PRIVATELY-OWNED SMALL IMPOUNDMENTS OF CENTRAL ALABAMA: A SURVEY AND EVALUATION OF MANAGEMENT TECHNIQUES AND ENHANCEMENTS

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.

____

Norman Victor Haley, III

Certificate of Approval:

Dennis R. DeVries, Co-Chair
Professor
Fisheries and Allied Aquacultures

Russell A. Wright, Co-Chair
Associate Professor
Fisheries and Allied Aquacultures

Micheal S. Allen
Associate Professor
Fisheries and Aquatic Sciences

George T. Flowers
Dean
Graduate School

PRIVATELY-OWNED SMALL IMPOUNDMENTS OF CENTRAL ALABAMA: A SURVEY AND EVALUATION OF MANAGEMENT TECHNIQUES AND ENHANCEMENTS

Norman Victor Haley, III

A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
August 10, 2009

PRIVATELY-OWNED SMALL IMPOUNDMENTS OF CENTRAL ALABAMA: A SURVEY AND EVALUATION OF MANAGEMENT TECHNIQUES AND ENHANCEMENTS

Norman Victor Haley, III

____
Signature of Author

____
Date of Graduation

VITA

Norman Victor Haley, III, son of Norman Victor Jr. and Debra (Patterson) Haley, was born November 2, 1982 in Toledo, Ohio. He graduated from Swanton High School in Swanton, Ohio in 2001 and received his Bachelor of Science degree in Fisheries Management from The Ohio State University in June 2005. In May 2007, he entered the Graduate School at Auburn University in the Department of Fisheries and Allied Aquacultures. While at Auburn, he received the David G. Partridge Memorial Award.

THESIS ABSTRACT

PRIVATELY-OWNED SMALL IMPOUNDMENTS OF CENTRAL ALABAMA: A SURVEY AND EVALUATION OF MANAGEMENT TECHNIQUES AND ENHANCEMENTS

Norman Victor Haley, III

Master of Science, August 10, 2009
(B.S., The Ohio State University, 2005)

123 Typed Pages

Directed by Dennis R. DeVries and Russell A. Wright

Small impoundments are abundant and widespread throughout central Alabama, and support a large portion of recreational fishing effort. Because the quality of fishing in these ponds is directly related to the management techniques and enhancements applied by the pond owners, it is important that these valuable water bodies be properly and efficiently managed. Successful management requires that any tools that are used be accurately assessed such that outcomes can be reasonably predicted.

Towards this end, I quantified the characteristics and use of private-ponds in central Alabama as well as the management objectives, pond management techniques/enhancements, and the awareness of available services of the region's private-pond owners via a telephone survey. I surveyed 135 randomly selected private-pond owners in 23 central Alabama counties. The three most common techniques/enhancements used by pond owners were fertilization (48%), providing supplemental pellet feed (45%), and stocking supplemental forage for largemouth bass (12%). Threadfin shad were the most commonly stocked forage species (33%). The results from these surveys were used to identify 50 ponds to assess fish population response to varying combinations of the most commonly used management enhancements/techniques.

Ponds were sampled using boat electrofishing to quantify largemouth bass and bluegill population characteristics. Water quality, morphometric, and watershed soil characteristics were also quantified for each site. Results showed that a great deal of variability existed within management classifications. However, threadfin shad enhanced ponds exhibited overall greater length-frequency distributions, stock density indices, growth, body condition, and density of largemouth bass when compared to those ponds that did not contain threadfin shad. Bluegill length-frequency distributions and densities were similar among all fertilizer and threadfin shad enhanced ponds and stock density indices and body conditions were similar among all management strategies. This information provides insight toward determining the most effective techniques and enhancements for the production and maintenance of quality sportfish populations in southeastern U.S. small impoundments, supporting further recreational and economic opportunities throughout the region.

ACKNOWLEDGEMENTS

The author would like to thank the many people who have helped throughout the course of this project: Co-advisors, Drs. Russell Wright and Dennis DeVries, for their faith in his ability as a graduate student and for their guidance, support, and expertise; Dr. Micheal Allen for serving as a committee member and for his generous assistance and input towards the study; Tammy DeVries, Troy Farmer, Mike Leonard and Tommy Purcell for their help in the field and in the laboratory; and Dave Glover for his extensive help with statistical analysis. He would also like to thank Graves Lovell from the Alabama Division of Wildlife and Freshwater Fisheries, Robert Gates from the Natural Resources Conservation Service, and Claude Reeves from the Alabama Cooperative Extension System for helping him locate ponds suited for the study. Finally, the author would like to thank each pond owner and property manager who volunteered access to their properties and special thanks to his parents and wife, Allison, for their unwavering support and encouragement throughout his graduate research assistantship.

Style manual or journal used North American Journal of Fisheries Management

Computer software used Microsoft Word, Microsoft Excel, Sigmaplot 11.0, SAS Version 9.1, Natural Resources Conservation Service Web Soil Survey

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Small impoundments are formed by constructing dams or digging depressions to store water from springs, streams, wells, direct precipitation, and surface runoff and can vary widely in depth (Dendy 1963). Small impoundments are abundant throughout the U.S., with more than 2.1 million ponds located on privately-owned lands (USDA 1982) with 50,000-100,000 in the state of Alabama alone (Modde 1980). Although small impoundments may serve many purposes such as flood control, swimming, aesthetics, irrigation, water supply, wildlife habitat, energy conservation, and sediment retention, the most common use is recreational fishing.

Swingle (1950) defined a balanced fish population as one that yields crops of harvestable fish year after year. For modern private pond owners, fish community balance is not only associated with harvest and yield, but also with the size and number of fish available for angling. Fish community balance dictates the overall quality of fishing in small impoundments and is directly related to the management techniques and enhancements applied by the pond owner. Many pond owners wish to maximize fish density and size (Hampton and Lackey 1976), however, achieving these goals while maintaining balance can be difficult through traditional pond management techniques, such as fertilizing, liming, balanced harvest, and weed control. Pond owners also apply enhancements in an attempt to increase production beyond what is generated by traditional management techniques. Abroad array of enhancements currently exists, ranging from installation of fish attractors and aerators, stocking alternative forage species, applying supplemental pellet feed, altering stocking and harvest rates, and stocking select predator and prey hybrids, sterile species, and/or genetic strains.

Swingle (1946) established the pond stocking combination of largemouth bass *Micropterus salmoides* and bluegill *Lepomis macrochirus* based on their highly compatible predator-prey relationship and their value as sportfish. The relationship between these species and their management in small impoundments is well studied and of great interest given that they are often the basis of recreational fishing in small impoundments, particularly in the Southeastern U.S. (Swingle and Smith 1941; Swingle 1946, 1950, 1952, 1956, Reiger 1962; Modde and Scalet 1985; Hambright et al. 1986; Guy and Willis 1990; Olson et al. 1995; Brenden and Murphy 2004; Olive et al. 2005). The bluegill exhibits several qualities that make them a sustainable prey fish for largemouth bass, including that they are desirable to anglers, tolerant of a wide range of temperatures, omnivorous, and they mature early, and can have multiple reproduction events within a year (Swingle and Smith 1941). As a forage fish, the ability of bluegill to outgrow the gape of largemouth bass is both a positive and negative quality because they are rarely eliminated from a system but they can become invulnerable to predation by smaller size classes of largemouth bass as their maximum size often exceeds the gape of most largemouth bass (Hambright 1991). Bluegill has some other shortcomings as a forage species for largemouth bass as they prey upon fish eggs and larvae (Neves 1975), have a lower caloric density than other forage species (Eggleton and Schramm 2002), be nearly invulnerable to predation in dense macrophytes (Savino and Stein 1982), and their coloration, spines, and predator avoidance behaviors can reduce the ability of largemouth bass to effectively prey upon on them (Turner and Mittelbach 1990). These shortcomings have led pond owners and managers to explore other supplemental prey species to stock in conjunction with bluegill to produce larger, faster growing, and more abundant largemouth bass.

The addition and manipulation of prey species, such as threadfin shad *Dorosoma petenense*, has become a popular technique for enhancing piscivorous sport fish populations in ponds, reservoirs, and lakes (Ney and Ney 1981; Noble 1981; see review in DeVries and Stein 1990). While the interactions of threadfin shad, largemouth bass, and bluegill populations have been examined in larger impoundments (Fast et al. 1982; DeVries 1989; see review in DeVries and Stein 1990; DeVries et al. 1991; DeVries and Stein 1994; Garvey et al. 1998), little to no information has been published regarding the interactions of these species in small impoundments. Despite this absence of scientific evaluation, private pond management consultants often recommend stocking threadfin shad in small impoundments as supplemental forage for largemouth bass in the expectation that threadfin shad, in conjunction with bluegill, will result in a higher quality largemouth bass population than would foraging on bluegills alone (e.g., Nutt 2004; Southeastern Pond Management 2005).

In larger systems (e.g., >405 ha), threadfin shad has been found to positively affect largemouth bass growth, survival, and recruitment. After assessing the pre- and post-stocking affects of two California lakes, von Geldern and Mitchell (1975) found largemouth bass growth rates to increase for all age classes after threadfin shad stocking. Miller (1971) and Tharatt (1966) found that growth of largemouth bass beyond age-2 was accelerated in the presence of threadfin shad. High use of threadfin shad by age-0 largemouth bass (Kimsey et al. 1957, von Geldern and Mitchell 1975), juvenile largemouth bass (Wanjala et al. 1986), and adult largemouth bass (Kimsey et al. 1957, Goodson 1965, Wanjala et al. 1986) has been well documented. However, even in systems that contain shad, centrarchids often remain the principal prey for largemouth bass (Timmons et. al. 1980; Jackson et al. 1991; Bettoli et al. 1992; Irwin et al. 2003).

Shad manipulations can also have negative effects on both the target and non-target species within an impoundment (Adams and DeAngelis 1987; see review in DeVries and Stein 1990; DeVries and Stein 1994; Garvey and Stein 1998). As life-long limnetic zooplanktivores, threadfin shad (Burns 1966; Heidinger 1983; Ziebell et al. 1986) can severely reduce zooplankton density (Johnson 1970; von Geldern and Mitchell 1975; Prophet 1982; Prohet 1985; Ziebell et al. 1986; Prophet 1988; Guest et al. 1990; Garvey and Stein 1998; DeVries et al. 1991). Negative competitive effects of threadfin shad on age-0 bluegill and largemouth bass recruitment and condition have been documented (Tharatt 1966; Miller 1971; DeVries et al. 1991; Stein et al. 1995). In addition, threadfin shad are vulnerable to sharp decreases in water temperature (Noble 1981) and temperatures below 12°C cause behavioral changes that increase their susceptibility to predation and population depletion. Water temperatures below 5°C can cause large or complete population die-offs that can lead to reduced predator growth and instantly unbalanced fisheries (Strawn 1965; Griffith and Tomljanovich 1976). Negative effects of threadfin shad could be amplified when compounded over several years (DeVries et al. 1991).

Another common enhancement of small impoundments is the application of pellet feed to supplement prey fish populations, namely bream (*Lepomis spp.*), and channel catfish *Ictalurus punctatus* (Berger 1982; Porath et al. 2003; Murnyak et al. 1984; Ligler 1971; Fisher 1979; Kilgen 1974; Schmittou 1969; Nail and Powell 1975). Pellet feeding as a food supplement for sunfish populations has been studied as a pond enhancement since 1943 (unpublished Fisheries Research Annual Report, Auburn University), yet never evaluated in conjunction with threadfin shad, bluegill, and largemouth bass communities. Because fish growth often is limited by food availability, supplemental feeding is a logical tool to improve the condition of fish in small impoundments as the energy cost for bluegill to feed on pellets is small relative to the high caloric intake, which can be 4-5 times greater than those fed natural foods (Schalles and Wissing 1976).

The application of supplemental feed to a pond may reduce the negative effects of competition and recruitment associated with the interaction of threadfin shad with bluegills and largemouth bass. Porath and Hurley (2005) found that the growth increments of pellet fed bluegill were greater than those of non-fed bluegill, except when gizzard shad were present, as the gizzard shad were likely competitors against bluegill for pellet feed and zooplankton. Berger (1982) and Schmittou (1969) found the overall length, weight, and relative weight of pellet-fed bluegills was greater than those of bluegills who did not receive feed. Substantial increases in the standing stock of bluegill in ponds that receive pellet feed have been recorded (Schmittou 1969) and, in lakes, pellet feeding has been found to increase the number of large bluegills (Nail and Powell 1975). Supplemental feeders can also provide the added benefit of serving as fish attractors capable of increasing angler success and harvest (Berger 1982).

Other factors beyond the applied management techniques and enhancements are also likely to affect the production and population state of the pond's fish community. One such factor is the soil characteristics of the pond's watershed. Because the interaction of the imports (e.g., sediments, nutrients, and carbon from dissolved or particulate organic matter) from the watershed to the pond can influence turbidity, water quality, primary production, habitat quality, species composition, and food web interactions, it is reasonable to speculate that soil characteristics of the surrounding watershed could directly or indirectly influence sport fish populations (Miranda 2008). Primary production of ponds in the Southeastern U.S. often is limited by phosphorous and buffering capacity or alkalinity. Fertilizer and calcium carbonate often are added to ponds to reduce such limitations by creating the nutrient base and buffering capacity needed to increase production from the top-down (Boyd 1990). However, the prairie soils found throughout portions of the Alabama Black Belt can provide sufficient fertility and alkalinity to ponds and seem to provide quality fishing on a more consistent basis than the loamy, acidic soils that are found throughout much of Alabama (Boyd 1990).

This study consisted of three objectives. First, I attempted to determine the management techniques and enhancements used by private pond owners in the Black Belt region of Central Alabama, their management objectives, the characteristics and uses of their ponds, and their awareness and perceptions regarding their pond, available management services, and management techniques and enhancements. Secondly, I attempted to evaluate the efficacy of stocking threadfin shad as supplemental forage and the application of supplemental pellet feed to improve sport fish production in recreational fishing ponds. In an effort to identify relationships between largemouth bass and bluegill population statistics and the enhancements of stocking threadfin shad and applying pellet feed, I quantified and compared the growth, condition, and population structure of bluegill and largemouth bass populations in private small impoundments that varied by management strategy. I predicted that if the enhancements improved bluegill or largemouth bass production or size, then their population statistics would be positively related to the enhancement. Lastly, in attempt to determine the extent at which soil characteristics influence water quality and sport fish communities in small impoundments, I explored the relationship between the watershed soil properties of calcium carbonate, cation exchange capacity (CEC), and organic matter among water quality characteristics and fish population statistics.

STUDY REGION

The Black Belt region of Alabama extends from the East-Central border to West-Central border of the state and includes some of the most impoverished counties in the United States. Based on the 2000 U.S. Census, the average median household income for counties of the Black belt region is $24,795.35, a meager figure when compared to the nation's median household income of $41,994. In the early 1800s, the region was defined by its dark fertile prairie soil that is derived from ancient ocean floor consisting of the limestone known as Selma Chalk. By the 1900s, the definition of the Black Belt region was expanded to include counties with the demographic and socio-economic make-up of their impoverished residents. The 17 counties included in the Black Belt of Alabama consist of Barbour, Bullock, Butler, Choctaw, Crenshaw, Dallas, Greene, Hale, Lowndes, Macon, Marengo, Montgomery, Perry, Pike, Russell, Sumter, and Wilcox (Figure 1). Six additional counties, Clarke, Conecuh, Escambia, Monroe, Pickens, and Washington, were added to my study to expand coverage and because their economic statuses closely resembled those of Black Belt counties.

METHODS

Pond Owner Survey

I conducted a survey of private pond owners throughout the Alabama Black Belt to determine the characteristics and uses of their ponds, their pond management objectives, the pond management techniques/enhancements they used, and their awareness of available services. I haphazardly selected twelve ponds in each of 23 Alabama counties (Barbour, Bullock, Butler, Choctaw, Clarke, Conecuh, Crenshaw, Dallas, Escambia, Greene, Hale, Lowndes, Macon, Marengo, Monroe, Montgomery, Perry, Pickens, Pike, Russell, Sumter, Washington, and Wilcox) via USGS 7.5 minute topographic quadrangle maps. Although Escambia, Clarke, and Washington are not traditional Black Belt counties, they were included in the survey to increase coverage and because their economies were similar to that of other Black Belt counties. Ownership information for the selected ponds was obtained from tax records. Pond owner surveys were conducted by telephone, mailed via the U.S. Postal Service when requested to do so by a pond owner, and, when applicable, conducted in person. The survey consisted of 18 questions that were developed to acquire information regarding physical pond characteristics, pond use, applied management techniques and goals, owner satisfaction, information sources, and perceived problems (see Appendix A for the survey instrument). The assessment within a county was considered complete when four of the twelve pond owner surveys were conducted. As time permitted, additional surveys were conducted for those counties that already had at least four completed surveys. Once a minimum of four surveys were completed in each of the 23 counties, the assessment was considered complete.

Field Sampling

Fifty ponds were selected for evaluation based on surface area (2-16 ha), time of stocking (≥5 yrs.), fish species stocked (largemouth bass and *Lepomis* spp.), and the management techniques that were being applied. Selected ponds qualified for one of five management categories:

1. Unfertilized: No additional management.
2. Fertilized: Fertilized and limed.
3. Fertilized and Feeder(s): Fertilized, limed, and received supplemental pellet feed (at least one feeder for every 2-4 ha of pond surface).
4. Fertilized and Shad: Fertilized, limed, and stocked with threadfin shad.
5. Fertilized, Shad, and Feeder(s): Fertilized, limed, received supplemental pellet feed (at least one feeder for every 2-4 ha of pond surface), and stocked with threadfin shad.

Ponds were identified through the pond owner survey and personnel from the Alabama Division of Wildlife and Freshwater Fisheries, Alabama Extension Service, and Alabama Natural Resources Conservation Service helped to identify ponds that met the criterion when the minimum of five ponds in a management type was not available through the telephone surveys.

Half of the selected ponds were evaluated once in fall 2007 and half were evaluated once in spring 2008. In each pond, four seine hauls were taken with a 4.5 m x 1.7 m seine with 3.2 mm mesh to collect young-of-year bream and largemouth bass (Swingle 1956). At some sites, it was not possible to conduct four seine hauls for reasons such as soft bottom, excessive algae/ aquatic vegetation, limited shoreline access, or excessive near shore depth. For the fall survey, all seined fish were counted and measured (TL; nearest mm). For the spring survey, seined *Lepomis* spp. and largemouth bass catches were categorized as low, medium, or high abundance and the number of *Lepomis* spp. greater than 75 mm TL were recorded. For each pond, boat-mounted, pulsed-DC electrofishing (Smith-Root Inc. DC electrofisher, 5.0 GPP, 1000 W) was used in three 15-minute transects or until sampling overlap occurred in smaller ponds. In an attempt to collect a representative sample of the fish community at each site, the three electrofishing transects were designated to cover one of three habitat types including the dam area, shallow/littoral habitat, and intermediate depth/offshore habitat. At each site, I attempted to collect a minimum of 50 largemouth bass and representative samples of available forage species. Each individual was measured (TL; nearest mm) and weighed (wet weight; nearest g). With the permission of the pond owner, 10 largemouth bass at 50 mm length groups from 100-350 mm were placed on ice and returned to the laboratory for age and growth assessment. All other fish were released on site.

Water samples were collected from the surface using 500 ml dark polyethylene bottles, placed directly on ice, and returned to the laboratory for further analyses. Chlorophyll-a concentrations were determined using a fluorometer (nm; Turner Designs Aquafluor). Turbidity was measured with a nephelometer (NTU; HF Scientific, Inc.

Microw TPW). Total alkalinity and hardness were measured on site using Lamotte water test kits (ppm $CaCO_3$). Dissolved oxygen ($mg \cdot L^{-1}$; Yellow Springs Instruments Model 51 B meter) and temperature (°C) profiles were conducted at each site at 1-m intervals in the deepest portion of the pond. Secchi transparency was recorded to the nearest 0.1 m. Cloud cover (%), estimated surface and submersed aquatic vegetation (%), GPS coordinates, wind (high, moderate, low), and precipitation presence were recorded at each site.

Two zooplankton samples were collected in each pond by vertically hauling a 30 cm diameter hand towed plankton net (50-µm mesh). Collection was limited to the photic zone, which was considered to be two times the secchi depth and samples were preserved in 95% ethanol. In the laboratory, zooplankton were sub-sampled so that a minimum of 200 of the most common species were counted. Cladocerans were identified to genus, copepods were identified to family, and nauplii were counted.

