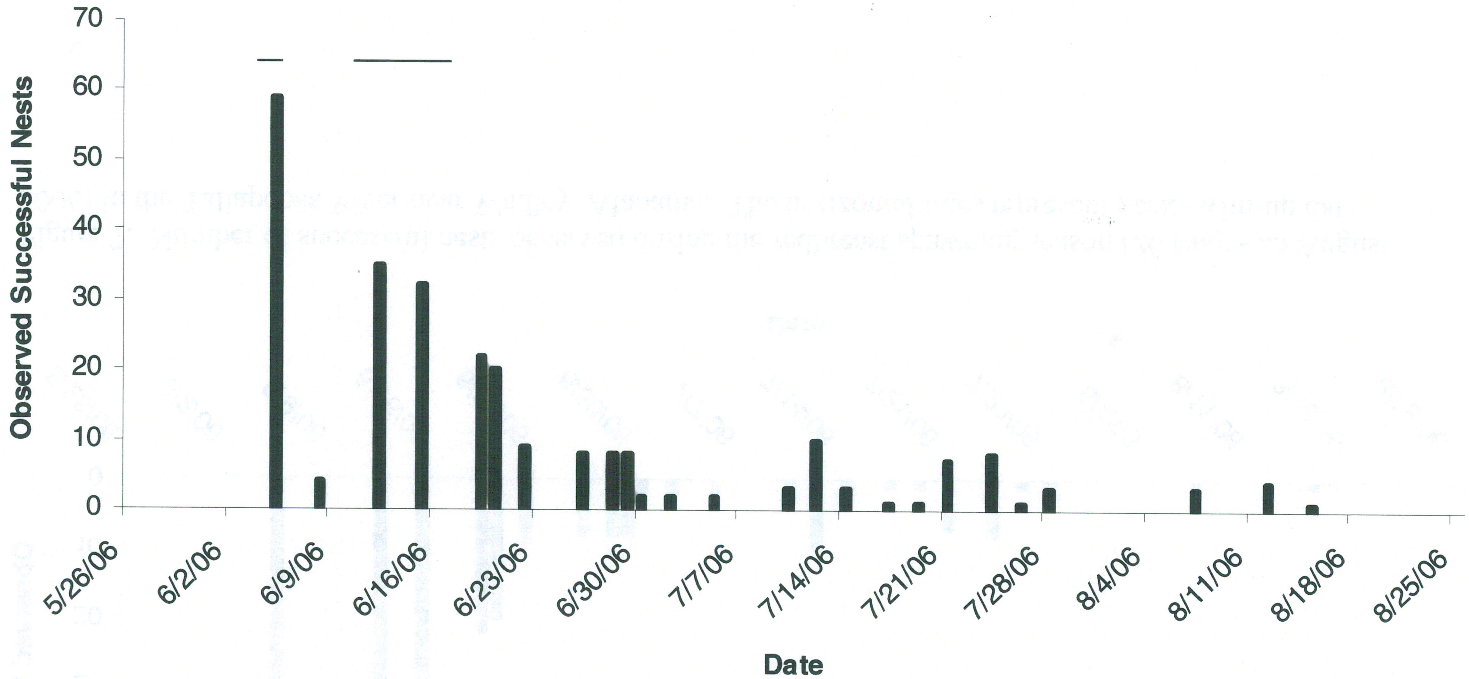


Figure 7. Number of successful nests observed during the redbreast spawning season (26 May - 25 August 2006) in the Tallapoosa River near Wadley, Alabama. The horizontal lines represent peak swim-up dates.

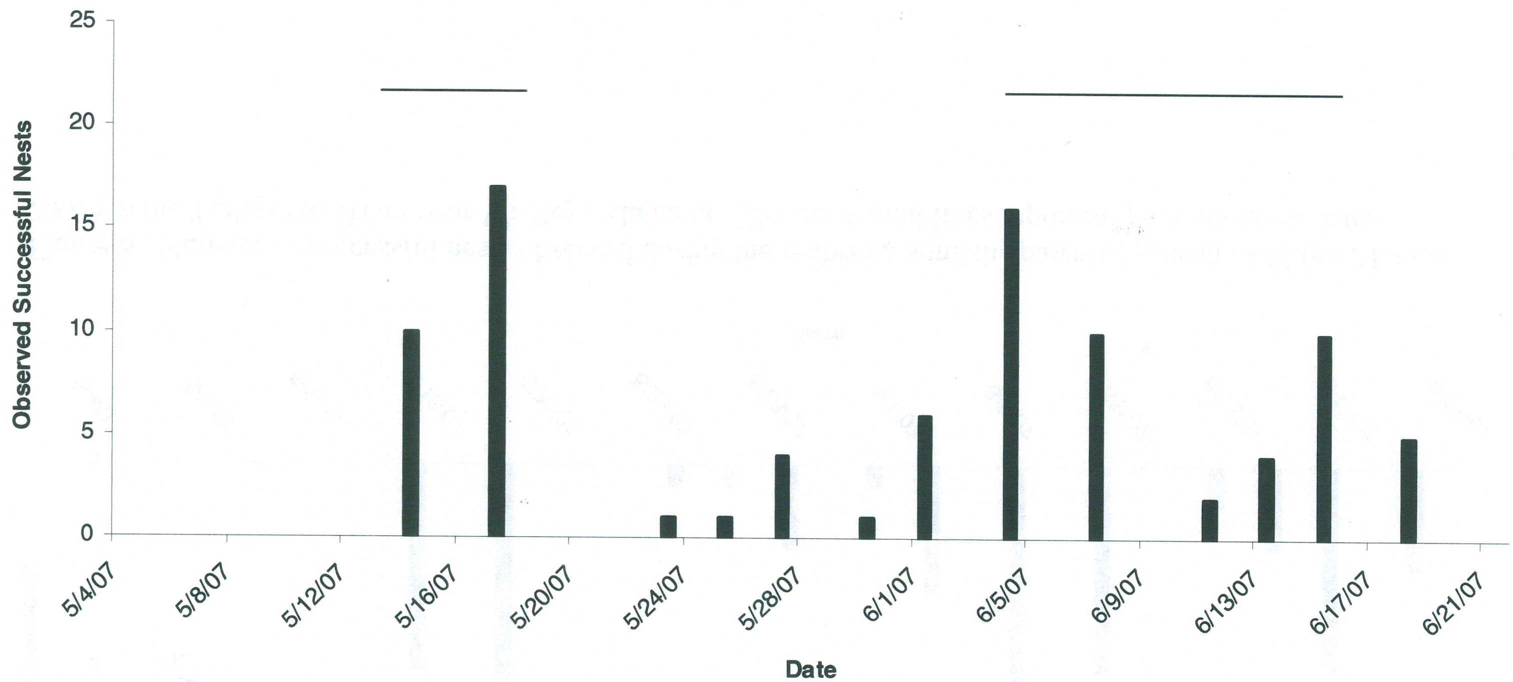


Figure 8. Number of successful nests observed during the redbreast sunfish spawning season (4 May - 21 June 2007) in the Tallapoosa River near Wadley, Alabama. The horizontal lines represent peak swim-up dates.