Largemouth bass collected for age-and-growth assessments were measured (TL; nearest mm) and weighed (wet weight; nearest g). Sagittal otoliths were removed, cleaned, dried, and stored in 10-ml plastic vials. Two independent readers aged each otolith in whole mount. A Nikon dissecting microscope and external fiber optic secondary light source were used to identify and count otolith annuli on whole, glycerine immersed, saggital otoliths. Using a micrometer, the distance from the focus to each annulus, to the posterior-most end, was measured (nearest 0.0001 mm). For fish aged at five years or older, otoliths were embedded in two-part epoxy and sectioned using a low speed diamond wheel saw (South Bay Technology Model 650). Sections were polished for clarity using 500 grit waterproof sand paper and placed on a slide. An image analysis system (MediaCybernetics Image-Pro Plus) was used to measure the distance from the focus to the ventral-most end of each annulus.

Back-calculated total length at the *i*th age (TL_i) was estimated using the direct proportion method (Le Cren 1947):

$$L_i = \frac{S_i}{S_c} \times L_c ,$$

where L_i is the back calculated length of the fish at the formation of the *i*th increment, L_c is the length of the fish at capture, S_c is the radius of the otolith at capture, and S_i is the radius of the otolith at the *i*th increment.

Relative weight (W_r) was calculated to estimate condition of each largemouth bass and *Lepomis* spp. collected (Wege and Anderson 1978) :

$$W_r = \frac{W}{W_s} \times 100 ,$$

where W is the mass of an individual and W_s is a standard, length-specific, mass for each species (Murphy et al. 1991). Mean relative weight was calculated for largemouth bass and *Lepomis* spp. within each pond.

The relative abundance of largemouth bass and *Lepomis* spp. was calculated at each site (CPUE; catch·hour^{-1}). Proportional Stock Density (PSD) (Anderson 1976) was calculated as:

$$PSD = \frac{number\ of\ fish\ \geq\ minimum\ quality\ length}{number\ of\ fish\ \geq\ minimum\ stock\ length} \times 100 ,$$

to determine the proportion of stock size largemouth bass and stock size bluegill at each site. Relative Stock Density (RSD) was calculated as (Wege and Anderson 1978):

$$RSD = \frac{number\ of\ fish\ \geq\ specified\ length}{number\ of\ fish\ \geq\ minimum\ stock\ length} \times 100,$$

to determine the proportion of preferred (RSD-P) and memorable (RSD-M) size largemouth bass and bluegill at each site.

Statistical Analyses

Data collected in fall 2007 and spring 2008 were pooled. A one-way analysis of variance (ANOVA) was used to examine differences in abundance (log transformed CPUE), condition (*Wr*), zooplankton density, soil types properties (i.e. $CaCO_3$, CEC, log transformed organic matter), water quality characteristics (i.e. secchi depth turbidity, chlorophyll-a concentrations, alkalinity, hardness) and morphometrics (i.e. maximum depth, surface area) among management strategies (Procedure GLM; SAS Institute 2003). Mean separation techniques were used when ANOVA indicated differences among management strategies ($\alpha = 0.05$). Fishers' least significance difference (LSD) procedure was used to examine differences among means. Differences in size structures of largemouth bass and bluegill across management strategies were examined using a Kruskal-Wallis test (PROC NPAR1WAY; SAS Institute 2003). Correlation analysis was used to examine relationships between CPUE and Wr, CPUE and MLA-2, Wr and MLA-2, water quality characteristics and soil properties, and water quality characteristics and CPUE (PROC CORR; SAS Institute 2003)

Largemouth bass RSD-P and bluegill PSD were transformed using the logit function (Berkson 1944):

$$logit(p) = ln\left(\frac{p}{1 - p}\right),$$

where p is the probability of a length of interest over stock size. Logit transformed stock density indices were then compared among management strategies using a one-way ANOVA.

Stock density indices plots were divided into four quadrants: quadrant 1 (largemouth bass RSD-P $\geq$ 10 and bluegill PSD < 20), quadrant 2 (largemouth bass RSD-P $\geq$ 10 and bluegill PSD $\geq$ 20), quadrant 3 (largemouth bass RSD-P $\leq$ 10 and bluegill PSDs <20), and quadrant 4 (largemouth bass RSD-P < 10 and bluegill PSDs $\geq$ 20; Figure 16). A baseline-category logit model was used to determine whether management strategy, water quality, watershed soil characteristics, and/or individual pond morphometrics affected the probability of a fish community being in a 'balanced' or higher state (i.e., occurring in quadrant 2). A stepwise model selection procedure was used to determine the model that best described the log-odds ratio of occurring in quadrant 2. Variables significant at the $\alpha = 0.10$ level were allowed to enter the model and were removed from the model if they increased above $\alpha = 0.10$ after the addition of subsequent variables. The probability of a pond's fish community occurring in each quadrant was also compared among management types alone. Log-odds ratio estimates were transformed to probabilities for interpretation (PROC LOGISTIC; SAS Institute 2003).

For the analysis of largemouth bass growth, only mean length-at-age-2 (MLA-2) was used because of the non-random collection of individuals less than 350 mm (many pond owners only permitted collections of largemouth bass less than 350 mm) and because it was likely that age-1 largemouth bass were not fully recruited to the sampling gear. Differences in largemouth bass growth by management type were tested by calculating bootstrap means of the total length of age-2 fish and comparing the confidence intervals provided by Monte Carlo simulation analysis on those means.

Soil Classification

For each site, a portion of the watershed soils were classified to determine whether they were the nutrient rich, alkaline Black Belt prairie soils or infertile, acidic loamy soils that are found throughout much of the state. Although it would have been ideal to classify the soil composition of the entire watershed of each site, such a task would have been arduous as that information would have been difficult to obtain, and the time frame of this study did not allow for such an undertaking nor did I have the resources to complete such a task. For this study, with the exception of those sites that were located in Lowndes County, soils were identified within 1.6 km^2 of each pond by use of the Natural Resources Conservation Service's Web Soil Survey (WSS, http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx). The area of interest (AOI) surrounding each site was positioned so that the dam of the pond was centered on one of the edges of the 1.6 km^2 area to include as much of the upstream watershed as possible. The soil classifications provided by the survey were categorized by the physical property of organic matter and the chemical property of calcium carbonate ($CaCO_3$). For the advanced options of each of these properties in the WSS, aggregation method was set to dominant component, the higher value was selected as the tie-break rule, nulls were not interpreted as zeros, and the layer option was set to include all layers of the soil horizon.

Soils information was not available for Lowndes County via WSS, so the dominant soil series for each site located in Lowndes County was provided by the Lowndes County Natural Resources Conservation Service and the properties of interest for those soil series were obtained from the WSS. These properties, in conjunction with the percentage of soil types within the area of interest, allowed for a relative measure of fertility, alkalinity, and buffering capacity of the landscape for at least a portion of the watershed at each site.

RESULTS

Pond Owner Survey

Of the 276 randomly selected private-pond owners, 160 in 23 central Alabama counties were contacted by telephone and 135 surveys were completed (Figure 1). Twenty-five of the contacts were unable to be surveyed for six distinct reasons (Appendix B). According to the respondents, ponds served a wide range of uses with the most common being recreational fishing (82% of those surveyed), followed by livestock watering (23%), and aesthetics (19%) (Figure 2). Thirty-eight percent of the contacts reported that their pond served multiple uses and 8% reported that their pond provided a source of income by leasing (n = 6), aquaculture (n = 3), or pay-to-fish operations (n = 2).

For those ponds that served as a source of recreational fishing, owners reported that largemouth bass, bream, and channel catfish were the three primary fishes stocked (Figure 3). Seventy-four percent of the ponds were managed by their owner, 13% were not managed by anyone, and 7% were managed by private pond consultants (Table 1). Owners reported that the two primary sources for the original fish stock were state hatcheries (32%) or private hatcheries (30%) (Table 2). Friends/family, the Alabama Cooperative Extension System, Alabama Department of Conservation and Natural Resources (ADCNR), and Auburn University were the most commonly reported sources of pond management information, and 21 of the respondents reported they did not use any pond management information resources (Table 3).

The most common management technique applied by pond owners was pond fertilization (48%). Those that fertilized reported that they did so based on water clarity (n = 39), a schedule (n = 21), at irregular intervals (n = 4), or by some other indication/time frame (n = 2) (Figure 4a). No need (n = 20), inconvenience (n = 16), and cost (n = 12) were the primary reasons that the other 52% of pond owners did not fertilize (Figure 4b). The most common management enhancements used by pond owners was supplemental pellet feed (45%) and stocking supplemental forage for largemouth bass (12%). Those that stocked supplemental forage most often stocked threadfin shad (n = 5) (Figure 5). Ninety-two percent did not aerate their ponds and 93% reported that they did not keep records of the fish harvested from their pond.

Most respondents (52%) reported their management strategy was to maintain “general balance”, 11% managed for “trophy bass”, and 24% reported that they did not have a management strategy for their pond (Figure 6). The five most highly ranked pond problems were slow largemouth bass growth, filamentous algae, beavers/muskrats, poachers, and slow bream growth (Table 4). Fifty-one percent of pond owners had never checked the “balance” of their pond’s fish community, 54% had never checked their pond’s water quality, and 64% were unaware of free pond checks available through the ADCNR. Seventy-six percent of those surveyed reported that they were either “extremely happy” or “generally satisfied” with their condition/state of their pond (Figure 7). Eight-three percent of the pond owners granted permission to access their pond for further assessment.

Field Sampling

Based on the results from the pond owner survey, I evaluated the two most commonly reported pond management enhancements: providing supplemental pellet feed for bream and stocking threadfin shad as supplemental forage for largemouth bass. I conducted field evaluations of 66 ponds in 20 Alabama counties (Appendix C-G). Initially, ten ponds were selected for each management category, but the final number of replicates was unbalanced, with 16 unmanaged, 15 fertilized, 11 fertilized-and-feeder, 12 fertilized-and-shad, and 12 fertilized-shad-and-feeder sites because owner description of the management techniques during the survey did not always match the applied management practices. For example, when surveyed, some owners reported that they fertilized and applied pellet feed to their pond when in reality, their pellet feeding program had ceased several years prior to our sampling visit, changing the management classification of the pond from fertilized-and-feeder, to simply fertilized.

In fall 2007 and spring 2008, 6,092 largemouth bass and 11,434 bluegill were collected via electrofishing and 544 bluegill >74 mm were collected by seining in these 66 ponds. A total of 1,897 largemouth bass from 56 different sites were returned to the laboratory for age-and-growth analysis. Largemouth bass age and growth information was not available for every site because some pond owners did not permit removal of largemouth bass from their ponds.

Size Structure: Cumulative length-frequency distributions for largemouth bass were significantly smallest in unmanaged management strategies (Kruskal-Wallis test, $P < 0.0001$), while those in fertilized-and-shad management strategy ponds had significantly longer length-frequency distributions than all other management strategies ($P < 0.0001$,

Figure 8). Cumulative length-frequency distributions for bluegill were significantly smallest for unmanaged management strategies ($P < 0.042$), while fertilized-and-feeder strategies had significantly smaller length-frequency distribution than fertilized-shad-and-feeder management strategy ponds ($P = 0.015$, Figure 9) (see Appendix H-L for largemouth bass and bluegill relative length-frequency distributions by management strategy).

Proportional stock density indices showed a general shift towards a balanced state as management efforts increased (Figure 10-14). Logit-transformed largemouth bass RSD-Ps differed significantly among management strategies (ANOVA; $P = 0.0067$), those management strategies that included threadfin shad (i.e., fertilized-and-shad, fertilized-shad-and-feeder) had significantly greater occurrences of quality and preferred size largemouth bass than those strategies that did not (i.e., unmanaged, fertilized, fertilized-and-feed) (Figure 15). Logit-transformed bluegill PSDs did not differ significantly among management strategies ($P = 0.30$). Logit-transformed RSD-Ms were not significantly different among management strategies for largemouth bass ($P = 0.071$) or bluegill ($P = 0.48$).

Baseline-category logit models indicated the probability of a pond occurring in any quadrant was not affected by management strategy ($\chi^2 = 7.6180$, df = 3, $P = 0.81$; Figures 17-18). Although insignificant, the probability of being in quadrant 2 tended to increase with management. Ponds that contained threadfin shad tended to have a higher probability of occurring in quadrant 1 and quadrant 2 and a lower probability of occurring in quadrant 4. The probability of a pond occurring in quadrant 3 was zero for fertilized-and-feeder, fertilized-and-shad, and fertilized-shad-and-feeder management strategies.

The stepwise model selection procedure indicated that the best model describing the probability of being in quadrant 2 only included secchi depth ($\chi^2 = 7.939$, df = 3, P = 0.047) because all other water quality, morphological, and watershed soil characteristics did not increase the predictive power of whether a pond would occur in quadrant 2 (P >0.10). The model indicated that secchi depth less than or equal to 0.59 m had a 50% probability of occurring in quadrant 2 (Figure 19).

CPUE: CPUE differed significantly among management strategies for stock (ANOVA, P = 0.36), quality (P = 0.0002), preferred (P <0.0001), and memorable size (P = 0.0019) largemouth bass and for stock (P = 0.0002), quality (P <0.0001), preferred (P = 0.0011), and memorable (P = 0.0022) size bluegill. Those management strategies that used threadfin shad (i.e., fertilized-and-shad, fertilized-shad-and-feeder) had greater CPUE of quality, preferred, and memorable size largemouth bass and CPUE of stock size bluegill than did those strategies that did not (i.e., unmanaged, fertilized, fertilized-and-feed) (Figure 20). CPUE of quality, preferred, and memorable size bluegill was significantly lower for unmanaged ponds (Figure 20).

Growth: Monte Carlo simulations of largemouth bass bootstrapped mean length-at-age 2 (MLA-2) were significantly different among management strategies because 95% confidence intervals did not overlap for all management strategies. Unmanaged and fertilized-and-feeder strategies had significantly lower age-2 largemouth bass growth than fertilized, fertilized-and-shad, and fertilized-shad-and feeder strategies (Figure 21).

Relative weight: Largemouth bass mean relative weight differed significantly among management strategies with ponds containing threadfin shad having the highest mean relative weights (ANOVA, P = 0.0058, Figure 22). Bluegill mean relative weights were not significantly different among management strategies (P = 0.21). Mean relative weights of bluegill and largemouth bass were not correlated (P = 0.81). Largemouth bass MLA-2 was positively correlated with largemouth bass mean relative weight when all management types were combined (Figure 23). When management strategies were examined separately, this relationship remained only for fertilized (P = 0.0092) and fertilized-shad-and-feeder strategies (P = 0.0089) (Appendix M).

Bluegill mean stock size CPUE and mean Wr exhibited no relationship (P = 0.66) when examined with all management strategies combined (Figure 24). When management strategies were examined separately, a significant negative relationship was indicated for mean stock size CPUE and mean Wr in fertilized-shad-and-feeder management strategies (Appendix M). Largemouth bass log mean preferred size CPUE and mean Wr exhibited significant positive relationship (P <0.0001) when examined with all management strategies combined (Figure 25). When examined separately, only fertilized and fertilized-and-feeder strategies maintained this relationship (Appendix M).

Correlated largemouth bass mean preferred size CPUE and MLA-2 exhibited a significant positive relationship (P <0.0001) with all management strategies combined (Figure 26). When management strategies were examined separately only fertilized and fertilized-shad-and-feeder strategies maintained this relationship (Appendix M).

Zooplankton: Zooplankton densities significantly differed among management strategies (ANOVA; P = 0.041). Unmanaged strategies and those strategies that used threadfin shad had the lowest zooplankton densities (Figure 27).

Water Quality, Morphological, and Soil Characteristics

Water quality and morphological measurements were collected for all 66 sites (Appendix C-G). Alkalinity (ANOVA, $P = 0.20$), turbidity ($P = 0.052$), and maximum depth ($P = 0.31$) were not significantly different among management strategies. Hardness ($P = 0.0028$) and chlorophyll-a concentrations ($P = 0.0099$) were significantly lower in unmanaged strategies, secchi depth was significantly greater in unmanaged strategies ($P < 0.0001$), and surface area was significantly greater for fertilized-and-shad and fertilized-shad-and-feeder strategies ($P = 0.0028$) (Figure 28). CPUE of stock size bluegill was positively related to alkalinity (Figure 29) and negatively related to secchi depth (Figure 30). Chlorophyll-a concentration was positively related with pond alkalinity (Figure 31) and maximum depth and surface area were positively related (Figure 32).

Soil series were classified for all of the 66 sites. Cation exchange capacity (CEC) information was not available on WSS for 16 sites. Correlation analysis was performed for all pairwise comparisons between water quality characteristics (i.e., alkalinity, hardness, chlorophyll-a, turbidity, secchi depth) and soil characteristics. Turbidity and secchi depth were not significantly related to any soil characteristic nor was the percent of organic matter in the soil related to any water quality characteristic ($P > 0.05$). A strong positive relationship existed between the percentage of $CaCO_3$ (Figure 33) and CEC (Figure 34) in the soils of the surrounding watershed and the alkalinity and hardness concentration in the pond ($P < 0.001$) (Table 5).

DISCUSSION

Pond Owner Survey

Recreational fishing for largemouth bass and bream was the primary use for privately-owned small impoundments in central Alabama. The majority of owners wished to maintain ‘generally balanced’ fish populations and were ‘generally satisfied’ or ‘extremely happy’ with the condition of their ponds. Fertilizing, applying pellet feed, and stocking threadfin shad were the three most common techniques/enhancements that owners used in attempt to produce and maintain quality fishing and their management goals. However, a number of techniques, tools, and information sources remained unfamiliar to or unused by many respondents.

One such tool was simple maintenance of harvest records of largemouth bass and bream. Only 7% of owners kept harvest records despite fish harvest being an integral component of recreational fishing and pond management (Gabelhouse 1987; Coble 1988; Guy and Willis 1990). The lack of harvest records made it impossible to quantify harvest for nearly all of the 66 ponds that I assessed in the field (only one of the field sites maintained harvest records). Another underused management technique was annual water quality and pond balance checks. More than half of the respondents had never checked fish community balance or water quality in their pond.

Information sources also represented a problem, as many of the surveyed pond owners were unable to rank more than one or two sources because they did not use multiple sources to gather pond management information. In fact, “family and friends”, which has a potential to provide inaccurate information, was the most frequently ranked primary source of pond management information, and numerous respondents claimed that they did not use any sources for pond management information. It was also clear that management information on the websites of Auburn University and the Alabama Cooperative Extension Service was being under used as only four respondents listed them as a primary information source. An example of poorly or uninformed pond owners is the high percentage of owners (35%) that determined when their ponds needed fertilized by using a technique other than monitoring water clarity. Such misinformation can lead to mismanagement that creates undesirable fish populations and poor fishing. These factors indicate a need to better inform pond owners of accurate and reliable information sources and perhaps the consequences of using inaccurate pond management resources.

Very few owners (8%) used their ponds to provide a source of income, which is unfortunate considering that the study region is struggling economically and because small impoundments can offer substantial income potential. From this survey, it is unknown why the other 92% of pond owners did not use their ponds as a source of income. It may be possible that leasing ponds and developing aquaculture and pay-to-fish operations had not occurred to many pond owners or because there is a lack of interest or know how in regards to private ponds providing income. Also, anglers may require that pay-to-fish properties have ponds with a greater surface area (>10 ha) in order to be willing to pay a fee and the average surface area of the ponds surveyed was

2.5 ha. With so few ponds providing income it is likely that pond owners could benefit from effort expended towards developing information and increasing awareness of the money-making potential of small impoundments.

Field Sampling

Although most pond owners claimed that they were satisfied with the state of their ponds, information I collected with my field survey indicated that management goals of many pond owners were not being achieved. Initially, I attempted to examine the state of the fish communities by calculating and plotting the traditional stock density indices of largemouth bass proportional stock density (PSD) and bluegill PSD. However, it became clear that largemouth bass PSDs generally over-represented largemouth bass population states. When plotting bluegill and largemouth bass PSD, most ponds were in a balanced or trophy state when this was obviously not the case when taking into account other population characteristics. This was likely because largemouth bass quality length (300 mm) was too small to predict bass crowding in small impoundments in the southeastern U.S. I found that largemouth bass preferred relative stock density (RSD-P) more accurately represented largemouth bass population states because largemouth bass at or above preferred length (380 mm) generally showed good condition in ponds with poor RSD-P and symptoms of largemouth bass crowding.

By plotting largemouth bass RSD-P versus bluegill PSD, it was clear that a great deal of variation existed for bluegill and largemouth populations both among and within management strategies and that the majority of ponds, regardless of management strategy, were not within a state of 'general balance'. Largemouth bass and bluegill populations ranged from a state of quality largemouth bass, quality bluegill, or transition between general balance/quality largemouth bass or general balance/quality bluegill.

Largemouth Bass

One of the primary questions I sought to address through the field portion of this study was whether stocking threadfin shad improved largemouth bass population characteristics in small impoundments and whether largemouth bass in these systems benefited from the ability to forage on threadfin shad and bluegills more so than when foraging on bluegills alone. Because stocking threadfin shad in small impoundments can be an expensive enhancement for pond owners to provide, we need to determine if such expenses are justified. If stocking threadfin shad did not improve largemouth bass population characteristics in small impoundments I would have expected length-frequency distributions, catch-per-unit-effort (CPUE), relative weight (Wr), RSD-Ps, baseline-category logit model probabilities of ponds occurring in quadrant 1 and 2 (largemouth bass RSD-P $\geq$10), and mean back-calculated length-at-age-2 (MLA-2) in systems where shad were present to not be significantly different from other management strategies. Another concern was that threadfin shad may negatively affect largemouth bass recruitment through direct competition with larval largemouth bass and through indirect effects by reducing bluegill production (Tharatt 1966; Miller 1971; DeVries et al. 1991). If threadfin shad were negatively affecting largemouth bass recruitment in small impoundments I would have expected length-frequency distributions to be skewed towards larger lengths, low CPUE of stock-size or smaller individuals, high Wr, high

RSD-Ps, higher probabilities of ponds occurring in quadrant 1 and 2, and greater MLA-2 for largemouth bass in systems where threadfin shad were present.

Fertilized-and-shad and fertilized-shad-and-feeder strategies yielded the highest logit transformed largemouth bass RSD-Ps and tended to have higher probabilities of largemouth bass populations occurring in quadrant 1 and 2 (i.e., balanced or trophy state) than other management strategies. These findings suggest that stocking threadfin shad has the potential to increase the size structure of largemouth bass. The analysis of CPUE across management strategies suggests that stocking threadfin shad and fertilizing can improve largemouth bass populations as fertilized-and-shad and fertilized-shad-and-feeder strategies yielded the greatest densities of quality, preferred, and memorable sized largemouth bass, while unmanaged management strategies (i.e. unfertilized) ponds had the lowest catch rates of stock, quality, and preferred sized largemouth bass. In addition, the positive relationships between CPUE and Wr and between CPUE and MLA-2 indicate that the management techniques/enhancements are increasing density while maintaining growth and body condition given that largemouth bass density was positively related to body condition and growth. Further support for both fertilization and stocking threadfin shad positively affecting largemouth bass populations comes from examining length-frequency distributions among management strategies, as unmanaged ponds yielded the smallest length-frequency distributions of any management strategy and fertilized-and-shad and fertilized-shad-and-feeder strategies produced the largest largemouth bass length-frequency distributions. Results for largemouth bass MLA-2 versus Wr also support stocking threadfin shad to improve largemouth bass populations as growth and body condition were among the highest in fertilized-and-shad and fertilized-shad-and feeder management strategies.

Given that strategies that used threadfin shad exhibited overall larger length-frequency distributions, greater CPUE, higher Wr, higher RSD-Ps, tended to have higher probabilities of ponds occurring in quadrant 1 or 2, and greater MLA-2 than in systems where threadfin shad were not present, I conclude that threadfin shad can positively affect largemouth bass population characteristics in small impoundments. Because strategies that used threadfin shad exhibited overall larger length-frequency distributions, average CPUE of stock size largemouth bass, greater CPUE of quality, preferred, and memorable size largemouth bass, higher Wr, higher RSD-Ps, tended to have higher probabilities of occurring in quadrant 1 or 2, and greater MLA-2 than in systems where threadfin shad were not present, my collections in the current study suggest that threadfin shad may be reducing largemouth bass recruitment, but these results may also be a product of threadfin shad increasing the condition and growth of adult largemouth bass.

Collections for this study were not sufficient for determining negative or competing interactions between these two species because larval collections, diet overlap analysis, and the densities of both threadfin shad and young-of-year largemouth bass would all be necessary to make such a determination. If threadfin shad are capable of reducing largemouth bass recruitment in small impoundments, such an interaction may not cause deleterious affects to largemouth bass populations. Instead, such a reduction in largemouth bass recruitment could result in a benefit to those largemouth bass that do recruit by reducing intraspecific competition (see example for white crappie; Guest et al. 1990). It also important to consider that any reduction in largemouth bass recruitment in small impoundments by threadfin shad may act in part as a buffer against insufficient harvest, consequently reducing intraspecific competition among largemouth bass and the effects of largemouth bass crowding, all of which may help to sustain community balance even when largemouth bass harvest is low. This is not to say that stocking threadfin shad is a viable alternative to appropriate harvest, but rather that threadfin shad may help to maintain balanced or quality largemouth bass populations in years of low harvest.

Bluegill

Negative interaction between bluegill and threadfin shad has been a concern when stocking threadfin shad into small impoundments; in particular, the effects of interspecific competition between bluegill and threadfin shad for zooplankton and its potential to reduce bluegill recruitment, adult condition, and density have been of interest (Tharatt 1966; Miller 1971; DeVries and Stein 1990; DeVries et al. 1991). I found that ponds that contained threadfin shad had some of the lowest zooplankton densities when compared to other management strategies. If threadfin shad were negatively affecting bluegill, I would have expected to see length-frequency distributions skewed towards shorter lengths, lower CPUE of stock-size bluegill, lower Wr, higher probability of occurring in quadrant 2 or 4 (i.e. bluegill PSD $\geq$20), and higher bluegill PSD in ponds where threadfin shad were stocked. Because bluegill size structure, CPUE, Wr, and PSDs, and quadrant probabilities were similar across all fertilized and threadfin shad enhanced ponds, I conclude that threadfin shad did not negatively affect bluegill in fertilized small impoundments.

I also addressed whether bluegill and largemouth bass populations that received pellet feed benefited from the resource in terms of improved density, growth, condition, and reproductive output, and if pellet feed provided more forage for largemouth bass (in terms of increased bluegill production) than those ponds whose bluegills foraged only on natural prey. If pellet feeding positively affected bluegill population characteristics I would have expected to see length-frequency distributions skewed towards longer lengths, greater CPUE of all sizes of bluegill, higher Wr, higher probability of occurring in quadrant 2 or 4 (i.e. bluegill PSD $\geq$20), and higher bluegill PSD in ponds where threadfin shad were stocked. Because length-frequency distributions, CPUE, Wr, and quadrant probabilities were similar among all ponds enhanced with fertilized ponds I concluded that pellet feeding at the rates examined in my field survey did not provide a measurable benefit to bluegill and, therefore, it is unlikely to indirectly influence largemouth bass. Logit-transformed bluegill PSDs and bluegill body condition (Wr) were similar among all management types, suggesting that the techniques/enhancements of stocking threadfin shad, fertilization, and supplemental pellet feeding had no effect on bluegill size structures. Although not significant, the probability of bluegill PSDs occurring in quadrant 2 was generally lower for unmanaged ponds and higher for ponds that contained threadfin shad. The probability of bluegill PSDs occurring in quadrant 4 tended to be higher in fertilized-and-feeder strategies and lower for ponds that contained threadfin shad, a possible indication that ponds owners that chose to enhance their ponds with fertilizer and pellet feeding were more oriented towards bluegill management than those that stocked threadfin shad. CPUE and length-frequency analysis provided evidence that fertilization can increase the density of stock, quality, and preferred size bluegill given that unmanaged (i.e., unfertilized) ponds had the lowest catch rates of those size classes and yielded the smallest length-frequency distributions of any management strategy.

In my study, the efficacy of applying supplemental pellet feed to directly enhance bluegill populations and indirectly enhance largemouth bass populations in small impoundments was limited because of variation among sites that applied pellet feed. Because the fish communities and sites examined throughout this study were uncontrolled, I was unable to accurately quantify the rate and duration that pellet feed was delivered. Also, accuracy of pond owner memories and their overall commitment to their pellet-feeding program limited assessment of this enhancement. It may also be likely that the minimum requirement of one pellet feeder for every 2-4 hectares was not sufficient to observe a feeding effect. The variables of rate and duration at which pellet feed is delivered to ponds are likely to prove key in assessing the direct effects of pellet feeding on bluegills and the indirect effects for largemouth bass. The need to control these variables suggests testing via a controlled experiment. Although anecdotal, my experience when sampling sites with pellet feeders was that the location of the pellet feeder had a tendency to concentrate fish, particularly bream, and produce localized high catch rates. This characteristic of pellet feeding in itself may hold great worth to pond owners as the response of fish to congregate around feeding sites has the potential to increase angler catch rates and harvest, a response that could also be experimentally tested.

Water Quality, Morphological, and Soil Characteristics

Modeling indicated secchi depth as the main driving force behind the probability of whether ponds occurred in quadrant 2 (i.e., largemouth bass RSD-Ps $\geq$10 and bluegill PSDs $\geq$20). Interestingly, no other water quality, morphological, or watershed soil characteristics were significant in predicting whether a pond would occur in quadrant 2. The final model indicated that when secchi depth is within the depth recommended by the Alabama Cooperative Extension System (0.46-0.61 m) that the probability of a pond occurring in quadrant 2 ranged in probability between 49-54% (Wright and Masser 2004). This is an important finding as fertilizing and monitoring secchi depth is one of the most common and cost-effective management techniques that pond owners can provide to their ponds and it indicates the value of consistent and appropriate fertilization techniques for maintaining desirable fish populations. Although the model predicted that secchi depths less than 0.61 m provided an even greater probability of occurrence in quadrant 2, such secchi depths are not recommended as they have been shown to cause fish kills associated with oxygen depletions (Boyd 1990; Wright and Masser 2004). It is also important to note that 71% of the pond owners in this study who maintained secchi depths between 0.46- 0.61 m also performed balance checks and 64% performed water quality checks.

The positive relationships between the percentage of watershed soil calcium carbonate ($CaCO_3$) and cation exchange capacity (CEC) and pond alkalinity and hardness and between alkalinity and chlorophyll-a are primary examples of interactions among soil and water quality characteristics. These relationships suggest that the watershed soil characteristics can not only influence the water quality characteristics of the pond, but can also indirectly influence fish production by increasing the buffering capacity of the system and foster primary production (Boyd 1990; Schultz et al 2008; Miranda 2008). Although I found no direct relationship between watershed soil characteristics and primary production, the CPUE of stock-size bluegill was related to pond alkalinity and secchi depth. The percentage of organic matter in the watershed soils showed no relationship to indicators of primary production (i.e., chlorophyll-a and secchi depth). However, it is important to consider that relationships between watershed soil characteristics and measures of primary production may have been masked due to the application of lime and fertilizer to ponds. These artificial sources of nutrients and minerals in areas with poorly buffered and unproductive soils likely led to increased production in those systems equal to or beyond that of whose watershed contained more alkaline and/or productive soils (Boyd 1990). This is supported when comparing water quality characteristics among management strategies as unmanaged ponds had the lowest chlorophyll-a concentrations and greatest secchi depths while all other management strategies did not differ.

Relative to morphological characteristics, I found that ponds stocked with threadfin shad were larger in surface area than those that were not stocked with threadfin shad. One possible explanation for this is that the convention of pond management suggests threadfin shad not be stocked in ponds smaller than 1.2 hectares due to low probability of survival and sustainability. Another probable explanation for this trend may be that pond owners whom are inclined to stock threadfin shad, an already expensive enhancement, may be able/willing to allocate more time, effort, and resources towards pond construction, leading towards the construction of a larger pond. This could be an important relationship as Schultz et al. (2008) found that morphometry was related to growth and size structure of bluegills and largemouth bass.

MANAGEMENT IMPLICATIONS

It is critical that private pond owners be made aware of sources for accurate pond management information as the vast majority of surveyed private pond owners managed their own ponds. As mentioned previously, sometimes the information pond owners are using is not in the best interest of their management goals, and misinformation can lead to undesirable fish populations and poor fishing. Because it is clear that private pond owners in central Alabama did not always rely on accurate resources for their pond management information, efforts should be taken effectively distribute and advertise accurate pond management information resources to private pond owners. The low frequency of respondents that used their ponds to provide a source of income suggests a need to inform private pond owners of the potential profitability of small impoundments and provide insight towards how to develop these types of properties.

I also showed that watershed soil characteristics can influence water quality and have the potential to indirectly influence fish production in small impoundments. Knowing this, pond owners should consider the local soil properties when selecting a site for pond construction as well as when managing an existing pond. Soil testing will provide pond owners with the knowledge of what the watershed soils have the potential to provide to a pond. This information may allow pond owners to reduce costs associated with liming and fertilizing and, when given a choice, allow pond owners to choose a site that is best suited towards fish production.

From the variability of bluegill and largemouth bass populations among and within pond management strategies documented by this study, I determined that the pond management techniques and enhancements of fertilizing, applying pellet feed, and stocking threadfin shad can not in themselves consistently produce and maintain ideal size structure, growth rate, and density of fish communities in small impoundments. Instead, a suite of factors and management practices must be understood, employed, and adhered to in order to increase the probability that a pond will meet, and ultimately maintain, the management agenda of its owner. It is incorrect to assume that the application of one technique/enhancement alone is capable of consistently providing quality fishing. Outside of this study, there are other techniques and enhancements that are likely to play an important role in the management of small impoundments, such as consistent and adequate harvest of prey and predator species, consistent and appropriate fertilization and liming schedules and techniques, accurate record keeping, and consistent water quality and fish community checks.

Although the fish population characteristics varied greatly within every management strategy I examined, it remains important to realize that these techniques and enhancements that I have studied have been shown to increase the probability of a pond reaching its owner's management goals. While standard management techniques are capable of providing quality recreational fishing in small impoundments, and because angler satisfaction is largely based on the number and quality of fish caught, many pond owners, managers, and consultants place great emphasis on maximizing these aspects

(Hampton and Lackey 1976; Nutt 2004; Southeastern Pond Management 2005). Through better understanding of the mechanisms and factors behind the enhancements that produce desirable numbers and sizes of game fish, pond owners will be able to more effectively manage their ponds to produce a quality of fishing that consistently meets or exceeds angler expectation.

I have shown that fertilization can increase the density and production of bluegill and largemouth bass compared to unfertilized ponds, that stocking threadfin shad has the capacity to improve the largemouth bass population characteristics in small impoundments without having strong negative impacts on its bluegill community. Although providing supplemental pellet feed may prove as a tool for improving largemouth bass and bream population characteristics, variation related to sites that used pellet feed limited the assessment of that enhancement. The findings of this study provide private pond owners with the ability to select and use those techniques/enhancements that yield the most cost effective and reliable results, whether their management goals are maintaining balanced, quality, or trophy largemouth bass or bluegill populations.

TABLES

Table 1. The number (N) and percent (%) of the personnel used to manage privately-owned ponds in Central Alabama.

Private Pond Managers	N	%
Owner/Family member	100	74
No one	17	13
Pond management consultant	9	7
Other	6	4
Leasee	2	1
Fishing club	1	1

Table 2. The number (N) and percent (%) of the stocking sources used for the original stock of fish in privately-owned ponds in Central Alabama.

Stocking Source	N	%
State	43	32
Private hatchery	41	30
Not sure	40	30
Not stocked	8	6
Self-stocked	3	2

Table 3. Primary sources for pond management information as ranked by central Alabama private pond owners. (ADCNR = Alabama Department of Conservation and Natural Resources)

Primary Sources for Pond Management Information	Rank
Friends and family	27
County/Regional extension agents	25
No information used	21
ADCNR	15
Auburn University	14
Private pond management consultant	8
Local feed and seed store	5
Extension/University website	4
Other internet websites	4
Other	4
Personal knowledge	3
Outdoor magazines	2

Table 4. Primary pond management problems as ranked by Central Alabama private pond owners.

Pond Problems	Rank
Slow largemouth bass growth	1
Filamentous algae	2
Beavers / Muskrats	3
Poachers	4
Slow bream growth	5
Cormorants or other fish-eating birds	6
Poor algae bloom	7
Leaky pond	8
Aquatic weeds	9
Other	10
Fish kills	11
Otters	12
Fish disease	13

Table 5. Pearson correlation coefficients (r), p-values (P), and number of observations (N) for relationships between watershed soil properties and water quality characteristics.

	Calcium carbonate (%)			Cation exchange capacity (milliequivalents / 100 g)			Log organic matter (%)		
	r	P	N	r	P	N	r	P	N
Alkalinity (ppm)	0.66	< 0.01	66	0.57	< 0.01	50	0.12	0.32	66
Hardness (ppm)	0.61	< 0.01	66	0.52	< 0.01	50	0.10	0.44	66
Chlorophyll-a (ppm)	0.16	0.19	66	0.19	0.18	50	-0.04	0.72	66
Turbidity (ppm)	0.12	0.36	65	0.27	0.06	50	0.12	0.34	65
Secchi depth (ppm)	0.11	0.39	66	-0.13	0.36	50	-0.04	0.73	66

FIGURES

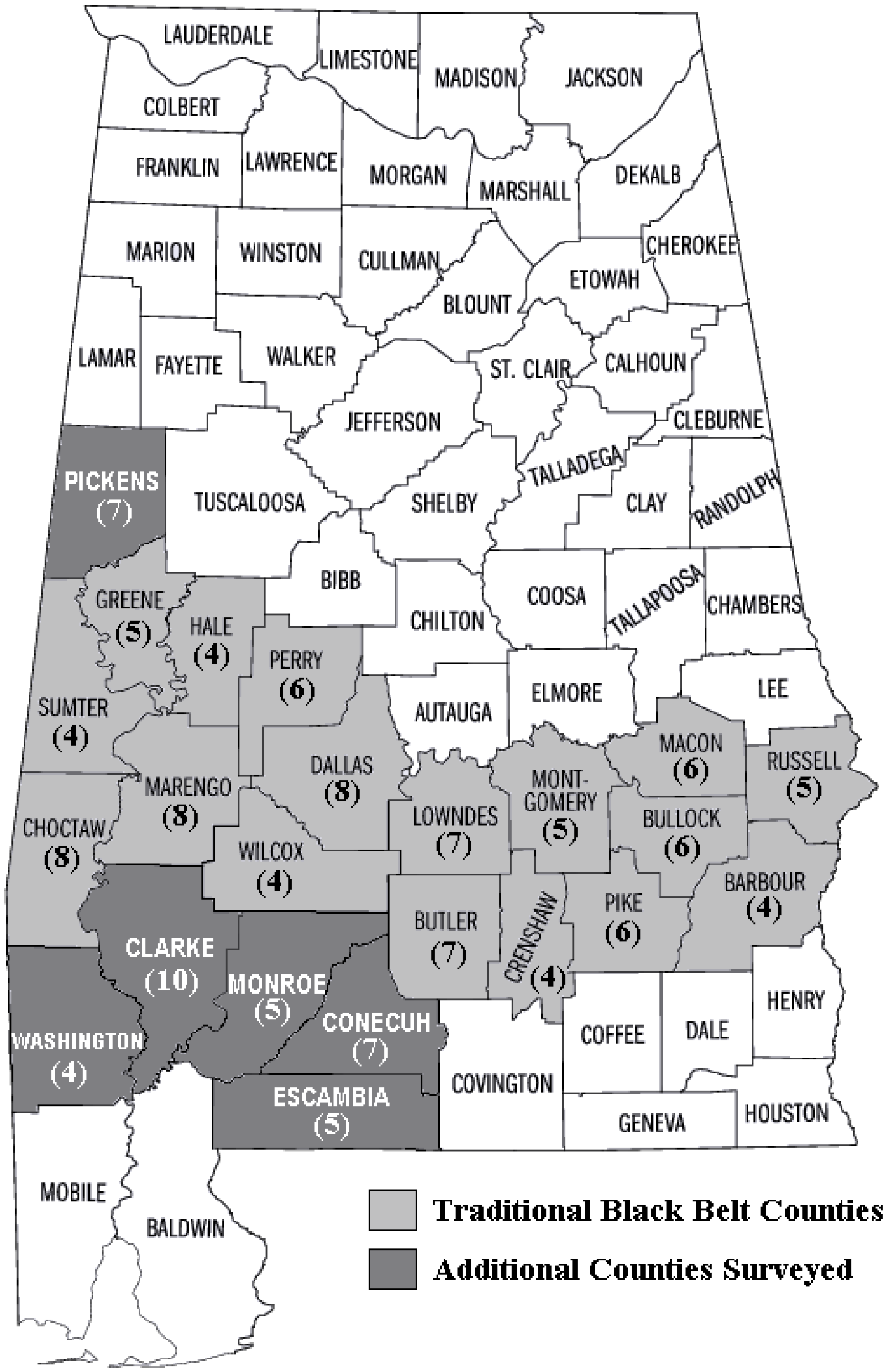


Figure 1. Map of traditional Alabama Black Belt counties and those that were added for the pond management survey. Numbers in parentheses indicate the number of completed pond owner surveys for that county.