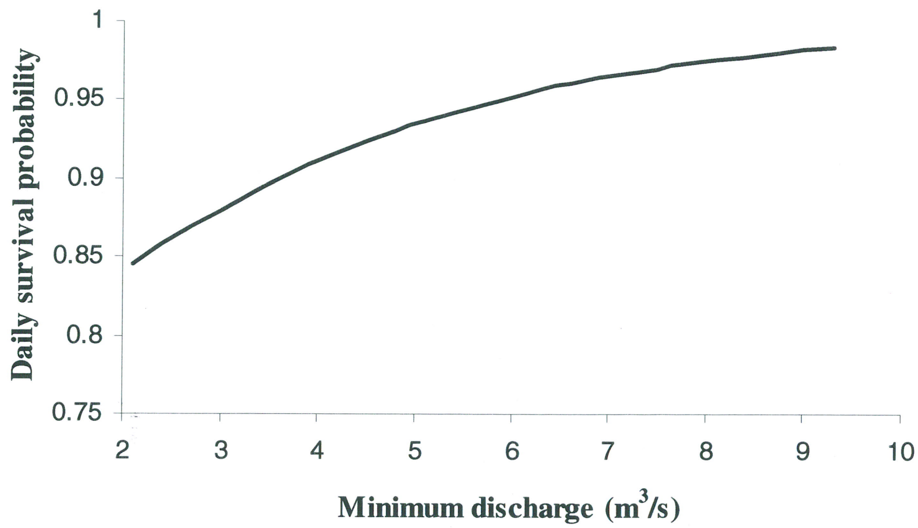


Figure 9. Daily survival probability of redbreast sunfish nests in response to minimum discharge (m^3/s) values observed during the spawning season (2006, Tallapoosa River, Wadley, Alabama).

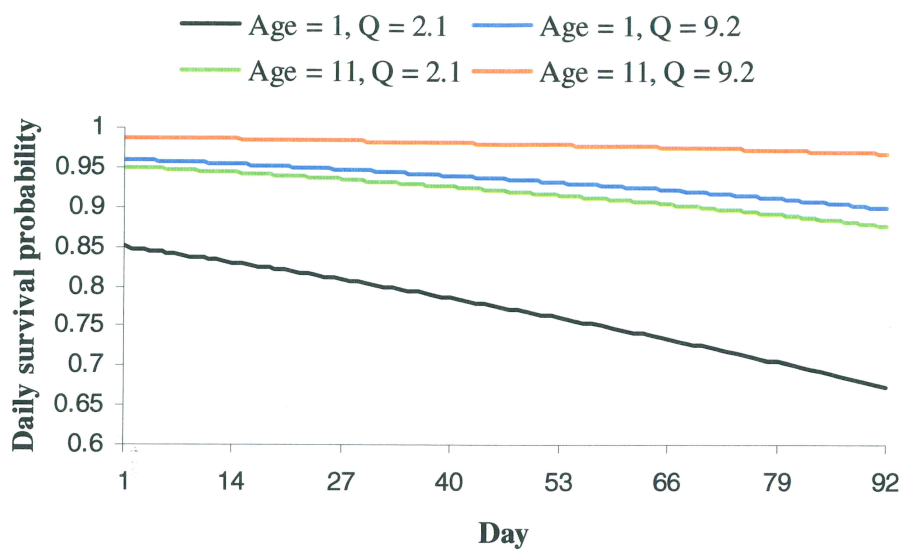


Figure 10. The effects of nest age (age 1 and 11-day old nests), and discharge (Q = 2.1 m^3/s: lowest minimum daily discharge; Q = 9.2 m^3/s: greatest minimum daily discharge) on the daily survival probability of redbreast sunfish nests across the spawning season (2006, Tallapoosa River, near Wadley, Alabama). Day 1 corresponds to 26 May, and day 92 corresponds to 25 August.

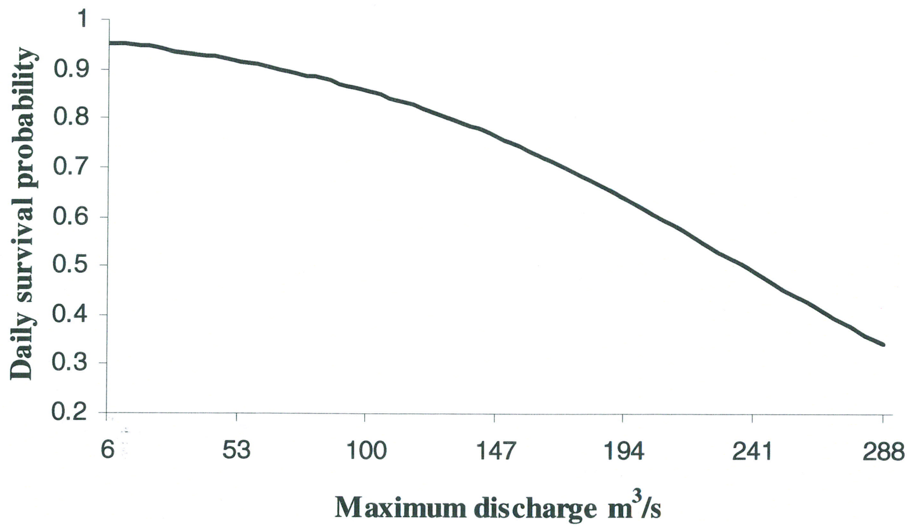


Figure 11. Daily survival probability of redbreast sunfish nests in response to maximum discharge (m^3/s) values observed during the spawning season (2007, Tallapoosa River, near Wadley, Alabama).

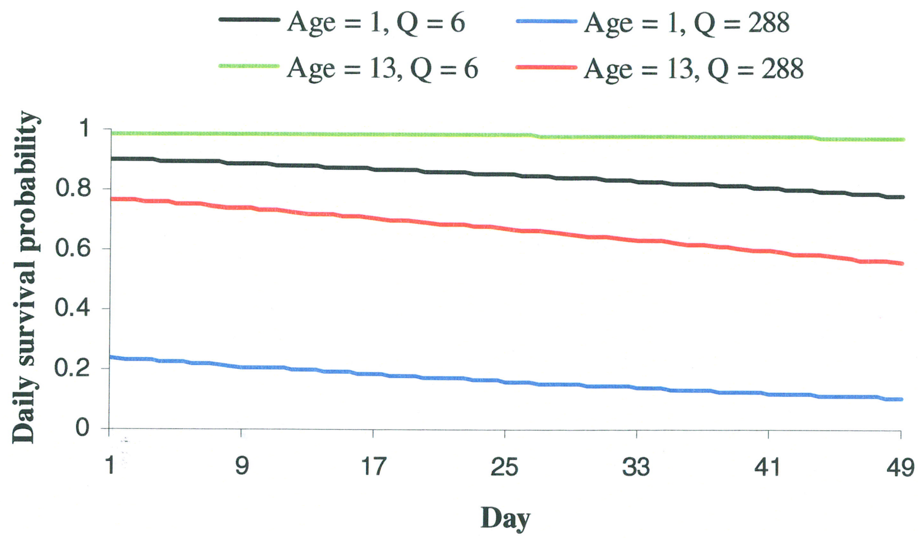


Figure 12. The effects of nest age (age 1 and 13-day old nests), and maximum discharge (Q = 6 m^3/s: lowest maximum daily discharge; Q = 288 m^3/s: highest maximum daily discharge) on the daily survival probability redbreast sunfish nests across the spawning season (2007, Tallapoosa River, near Wadley, Alabama). Day 1 corresponds to 4 May, and day 49 corresponds to 21 June.

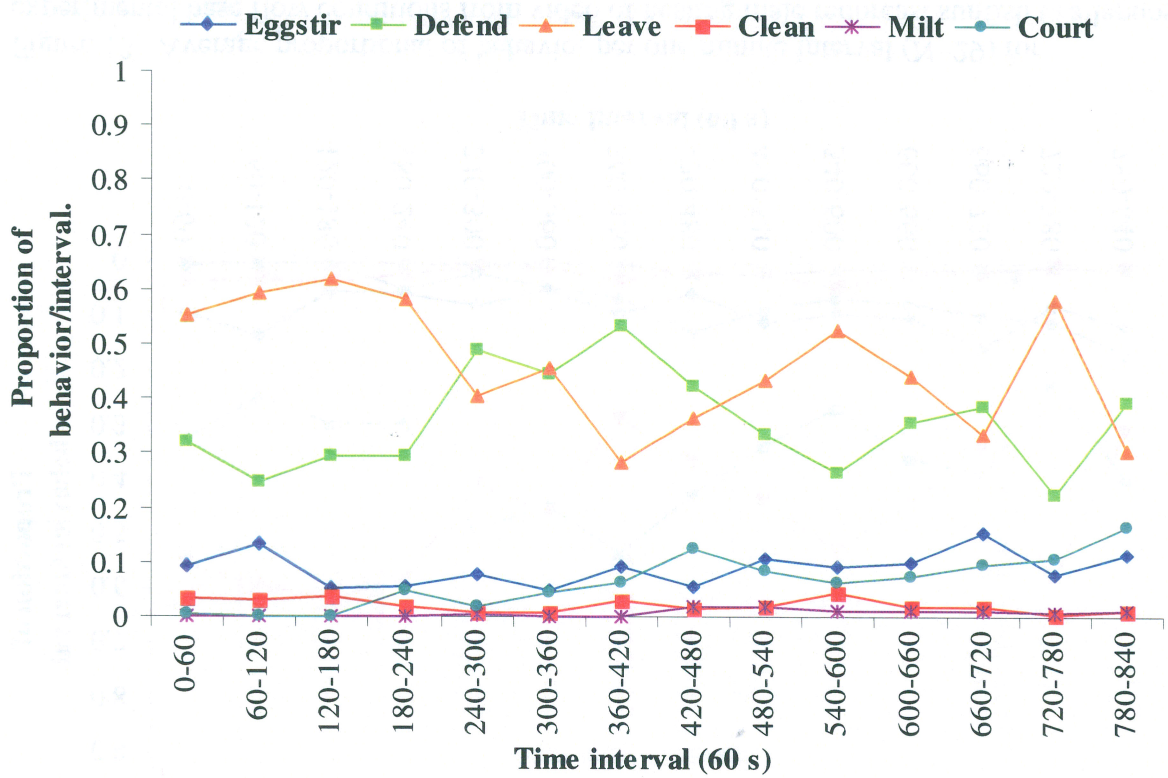


Figure 13. Average proportional of behavior per one minute interval (N=29) for experimental base flow conditions from video of nesting male redbreast sunfish (Tallapoosa River, Wadley, Alabama 2006 and 2007).

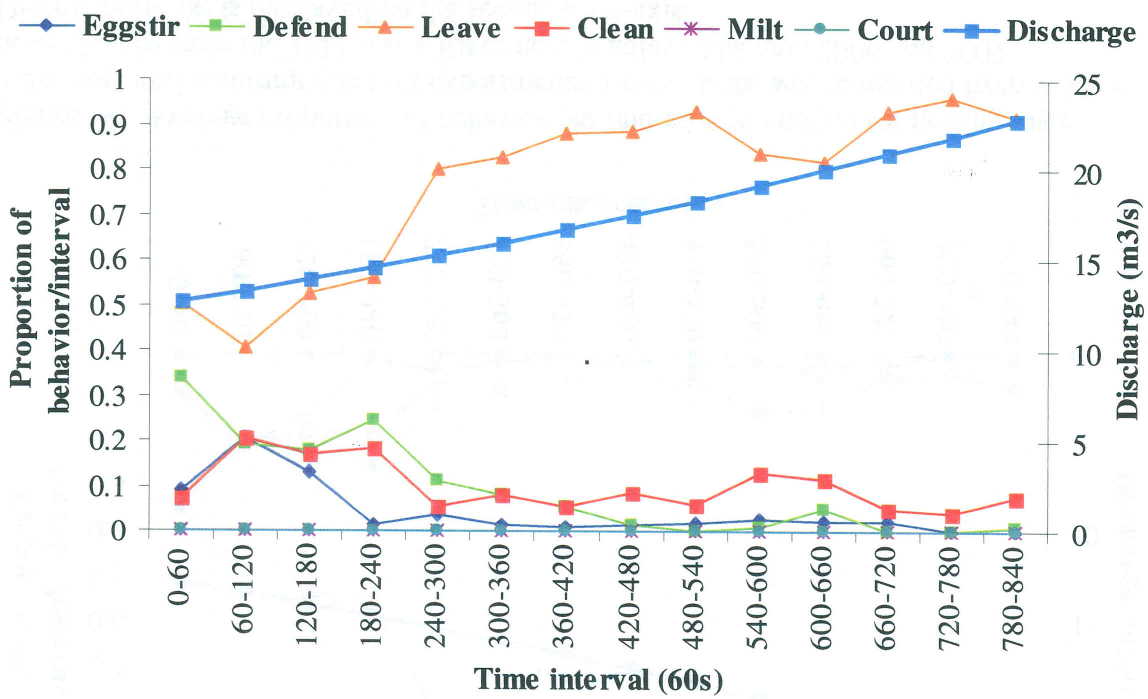


Figure 14. Average proportion of behavior per one-minute interval for nesting male redbreast sunfish during one-unit experimental flows. Data were compiled from video of nests (N=10) from the Tallapoosa River near Wadley, Alabama 2006 and 2007. Discharge (m^3/s) is displayed on the secondary y-axis.