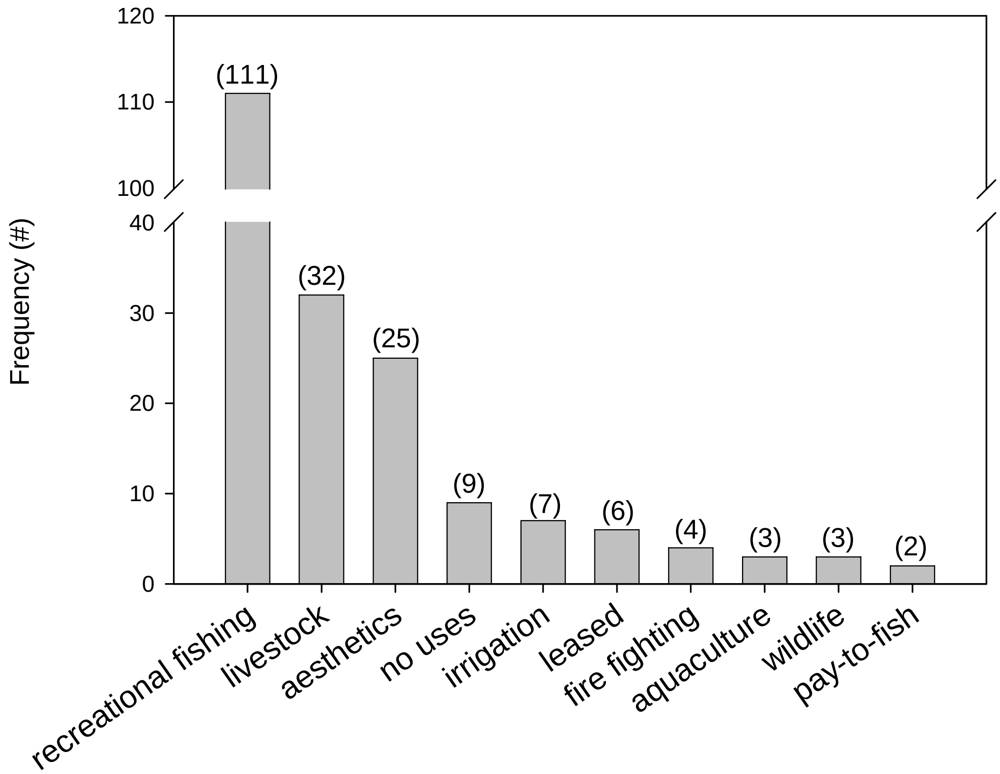


Figure 2. Pond use as reported by surveyed central Alabama private pond owners. Frequency (#) of response is represented in parentheses at the top of the bars. Uses with only one response (home heating and cooling, swimming, and water supply) were not included in the figure.

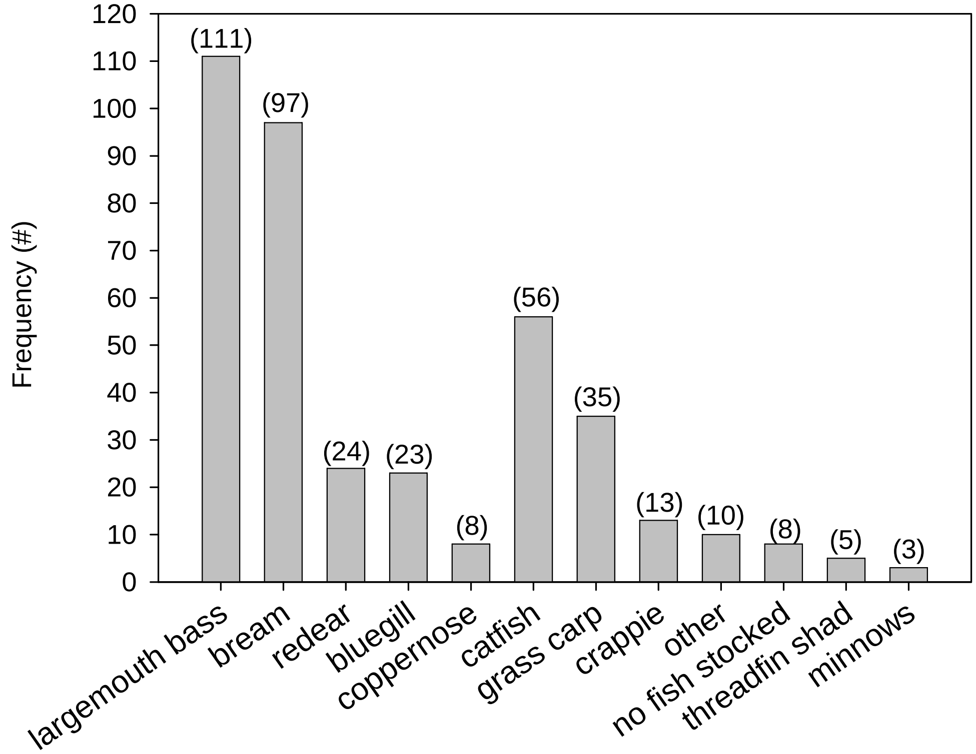


Figure 3. Fishes stocked by surveyed central Alabama private pond owners. Frequency (#) of response is represented in parentheses at the top of the bars. The classification 'bream' refers to *Lepomis spp*. Stocked fishes with only two responses (fathead minnows, shad, and shiners) were not included in the figure.

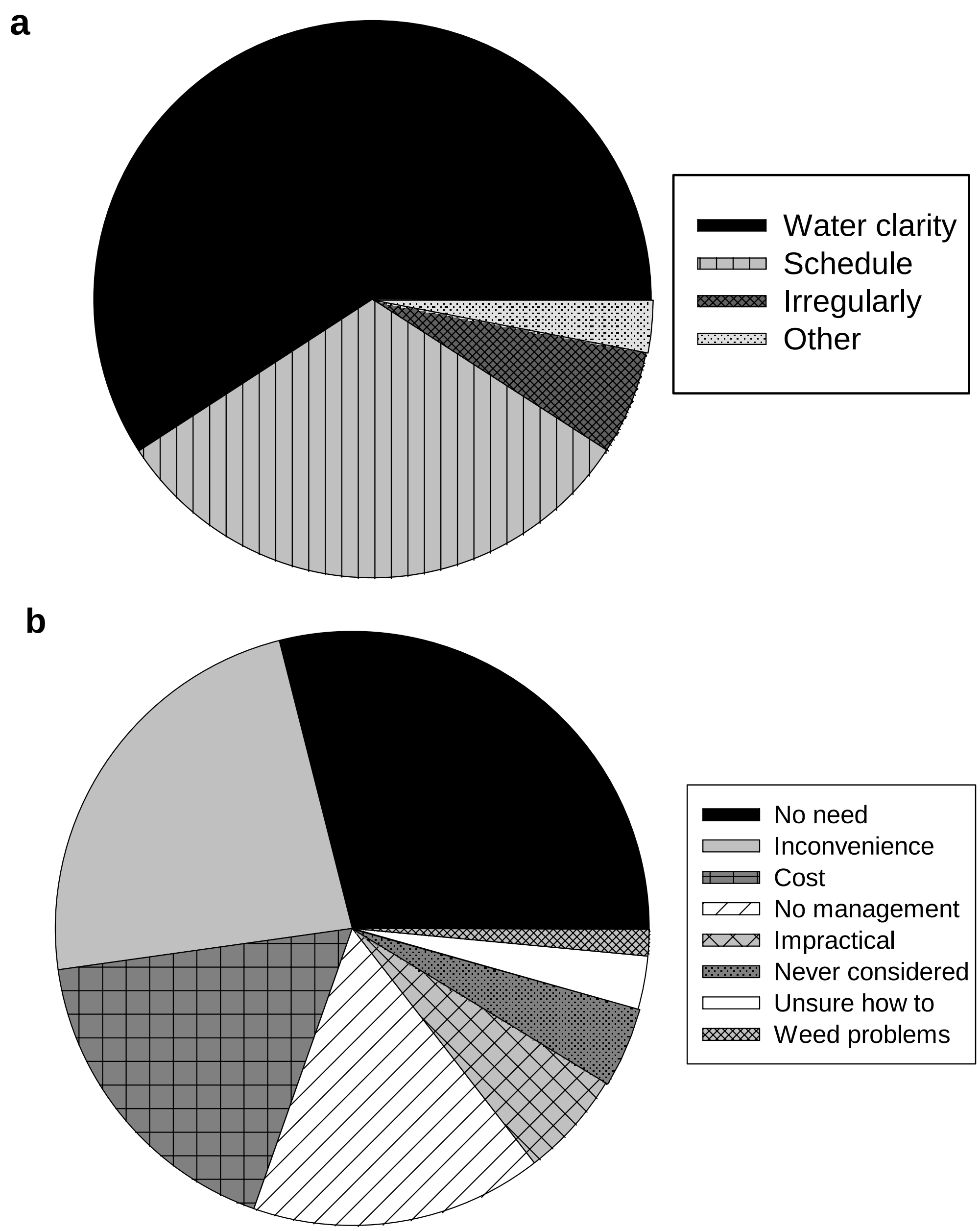


Figure 4. a). Techniques/indications used by the 48% of surveyed central Alabama private pond owners that fertilize to determine when to apply fertilizer. b). Reasons why the 52% of the surveyed central Alabama private pond owners do not fertilize their ponds.

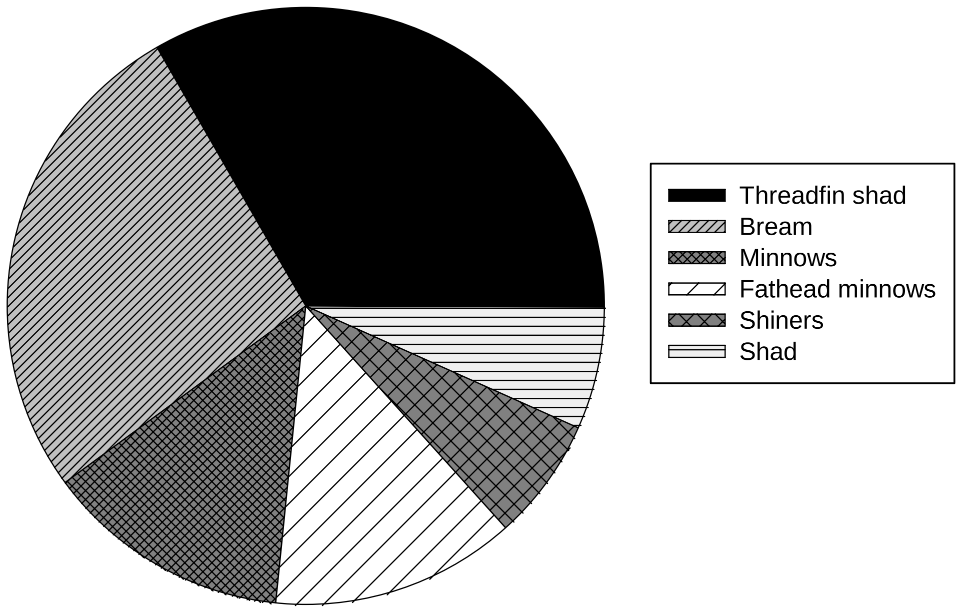


Figure 5. Of the 13% of surveyed central Alabama pond owners that stocked supplemental forage, 33% stocked threadfin shad, 27% stocked bream, 13% stocked minnow, 13% stocked fathead minnows, 7% stocked shiners, and 7 % stocked shad. The classification 'bream' refers to *Lepomis spp*., and the generic classifications of 'minnows', 'shiners', and 'shad' are because owners were unsure of the species of forage they had stocked.

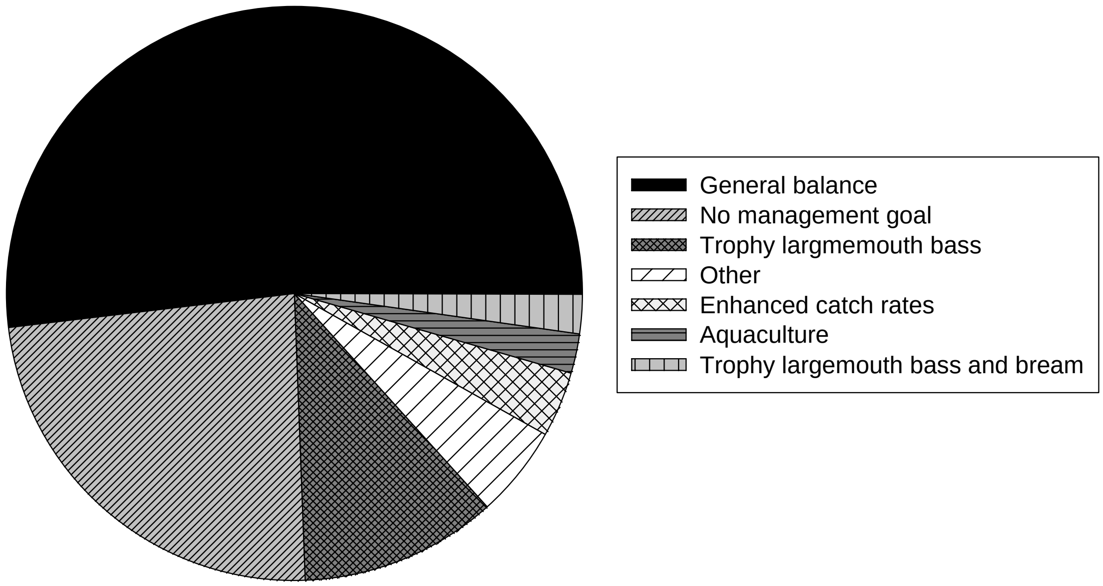


Figure 6. Pond management strategies reported by surveyed central Alabama private pond owners.

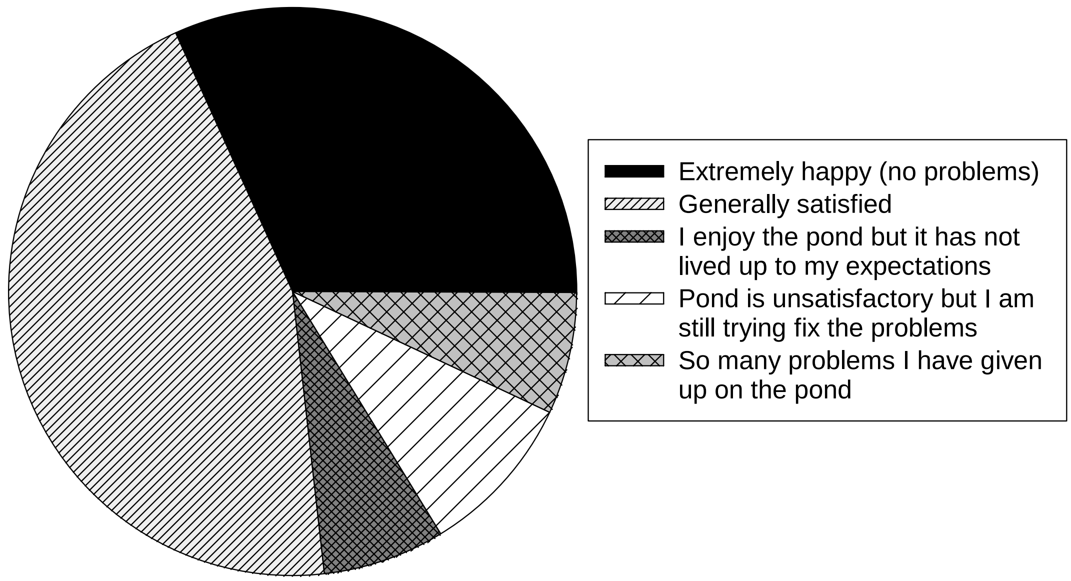


Figure 7. Pond satisfaction as reported by surveyed central Alabama private pond owners.

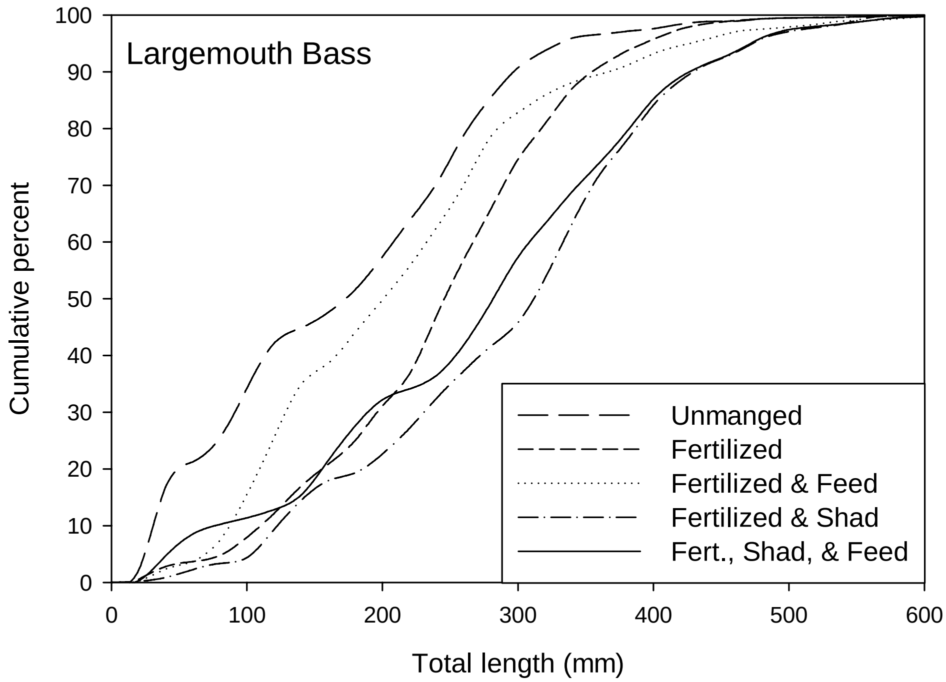


Figure 8. Cumulative length-frequency distributions for largemouth bass. Each line represents a different management strategy.

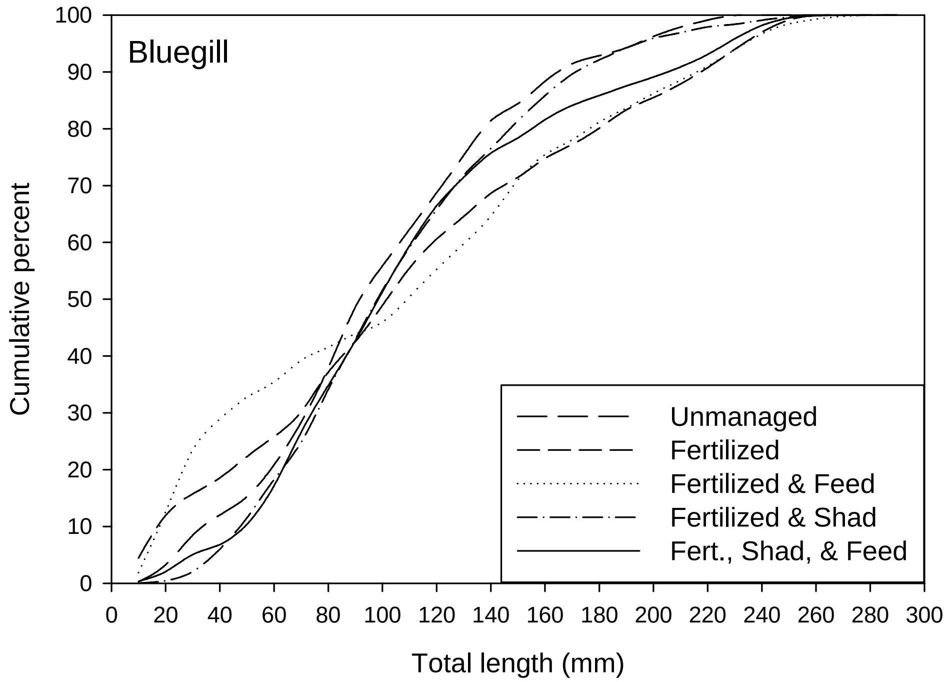


Figure 9. Cumulative length-frequency distributions for bluegill. Each line represents a different management strategy.