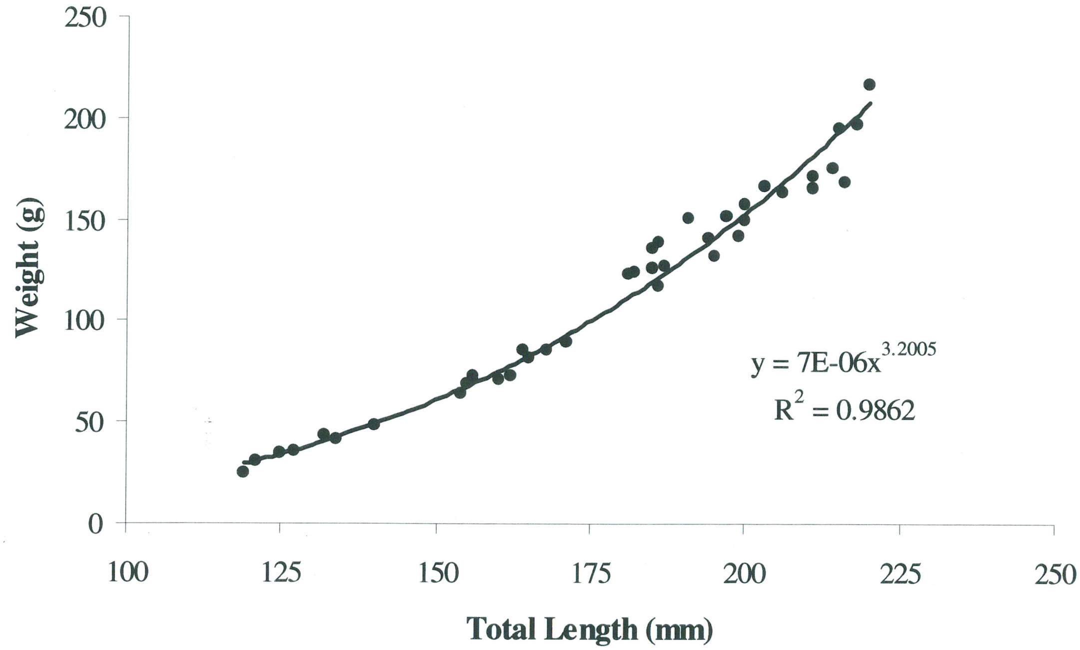


Figure 15. Length:weight regression of male redbreast sunfish collected during April 27, 2007 – May 17, 2007 and June 28, 2007 from the Tallapoosa River near Wadley, Alabama (2007).

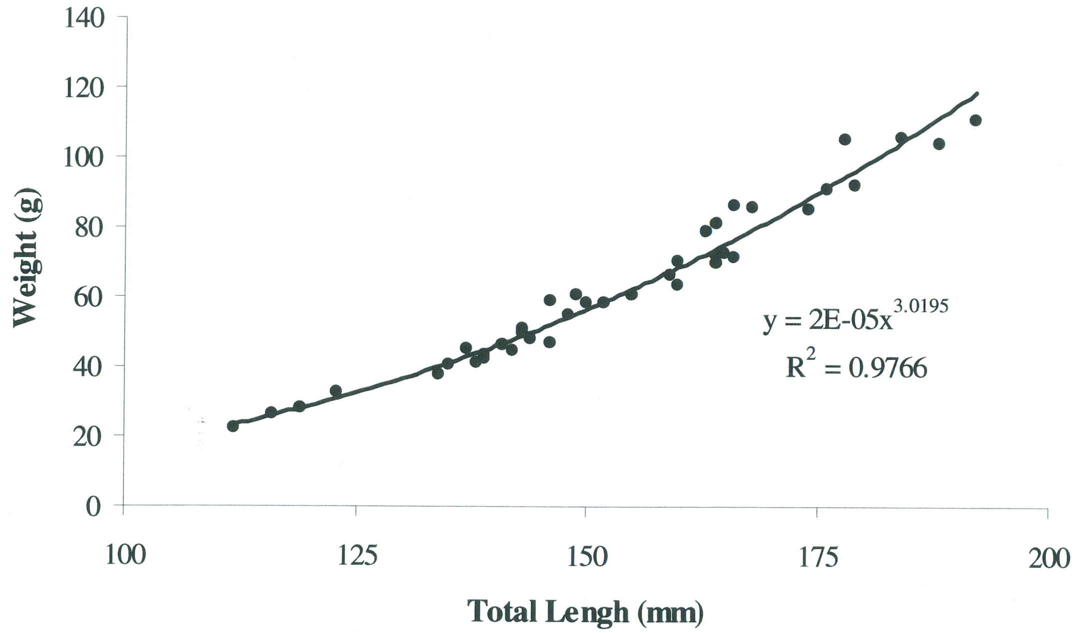


Figure 16. Length:weight regression for male redbreast sunfish collected during May 10 – May 29, 2007 and July 26, 2007 from Saugahatchee Creek, Notasulga, Alabama (2007).