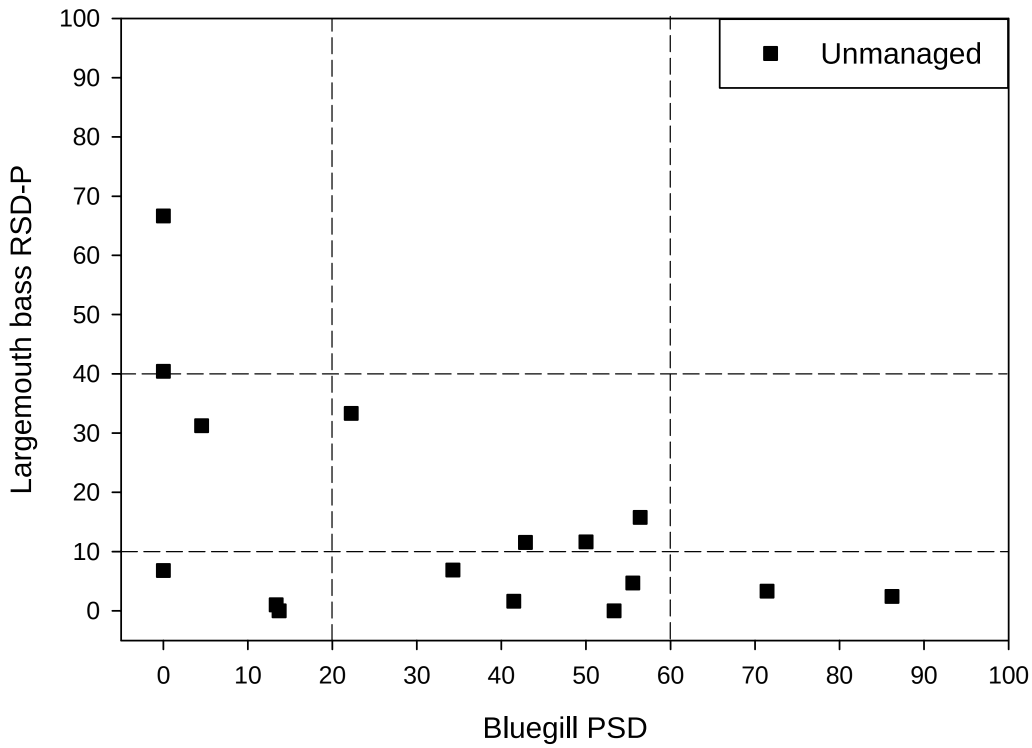


Figure 10. Largemouth bass RSD-P and bluegill PSD for unmanaged management strategies. Each point represents a single pond.

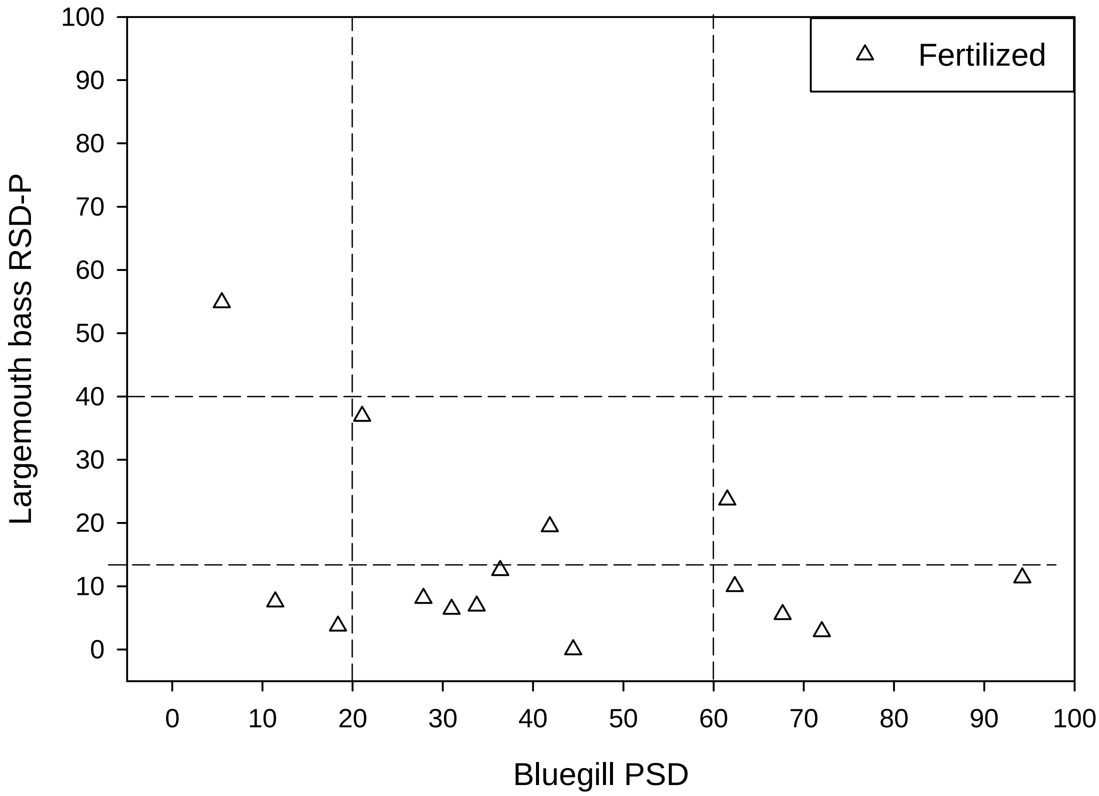


Figure 11. Largemouth bass RSD-P and bluegill PSD for fertilized management strategies. Each point represents a single pond.

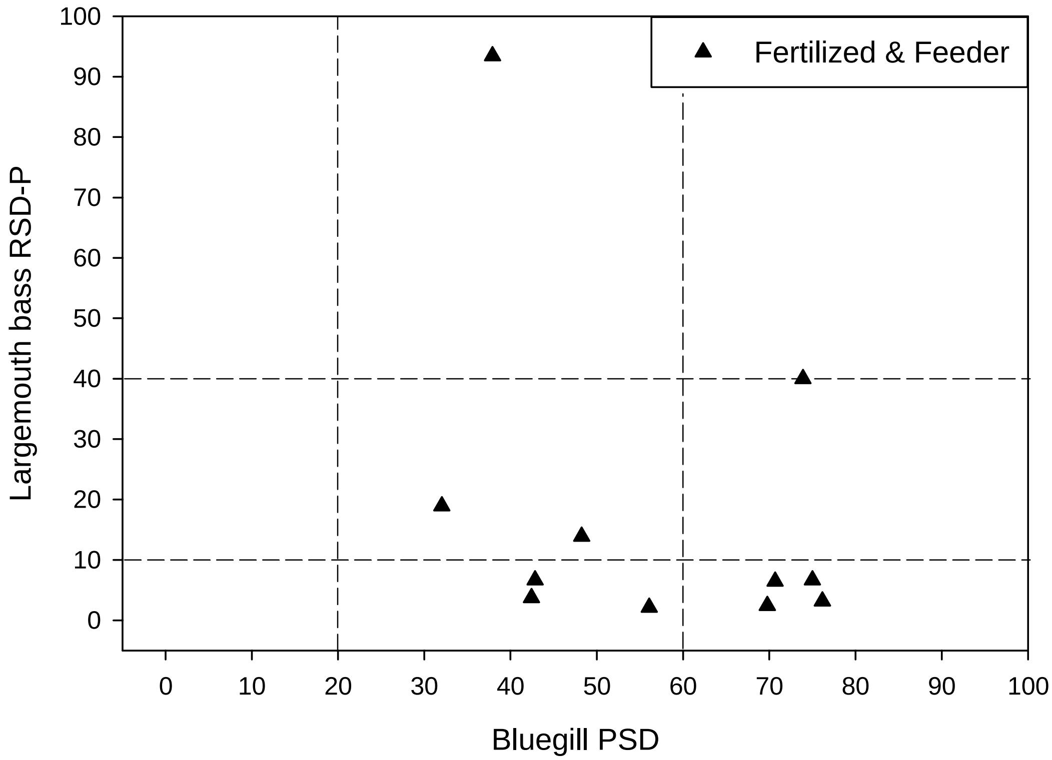


Figure 12. Largemouth bass RSD-P and bluegill PSD for fertilized-and-feeder management strategies. Each point represents a single pond.

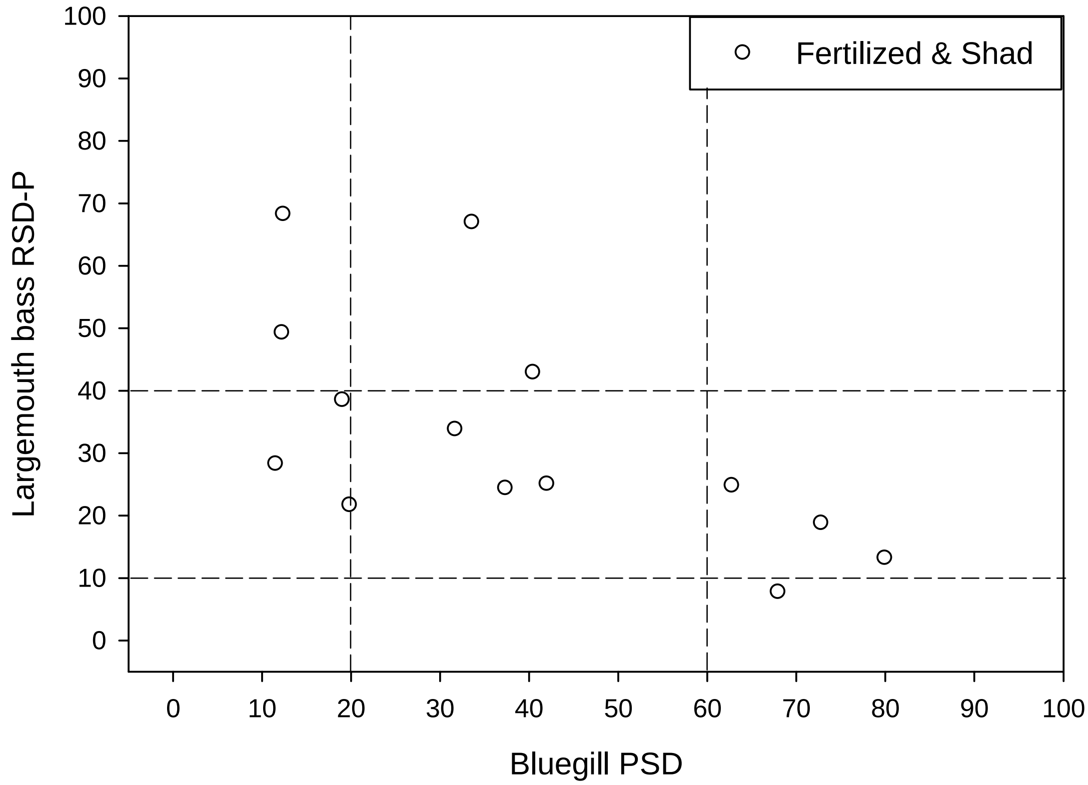


Figure 13. Largemouth bass RSD-P and bluegill PSD for fertilized-and-shad management strategies. Each point represents a single pond.

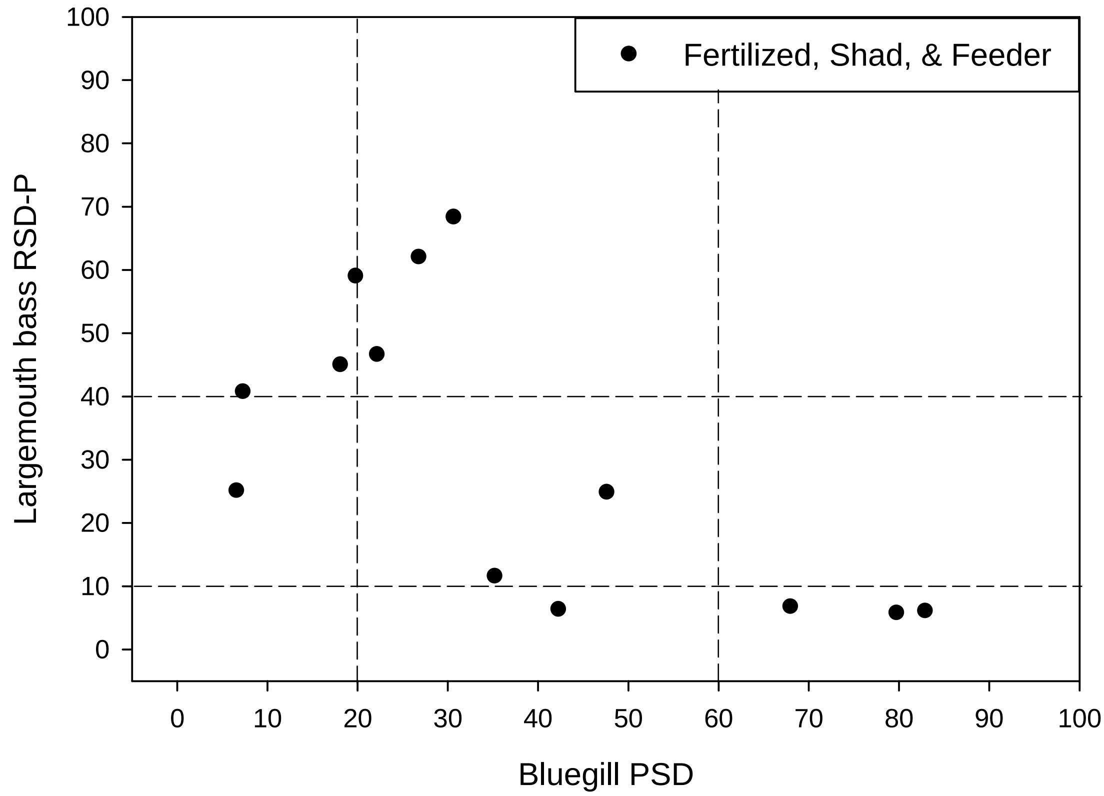


Figure 14. Largemouth bass RSD-P and bluegill PSD for fertilized-shad-and-feeder management strategies. Each point represents a single pond.

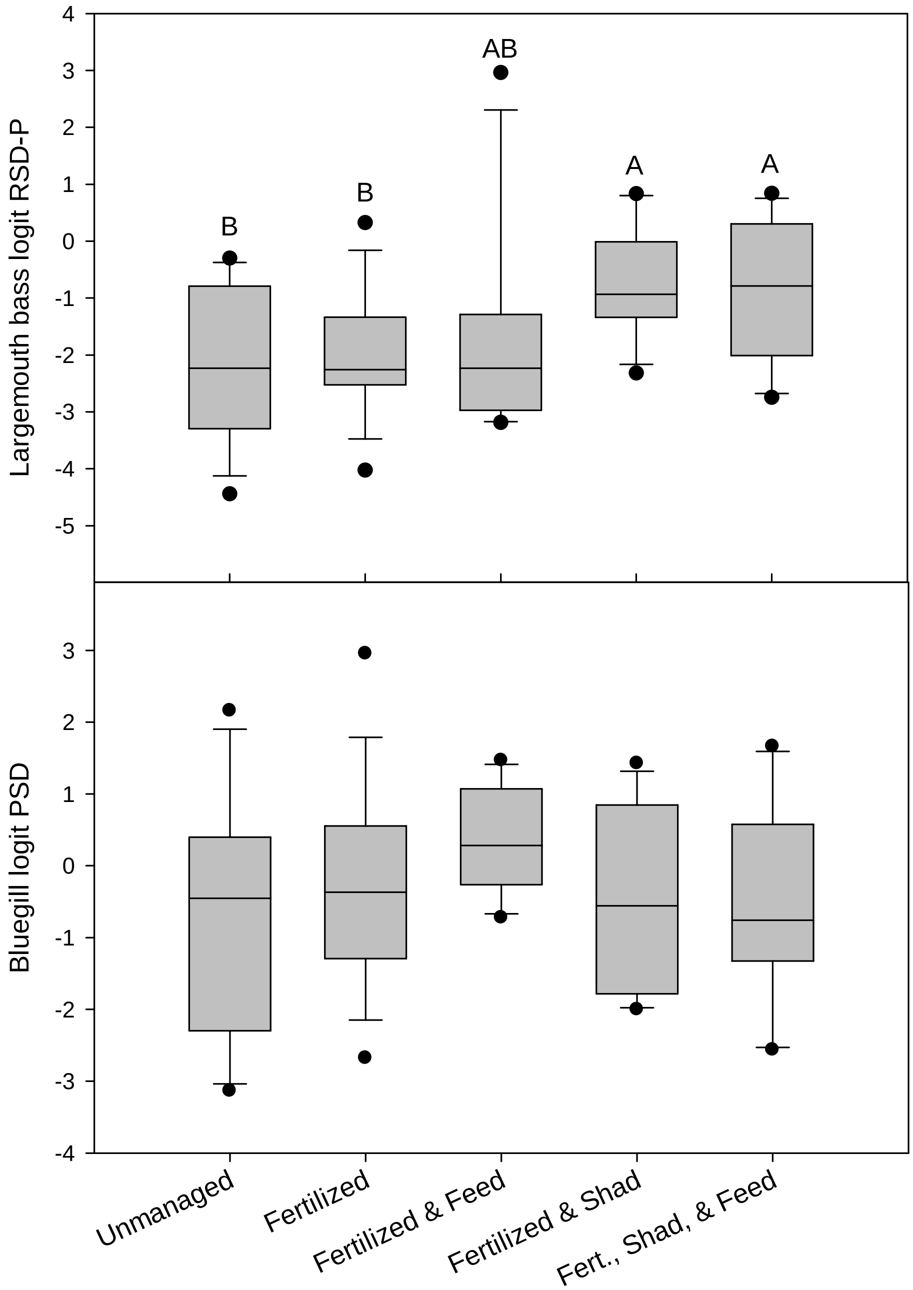


Figure 15. Tukey box plots for logit transformed largemouth bass RSD-P and logit transformed bluegill PSD by management strategy. Error bars indicate the 10th and 90th percentiles and points represent the minimum and maximum values of the observations. Strategies that share the same letter are not significantly different (P >0.05). Bluegill logit PSDs did not significantly differ (P = 0.30).

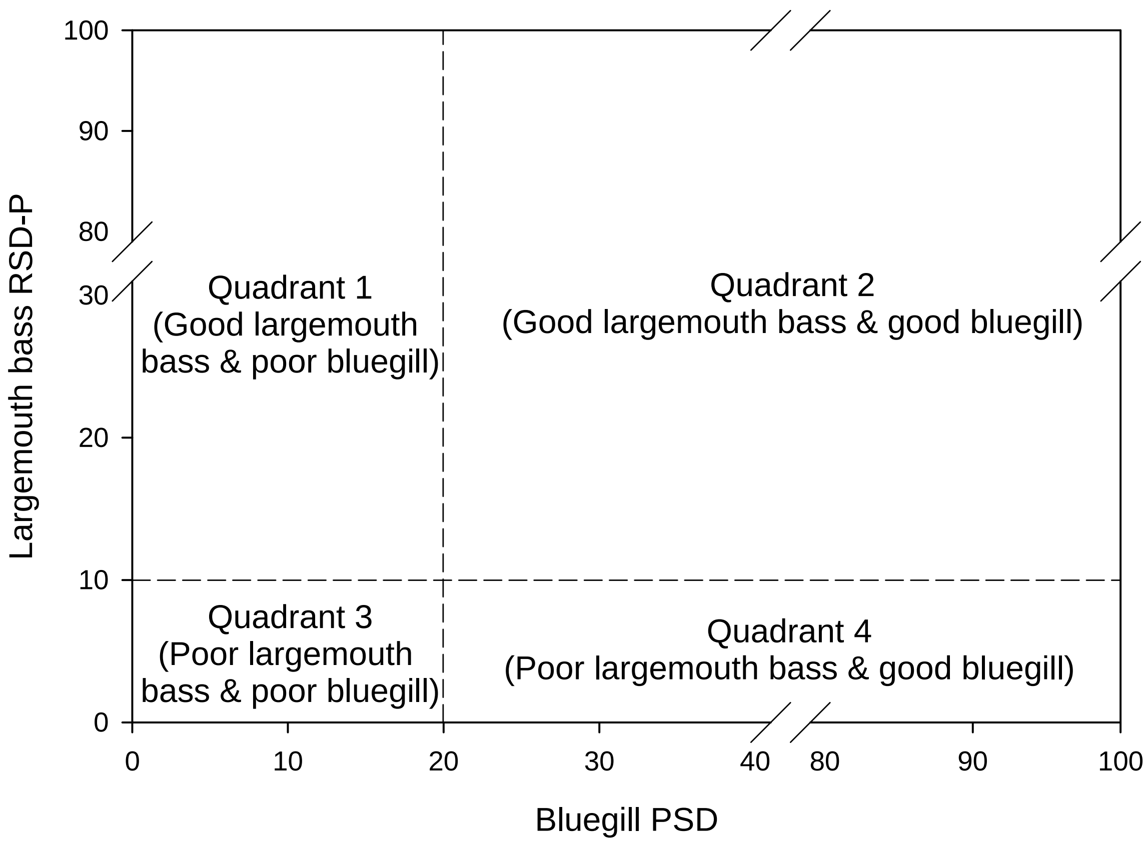


Figure 16. Stock density indices quadrant delineation for baseline-category logit model analyses. Quadrant 1 = largemouth bass RSD-P ≥10 and bluegill PSD <20. Quadrant 2 = largemouth bass RSD-P ≥10 and bluegill PSD <20. Quadrant 3 = largemouth bass RSD-P <10 and bluegill PSD <20. Quadrant 4 = largemouth bass RSD-P <10 and bluegill PSD ≥20.