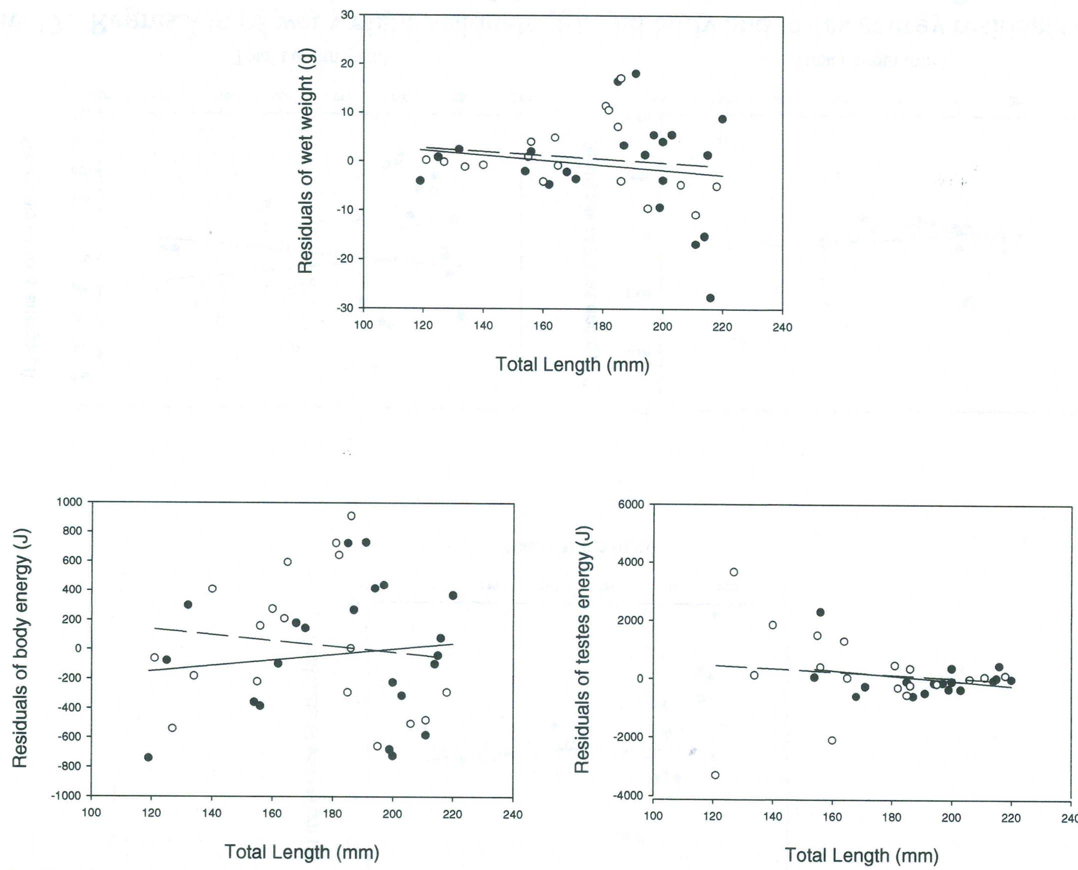


Figure 17. Regression of wet weight residuals (g), and body and testes energy residuals (J) of pre- and post-spawn male redbreast sunfish against total length (Tallapoosa River, Wadley, Alabama collected: April 27, 2007 – May 17, 2007 and June 28, 2007). Solid lines and filled circles represent pre-spawn and dashed lines and hollow circles represent post-spawn individuals.

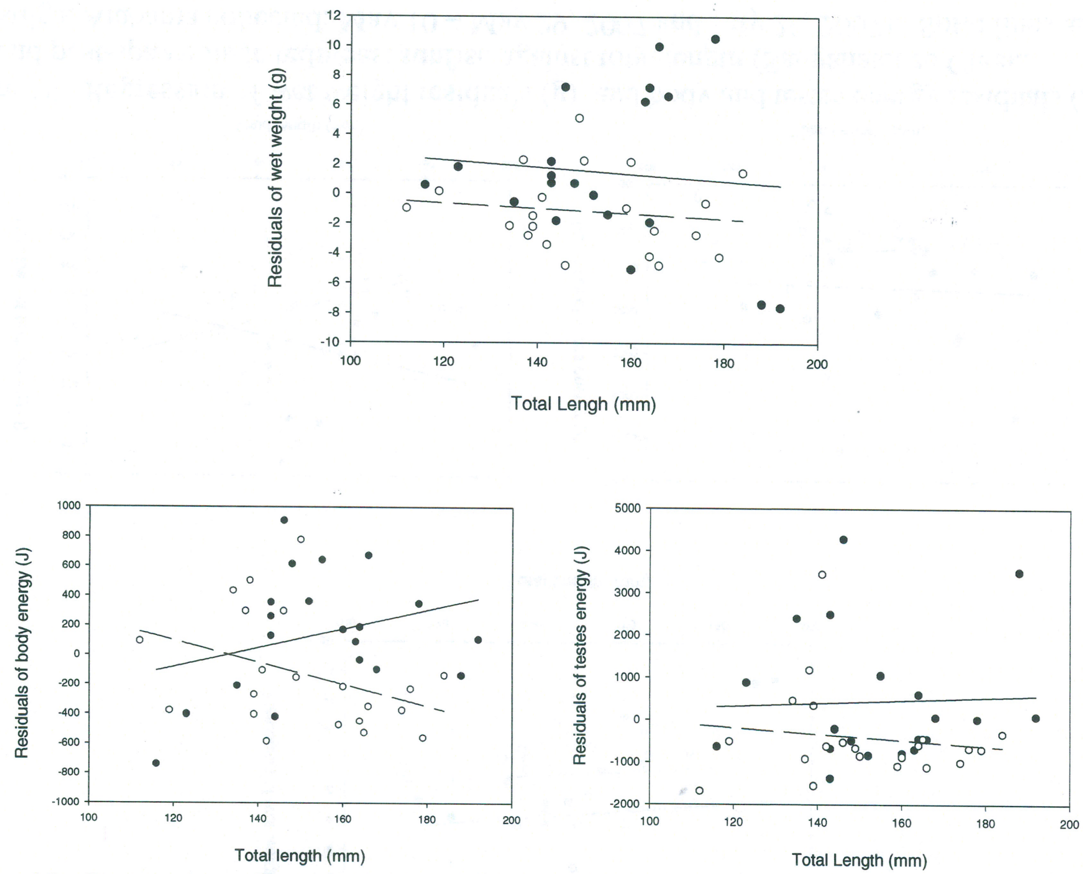


Figure 18. Regression of wet weight residuals (g), and body and testes energy residuals (J) of pre- and post-spawn male redbreast sunfish against total length (Saugahatchee Creek, Notasulga, Alabama collected: May 10 – May 29, 2007 and July 26, 2007). Solid lines and filled circles represent pre-spawn and dashed lines and hollow circles represent post-spawn individuals.

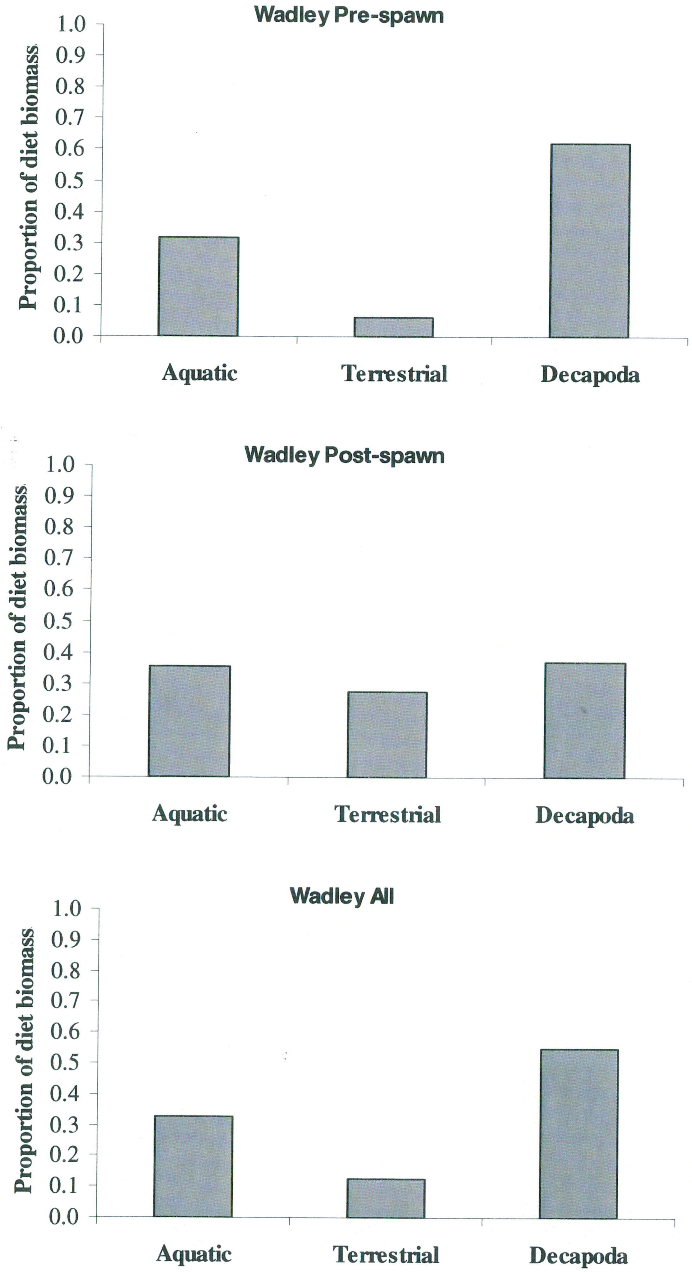


Figure 19. Diet biomass proportions for male redbreast sunfish collected from the Tallapoosa River, near Wadley, Alabama during April 27, 2007 – May 17, 2007 and June 28, 2007.