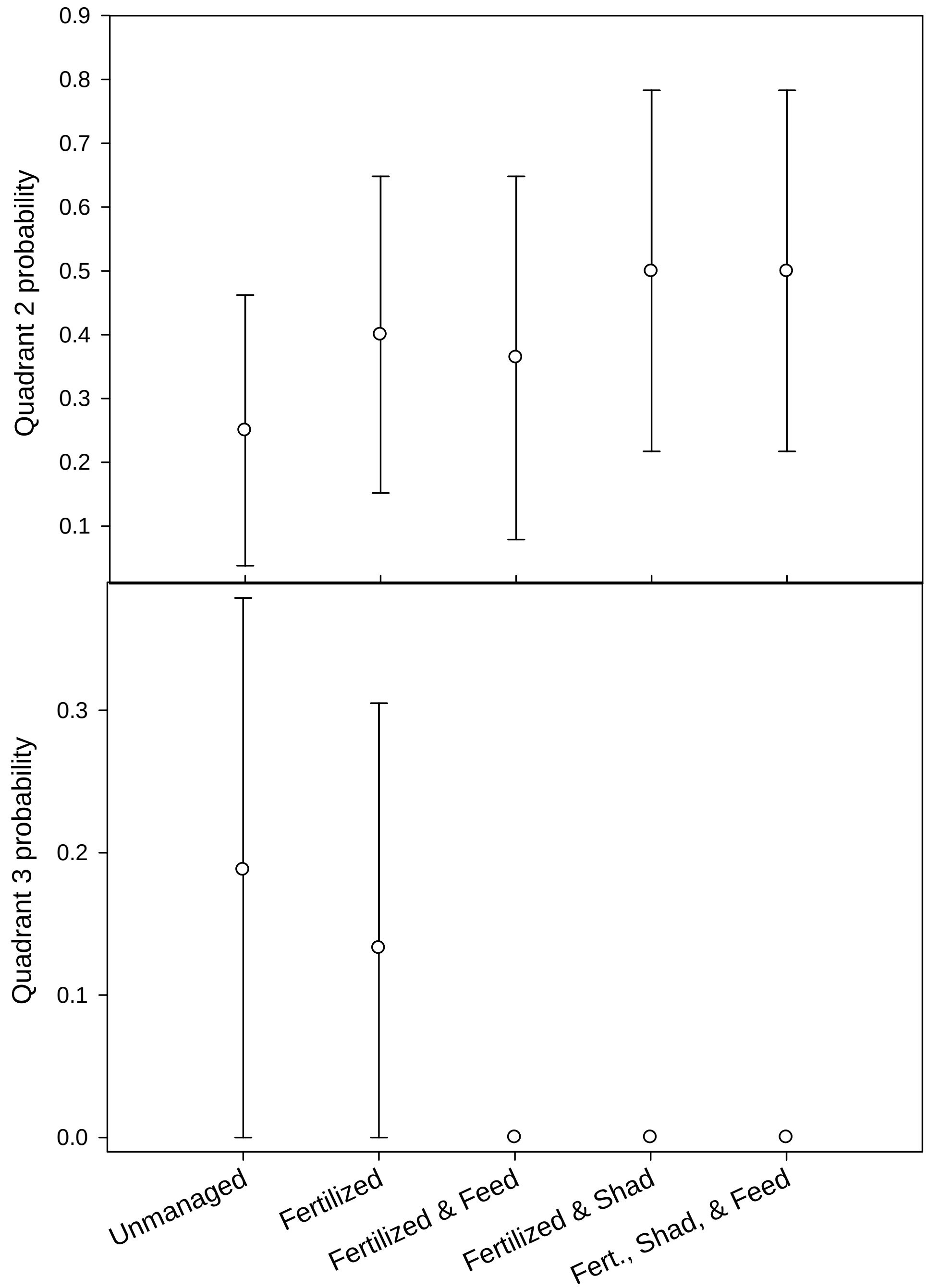


Figure 17. Probabilities of a pond's fish community occurring in quadrant 2 or quadrant 3 by management strategy (quadrant 2 = largemouth bass RSD-P ≥10 and bluegill PSD ≥20; quadrant 3 = largemouth bass RSD-P <10 and bluegill PSD <20) as determined by a baseline-category logit model. Error bars indicate 95% confidence intervals.

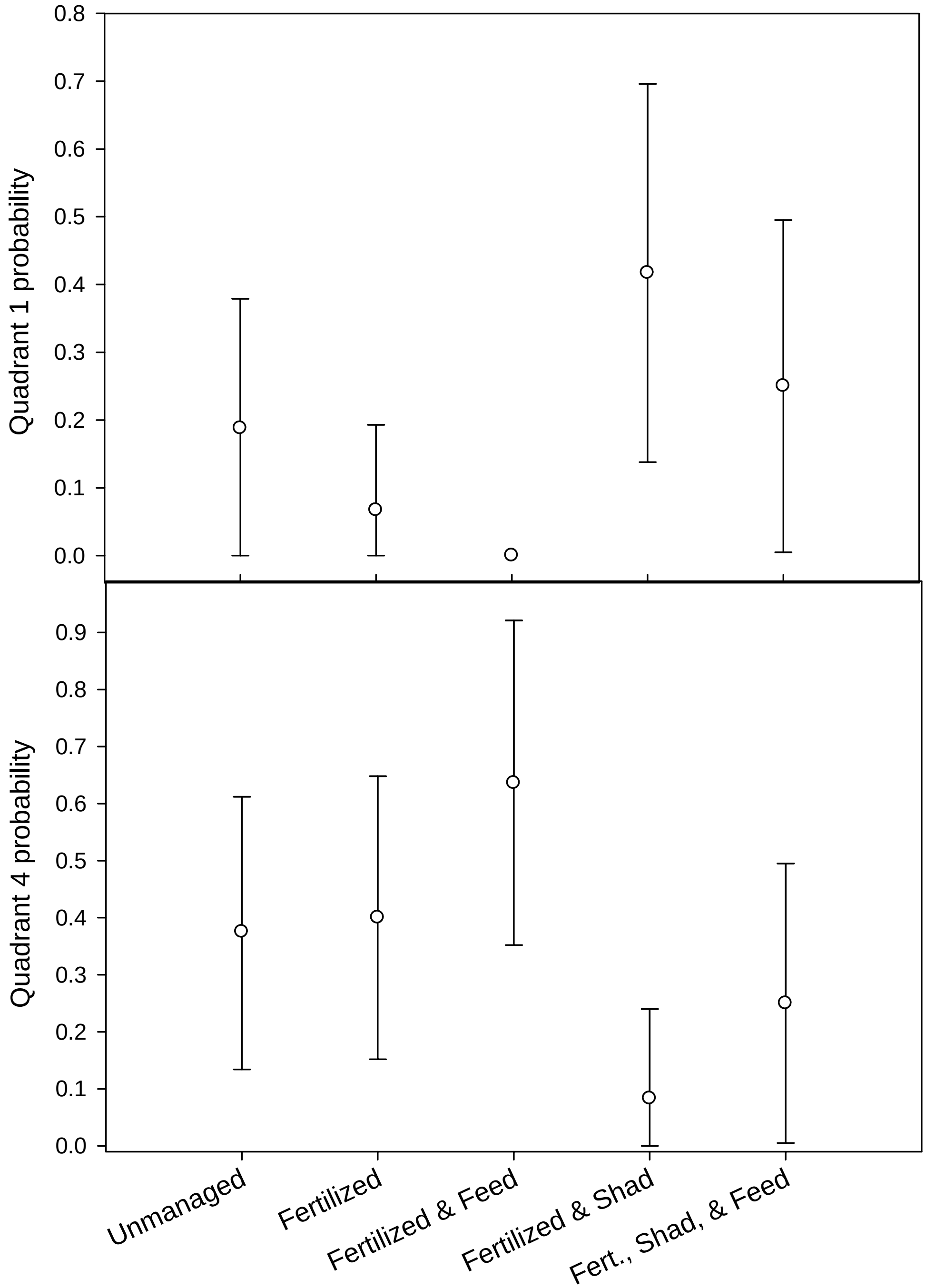


Figure 18. Probabilities of a pond's fish community occurring in quadrant 1 or quadrant 4 by management strategy (quadrant 1 = largemouth bass RSD-P ≥10 and bluegill PSD <20. quadrant 4 = largemouth bass RSD-P <10 and bluegill PSD ≥20) as determined by a baseline-category logit model. Error bars indicate 95% confidence intervals.

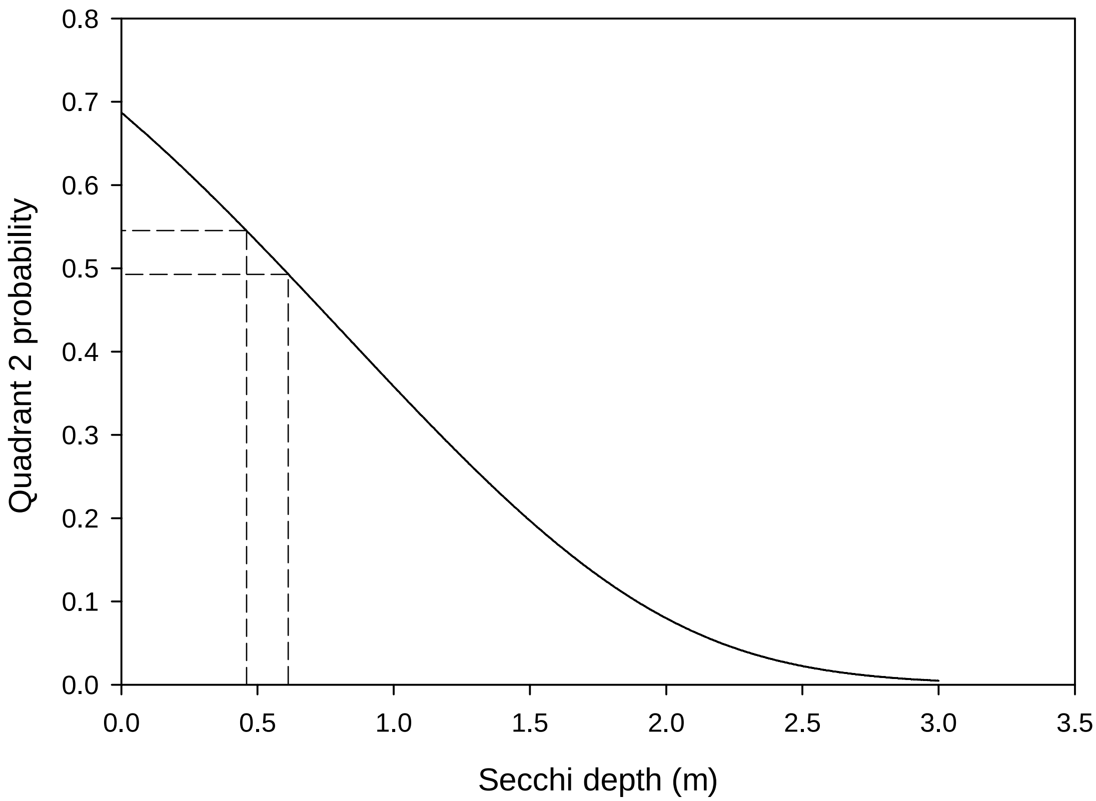


Figure 19. Probability of a pond's fish community occurring in quadrant 2 as a function of secchi depth (m) as determined by a baseline-category logit model (quadrant 2 = largemouth bass RSD-P ≥10 and bluegill PSD ≥20). Dashed lines indicate the range of secchi depth recommended by the Alabama Cooperative Extension System (0.46-0.61 m) and their associated probabilities of occurring in quadrant 2.

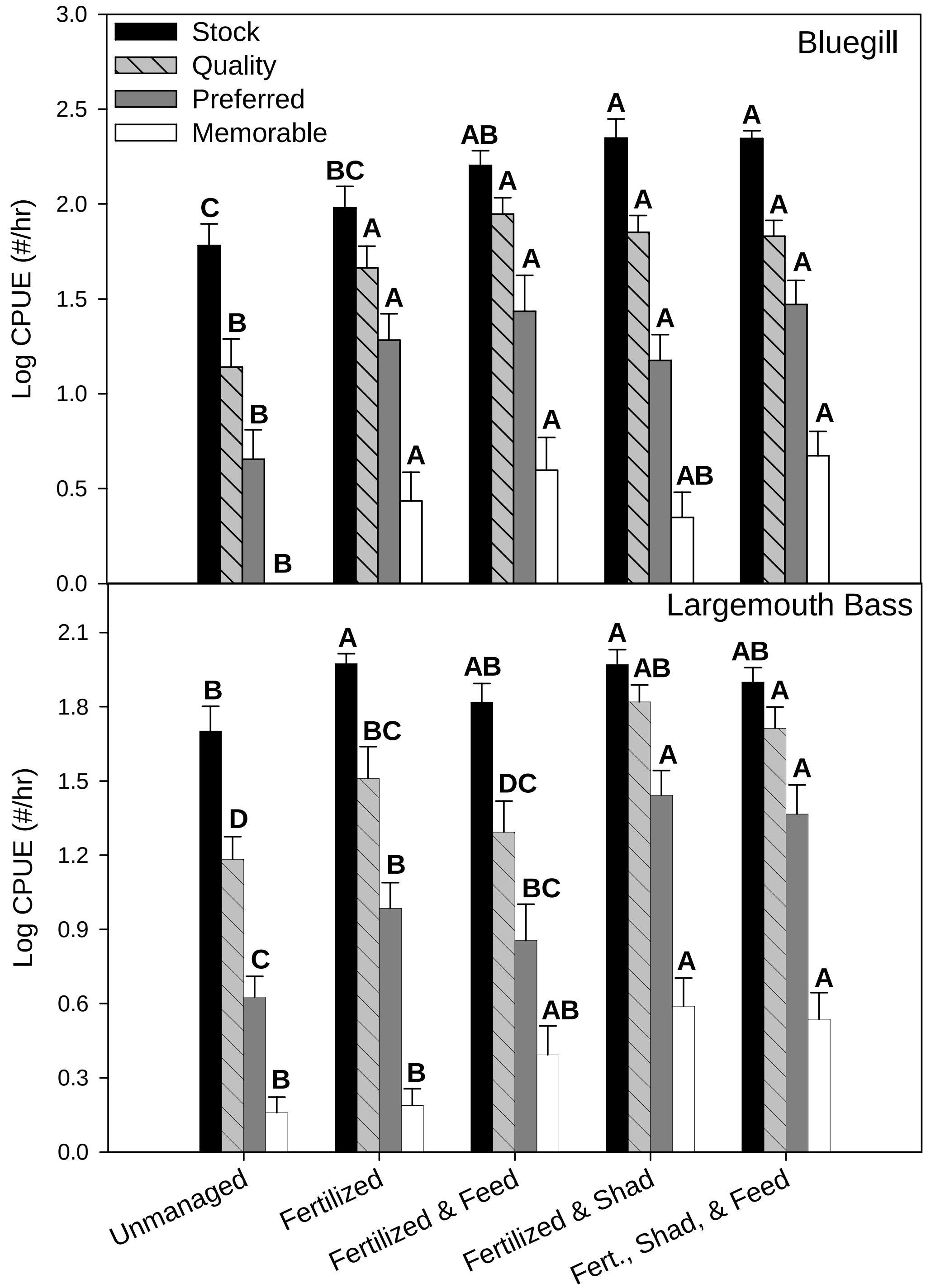


Figure 20. Largemouth bass and bluegill log CPUE (#/hr) by management strategy. Lettered groupings relate only to that size class. Strategies that share the same letter are not significantly different (P >0.05).

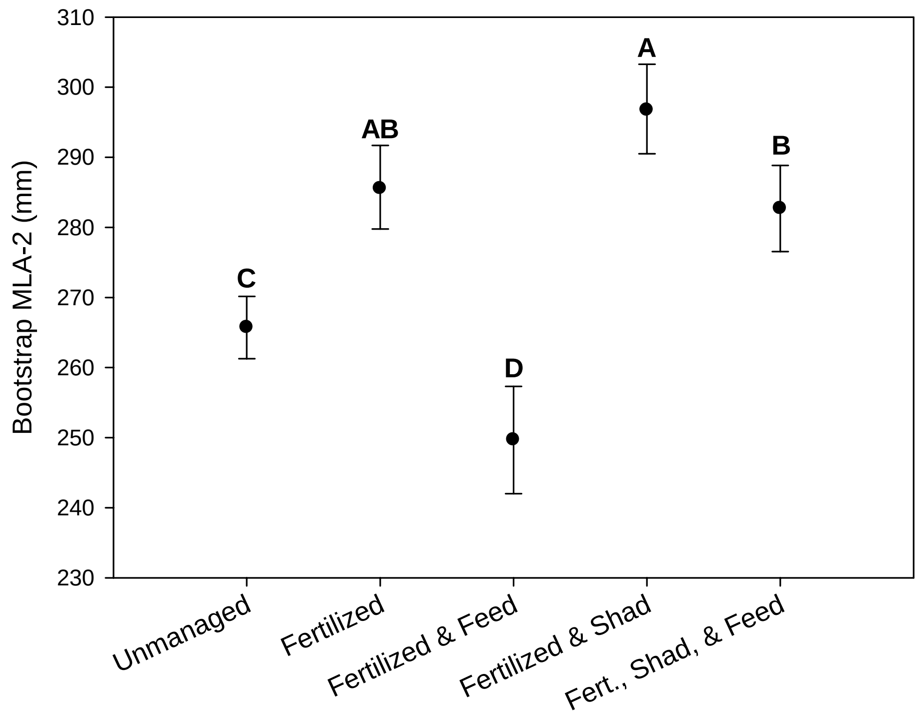


Figure 21. Largemouth bass back-calculated mean length-at-age-2 (MLA-2) bootstrap means by management strategy. Error bars indicate 95% CI derived from Monte Carlo analysis. Strategies that share the same letter and are not significantly different (P >0.05).