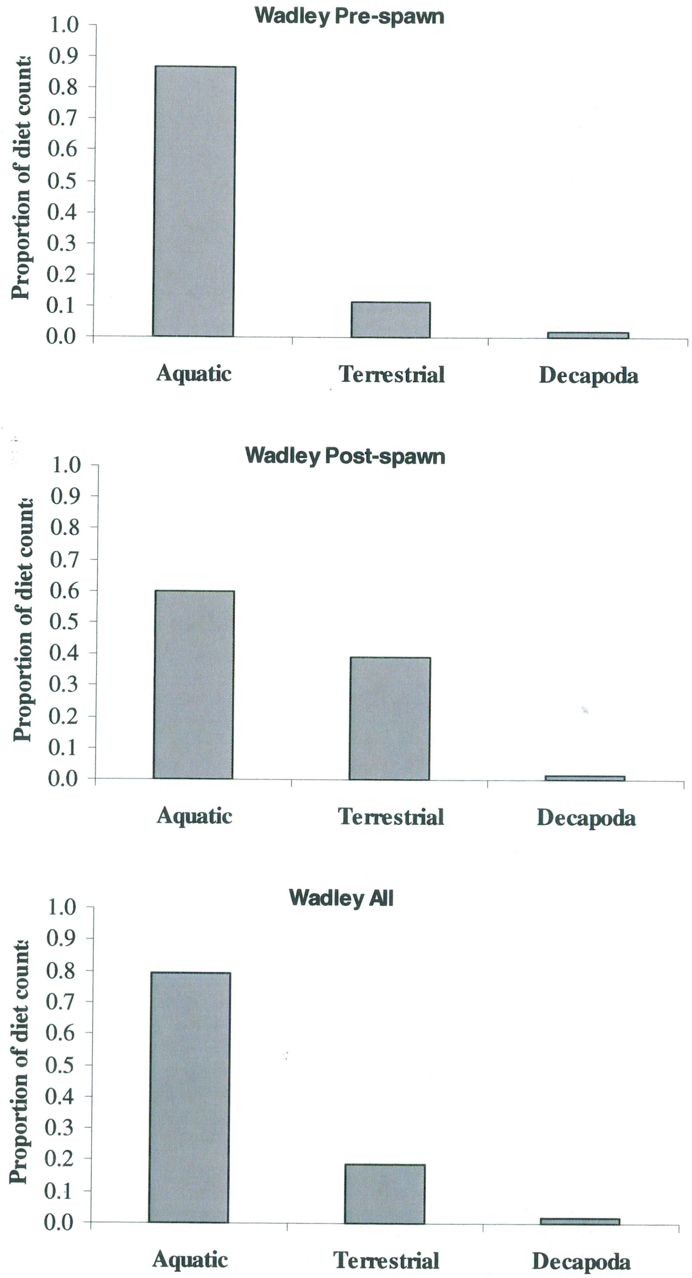


Figure 20. Diet count proportions for male redbreast sunfish collected from the Tallapoosa River, near Wadley, Alabama during April 27, 2007 – May 17, 2007 and June 28, 2007.

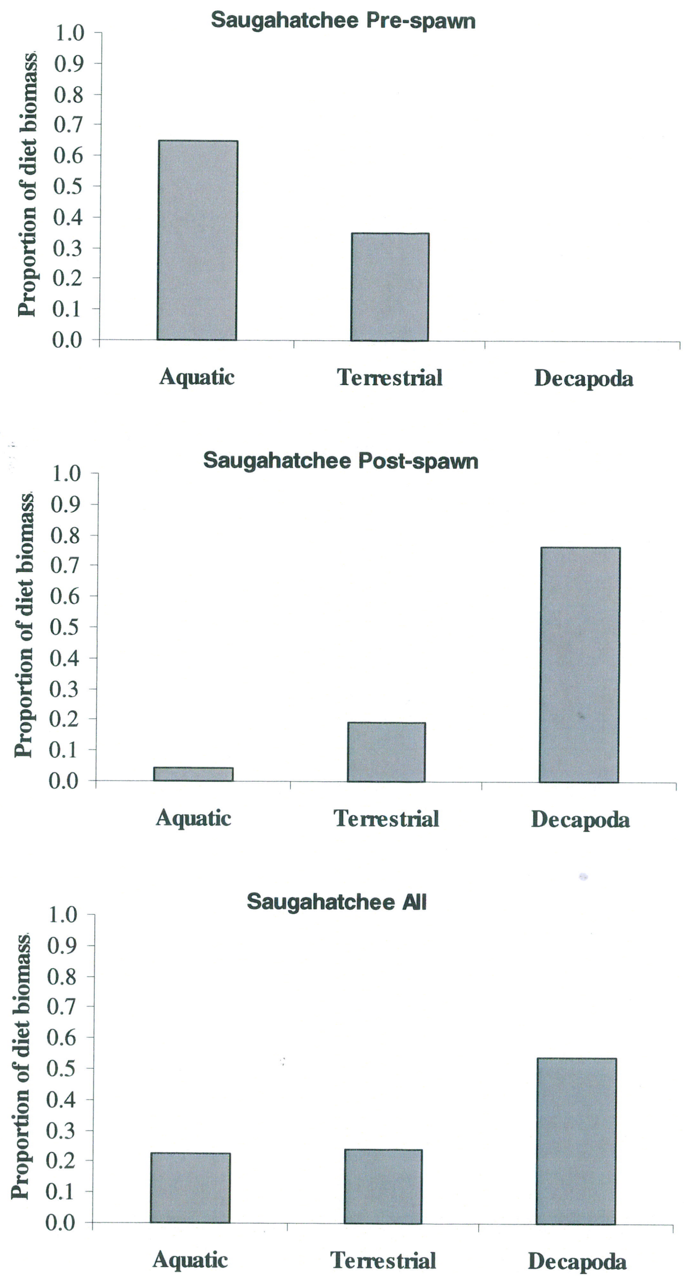


Figure 21. Diet biomass proportions for male redbreast sunfish collected from Saugahatchee Creek, Notasulga, Alabama during May 10 – May 29, 2007 and July 26, 2007.

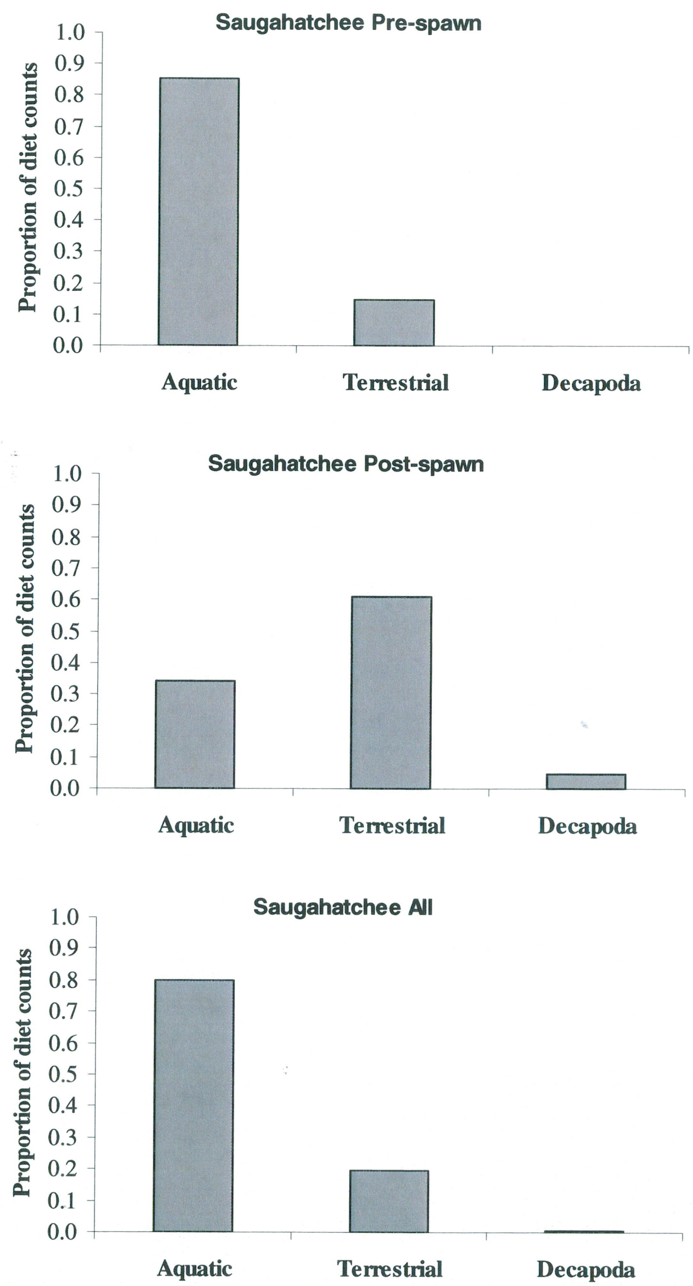


Figure 22. Diet count proportions for male redbreast sunfish collected from Saugahatchee Creek, Notasulga, Alabama during May 10 – May 29, 2007 and July 26, 2007.

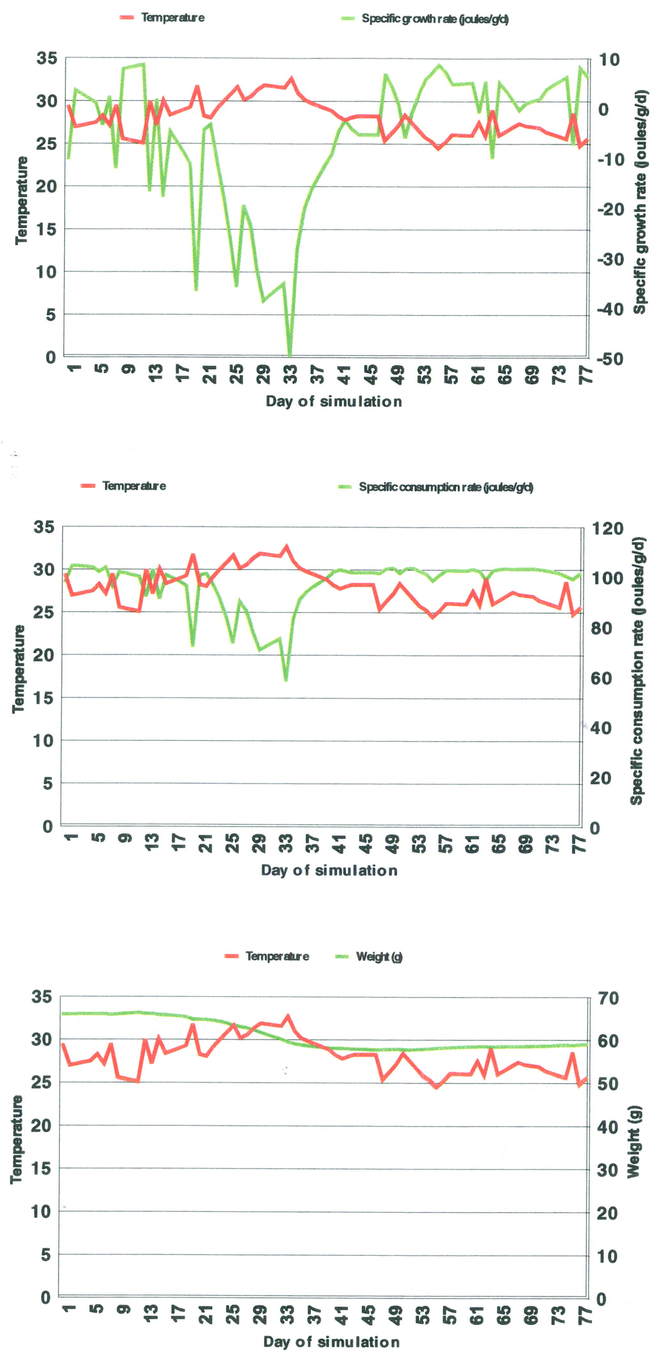


Figure 23. Estimated specific growth rate (J/g/d), specific consumption rate (J/g/d), and weight (g) from bioenergetic modeling of base metabolic parameters for adult bluegill and lab measurements taken from male redbreast sunfish collected from Saugahatchee Creek, Notasulga, Alabama (May 10 – May 29, 2007 and July 26, 2007).