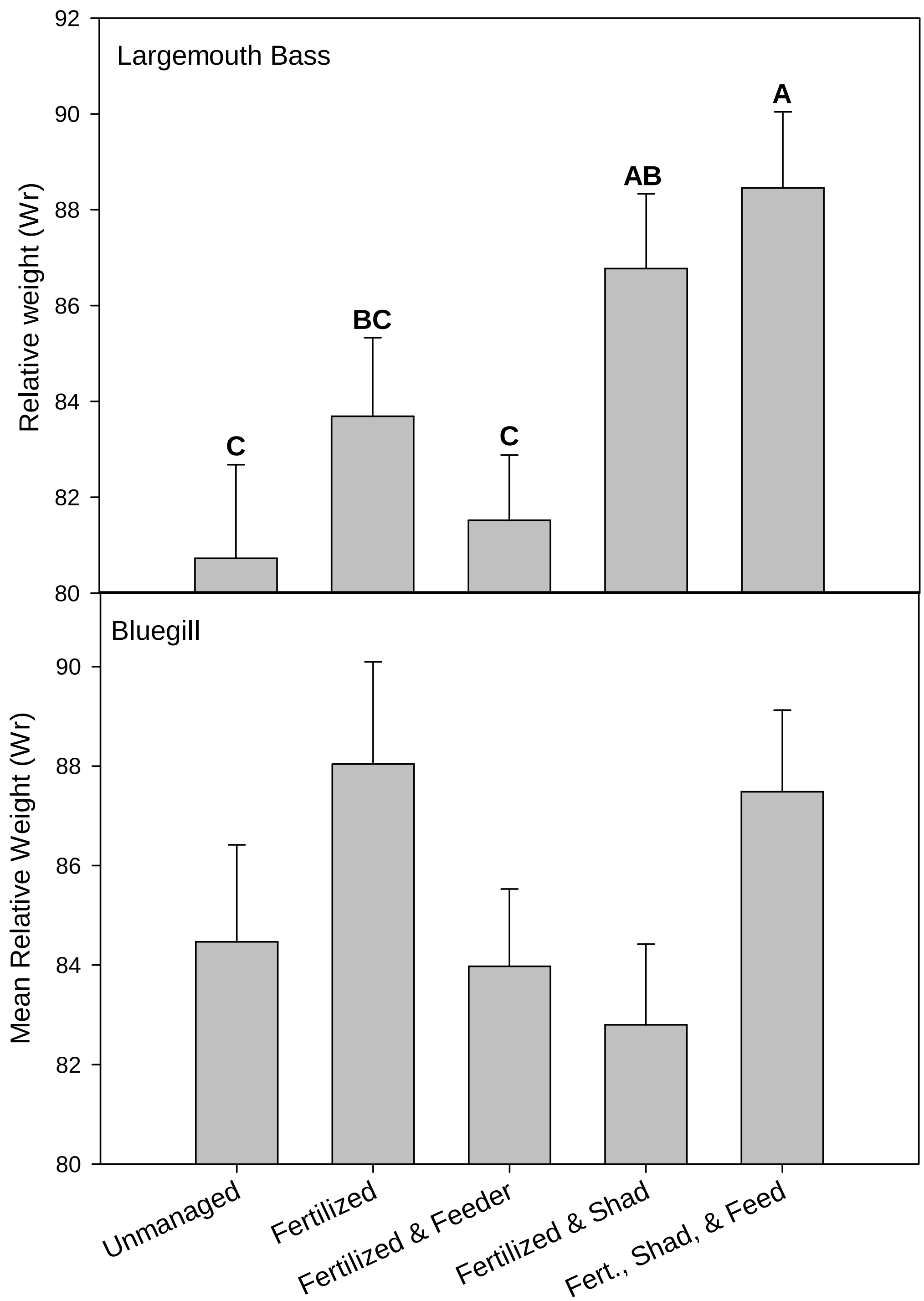


Figure 22. Largemouth bass and bluegill mean relative weight (Wr) by management strategy. Strategies that share the same letter are not significantly different (P >0.05). Bluegill Wr did not significantly differ (P = 0.21).

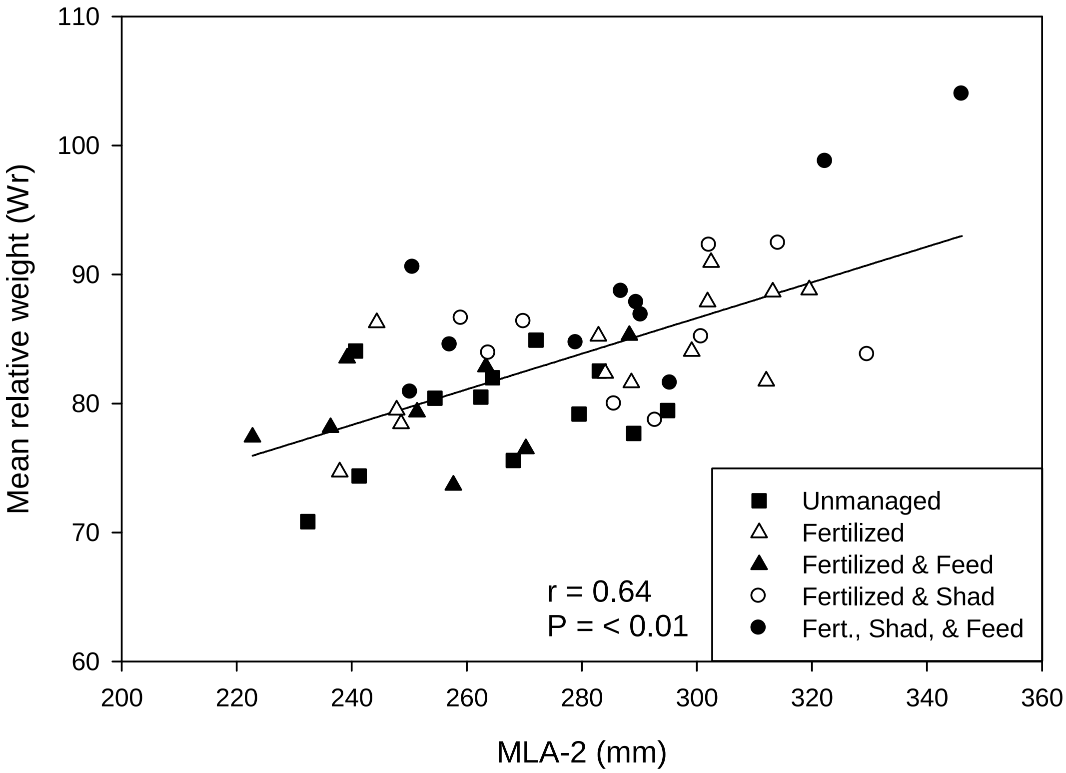


Figure 23. Relation between largemouth bass back-calculated mean length-at-age2 (MLA-2) and mean relative weight. Each point represents a single pond.

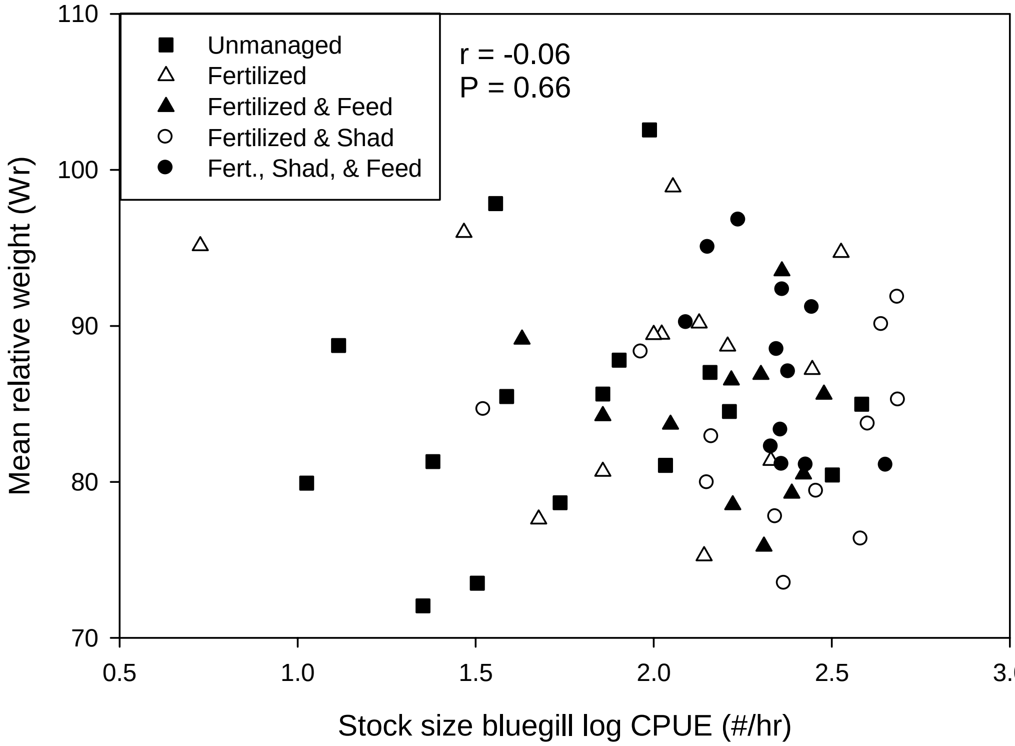


Figure 24. Relation between mean log CPUE of stock size bluegill and mean relative weight. Each point represents a single pond.

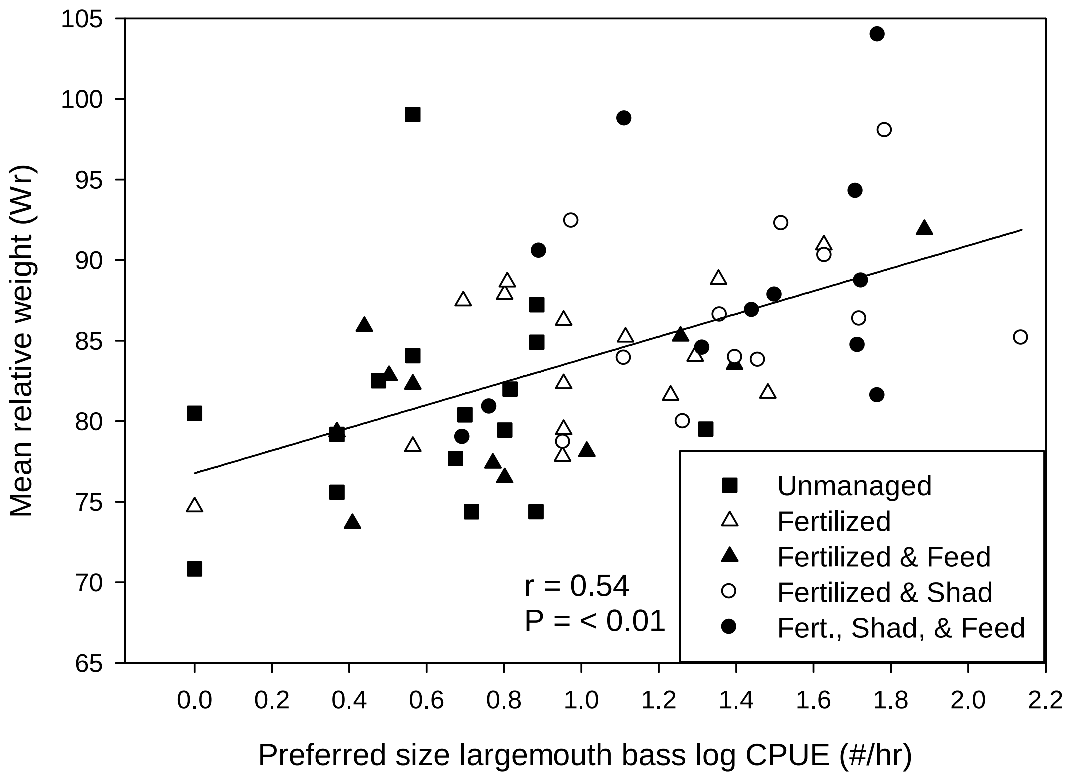


Figure 25. Relation between mean log CPUE of preferred size largemouth bass and mean relative weight. Each point represents a single pond.

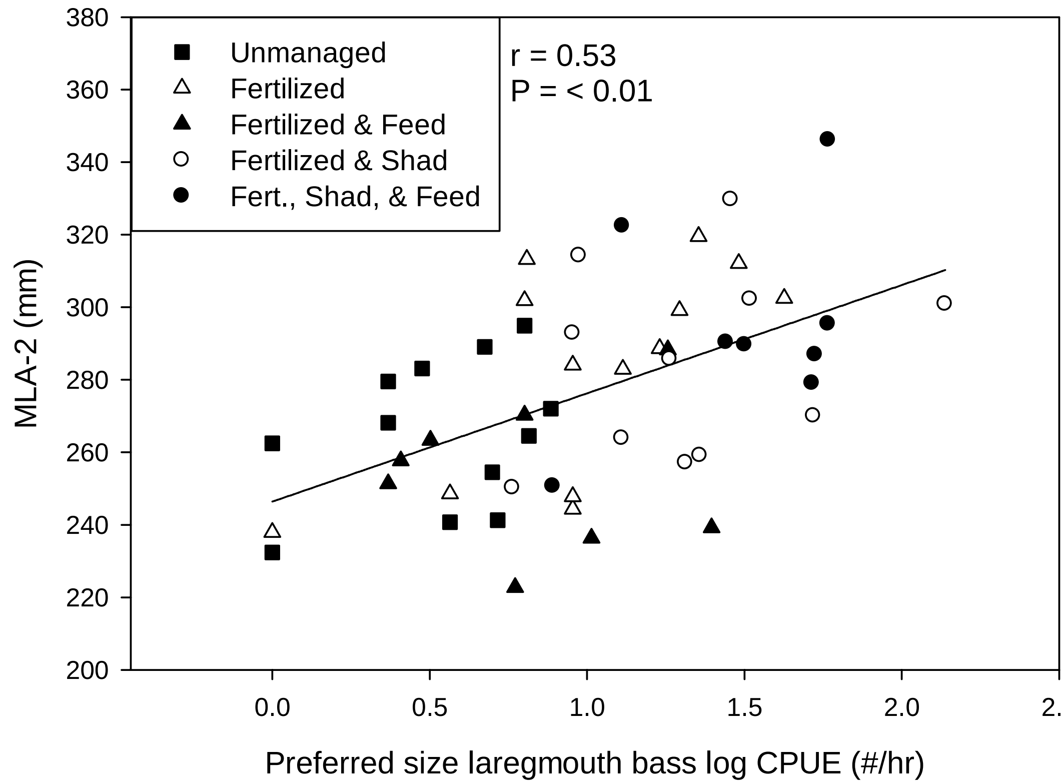


Figure 26. Relation between mean log CPUE of preferred size largemouth bass and back –calculated mean length-at-age-2 (MLA-2). Each point represents a single pond.

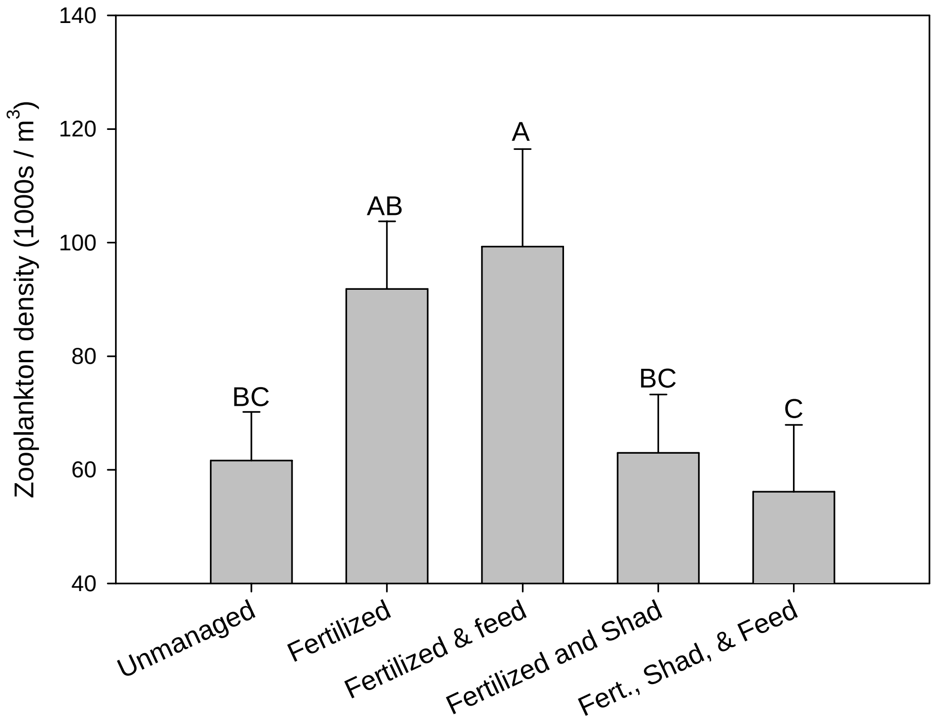


Figure 27. Zooplankton density (1000s / m^3) by management strategy. Strategies that share the same letter are not significantly different (P >0.05).

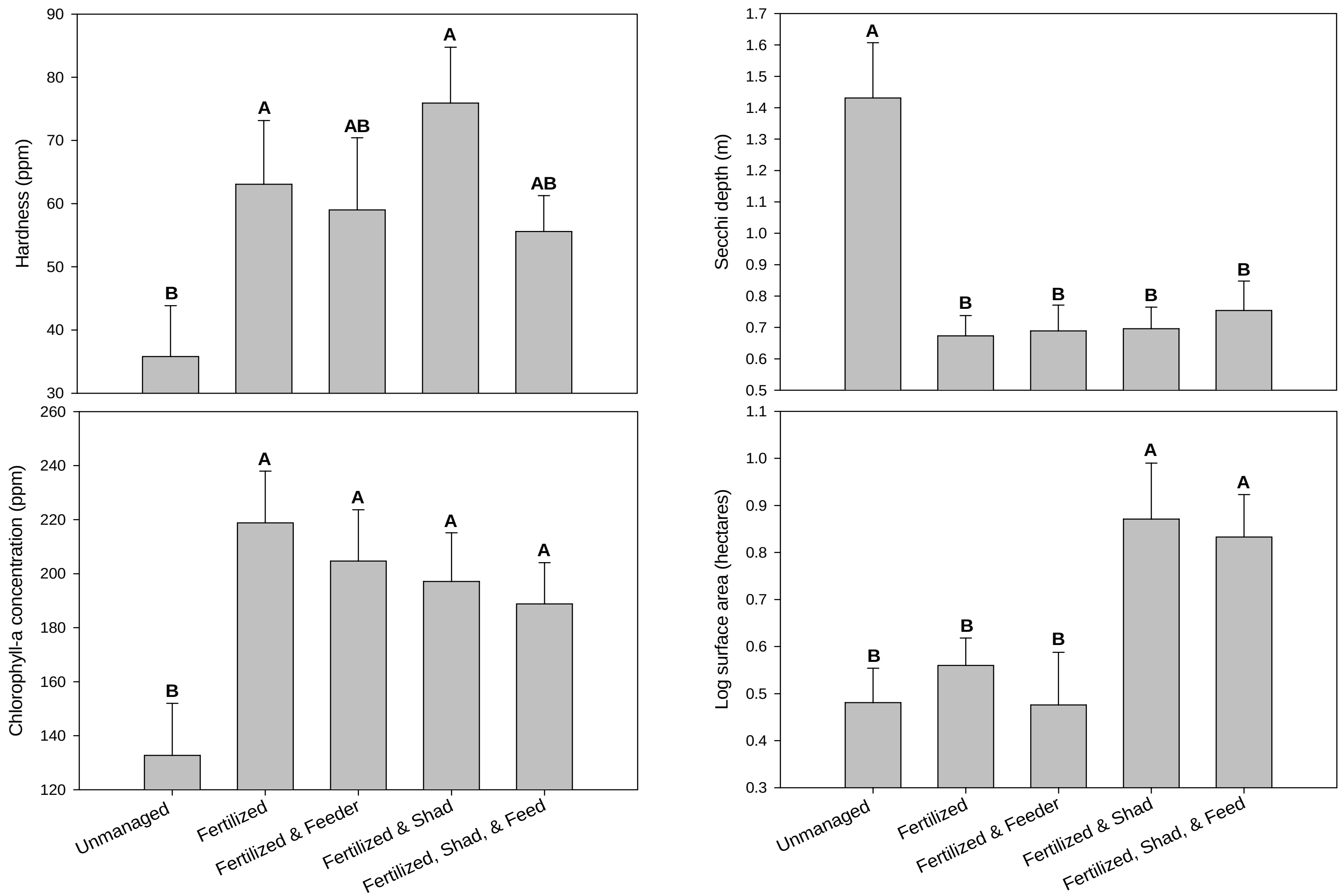


Figure 28. Chlorophyll-a concentration, hardness, secchi depth, and surface area by management strategy. Strategies that share the same letter are not significantly different (P >0.05).