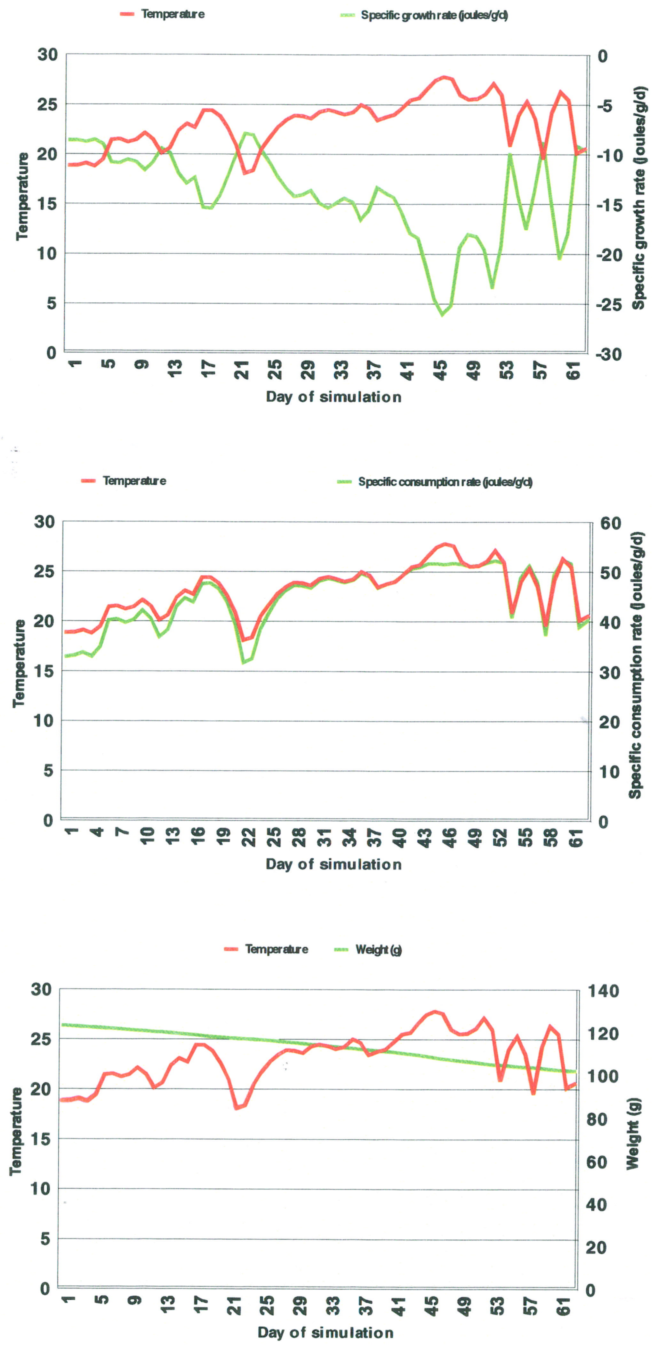
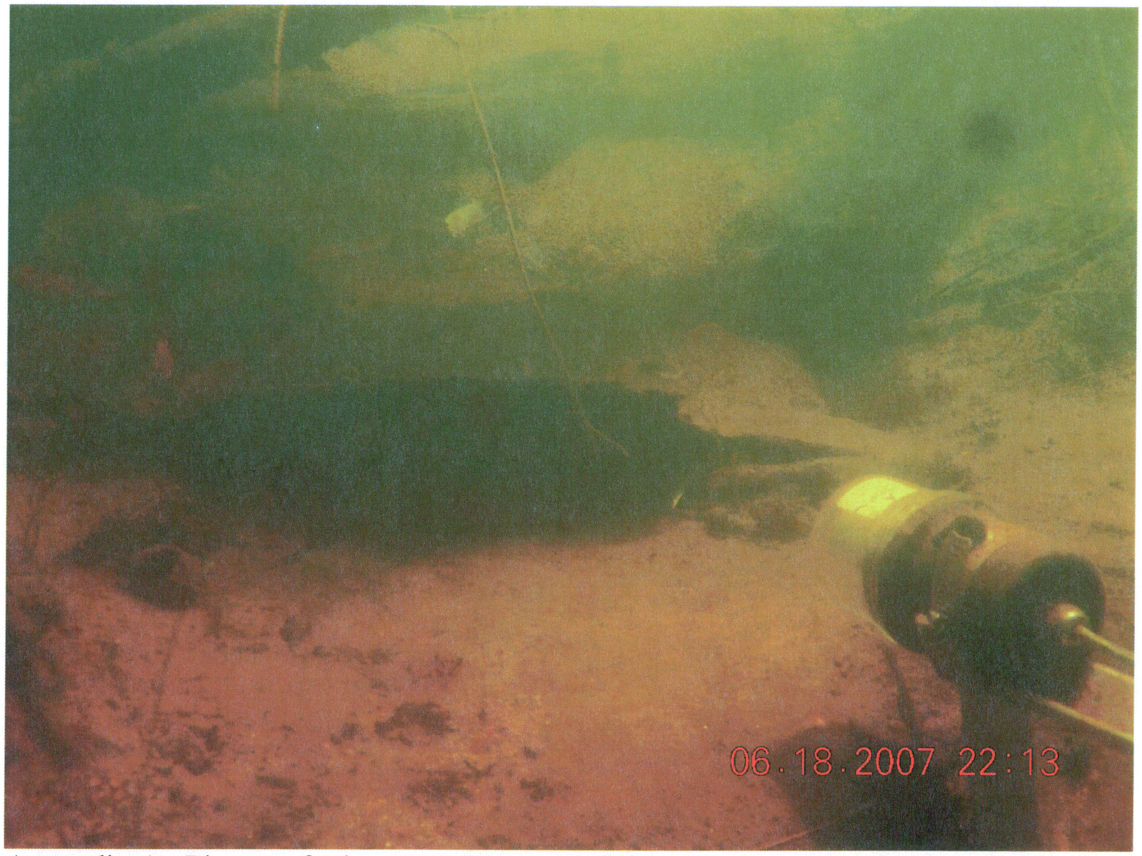


Figure 24. Estimated specific growth rate (J/g/d), specific consumption rate (J/g/d), and weight (g) from bioenergetic modeling of base metabolic parameters for adult bluegill and lab measurements taken from male redbreast sunfish collected from the Tallapoosa River, Wadley, Alabama (April 27 – May 17, 2007 and June 28, 2007).

APPENDICES



Appendix A. Picture of where a redbreast sunfish nest was previously recorded on June 17, 2007 during a two-unit generation. Camera left from previous day in bottom right corner of the picture.

Appendix B. The CD contained with this thesis contains examples of behaviors recorded during experimental flows below Harris Dam on the Tallapoosa River, near Wadley, Alabama. Two formats are available on the CD which are supported by Window Media Player (.wmv) and Quicktime (.mov). ***If you have the electronic version on this thesis you can obtain these video files from www.rivermanagement.org by clicking on the contact link and emailing the project coordinator.

Video files:

1. Court and Milt - The court behavior is observed throughout this video and the milt behavior can be seen towards the end of the film where the female tilts her body to a more horizontal position and the male expels milt that appears like a spray.

2. Defend - This video shows the defend behavior which is different from the leave behavior where the male displays aggressiveness as can be seen by rapid swimming and splayed fins.

3. Egg-stir - This video shows the male fanning the eggs heavily with the caudal fin to help eggs adhere to the substrate.

4. Leave - This video shows a male swimming from the nest with no apparent justification (i.e., no fns splayed).

5. One-unit clean - This video displays a male performing the clean behavior (e.g., debris removal) from the nest during a one-unit transition.

6. Two-unit transition - The video shows a limb being pushed into a nest during a two-unit transition then displays the inability to see the nest as discharge increases.