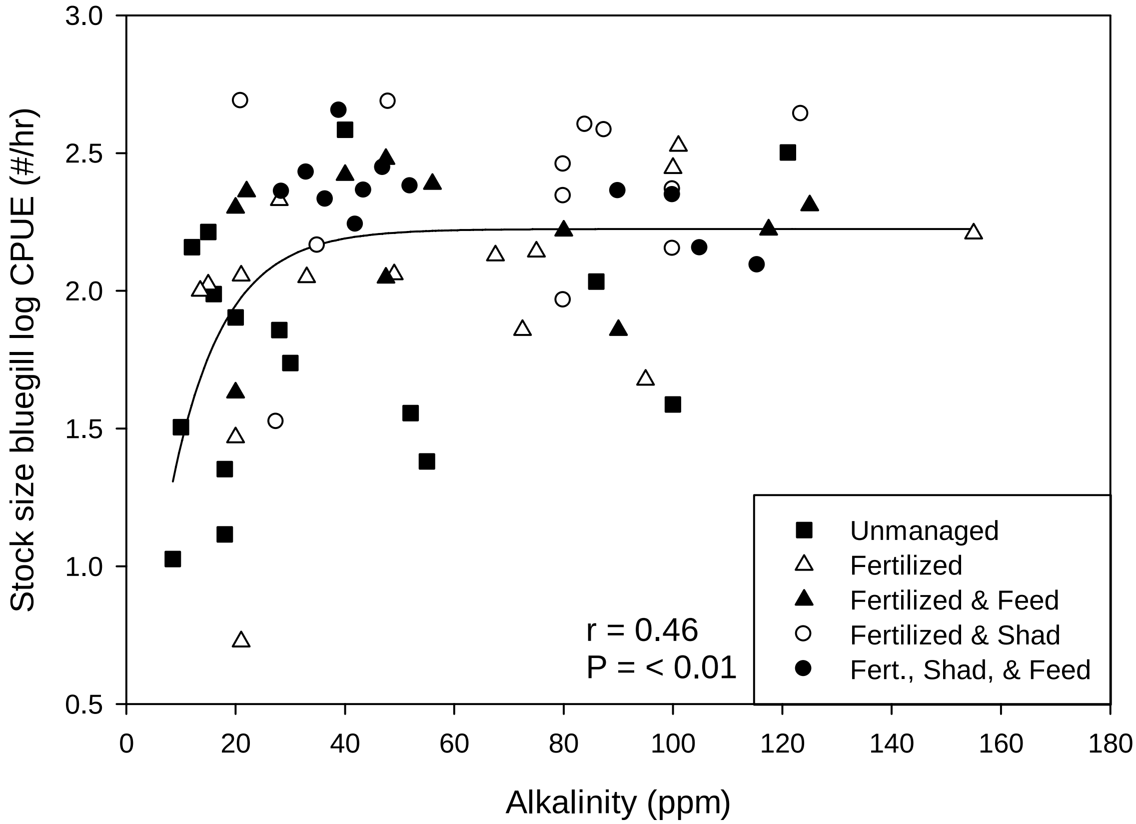


Figure 29. Relation between pond alkalinity concentration and CPUE of stock size bluegill. Each point represents a single pond.

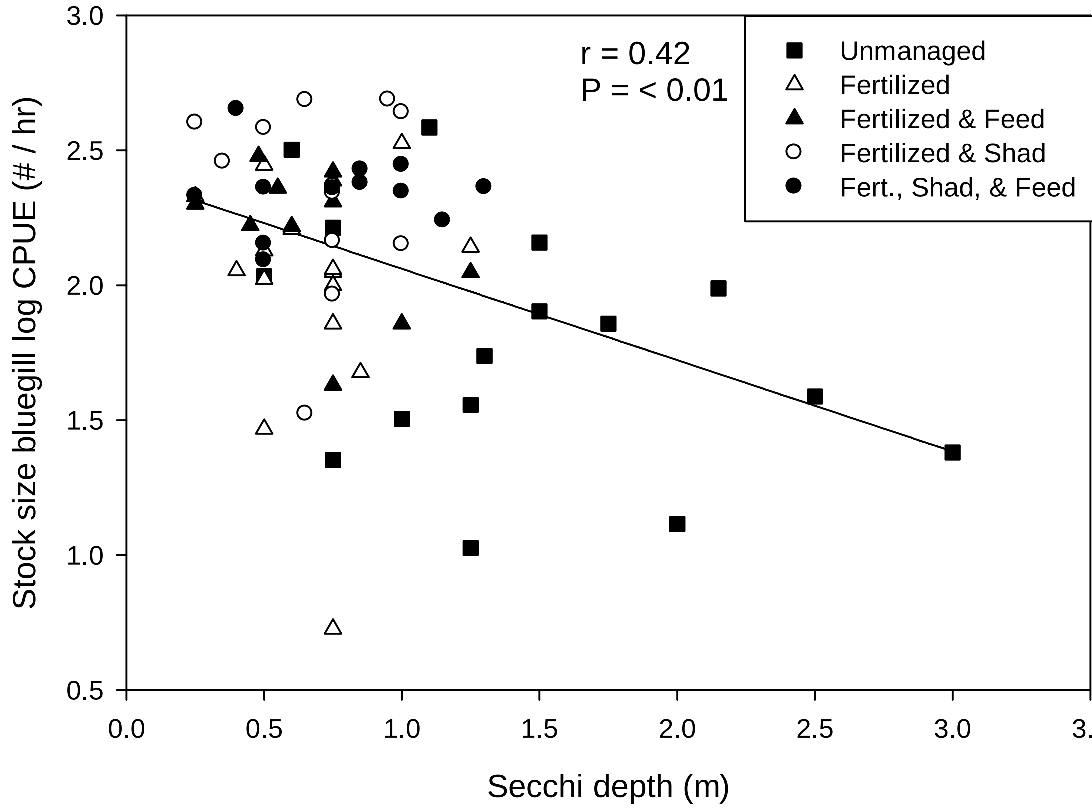


Figure 30. Relation between secchi depth and CPUE of stock size bluegill. Each point represents a single pond.

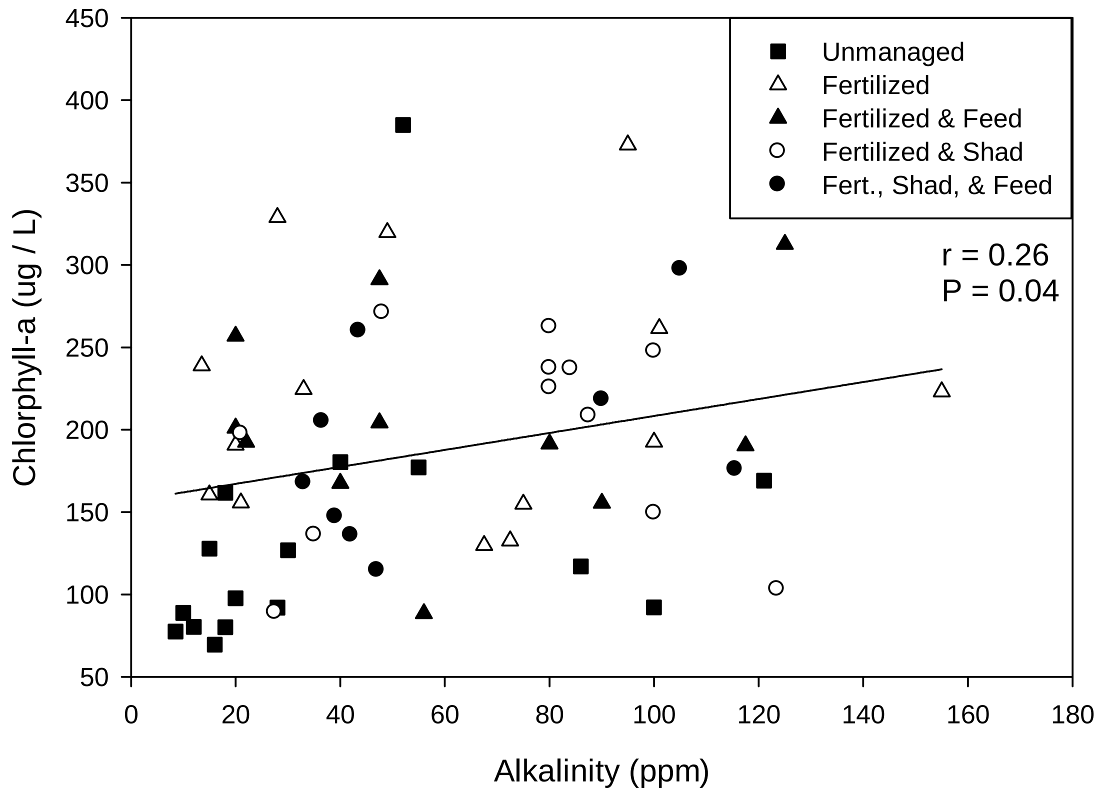


Figure 31. Relation between pond alkalinity and chlorophyll-a concentration. Each point represents a single pond.

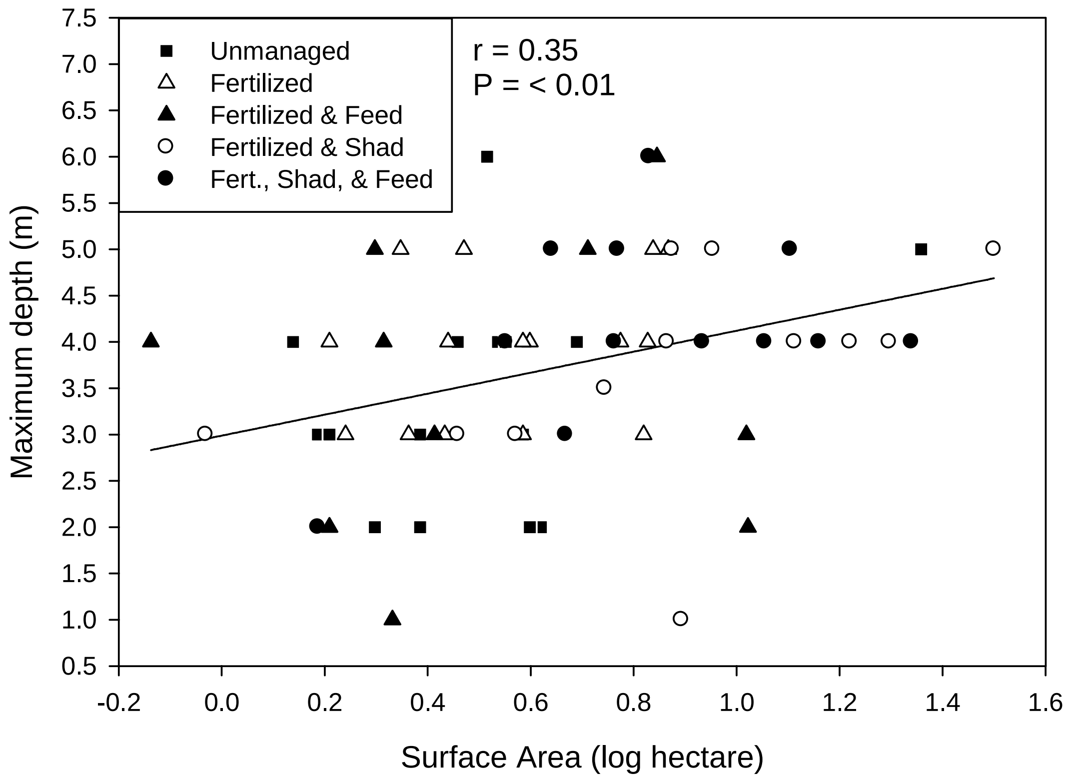


Figure 32. Relation between pond surface area and maximum depth. Each point represents a single pond.

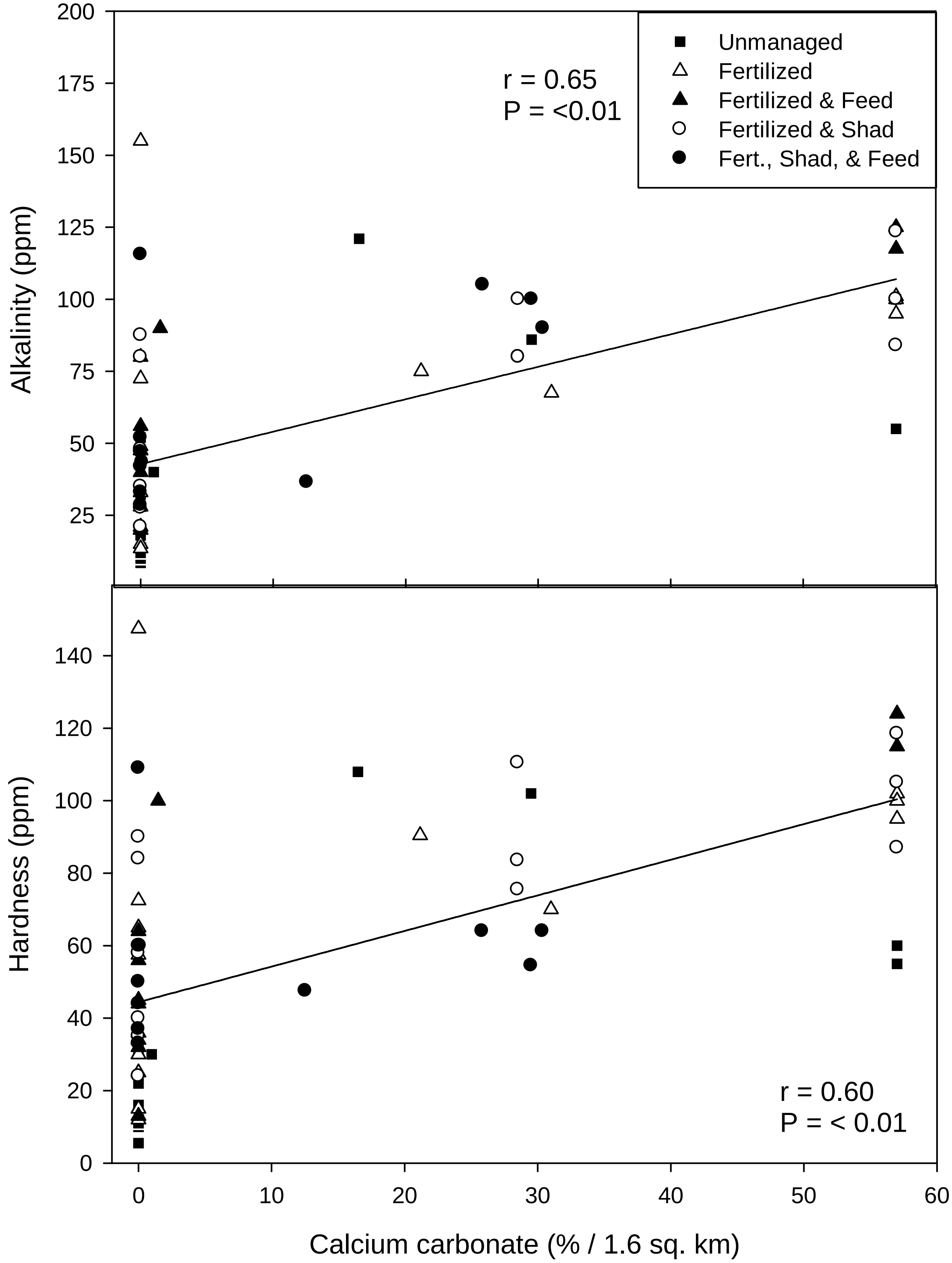


Figure 33. Relation between pond alkalinity and hardness concentration and calcium carbonate concentration of the watershed soil. Each point represents a single pond.

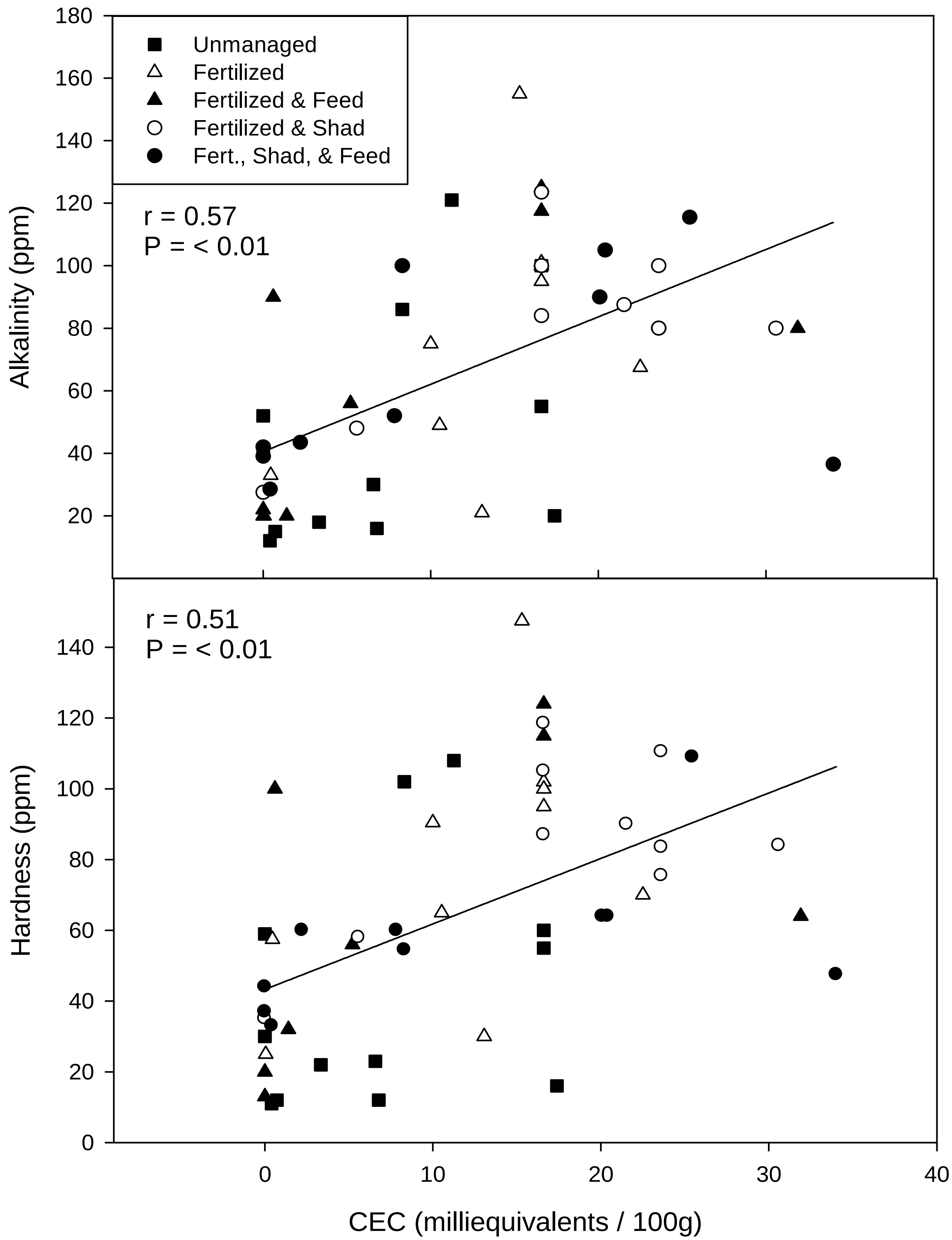


Figure 34. Relation between pond alkalinity and hardness concentration and calcium carbonate concentration of the watershed soil. Each point represents a single pond.

LITERATURE CITED

Adams, S. M., and D. L. DeAngelis. 1987. Indirect effects of early bass–shad interactions on predatory population structure and food web dynamics. Pages 103-117 *in* W. C. Kerfoot and A. Sih, editors. Predation: direct and indirect impacts on aquatic communities. University Press of New England, Hanover, New Hampshire.

Anderson, R.O. 1976. Management of small warmwater impoundments. Fisheries (Bethesda) 1(6):5-7, 26-28.

Auburn University, Agricultural Experiment Station, unpublished Fisheries Research Annual Reports 1943.

Berger, T.A. 1982. Supplemental feeding of a wild bluegill population. North American Journal of Fisheries Management 2: 158-163.

Berkson, J. 1944. Application of the logistic function to bio-assay. Journal of American Statistical Association 39:357-365.

Bettoli, P.W., M.J. Maceina, R.L. Noble, and R.K. Betsill. 1992. Piscivory in largemouth bass as a function of aquatic vegetation abundance. North American Journal of Fisheries Management 12: 509-516.

Boyd, C.E., 1990. Water Quality in Ponds for Aquaculture. Alabama Agricultural Experiment Station, Auburn University, AL, USA.

Brenden, T. O. and B. R. Murphy. 2004. Experimental assessment of age-0 largemouth bass and juvenile bluegill competition in a small impoundment in Virginia. North American Journal of Fisheries Management 24: 1058-1070.

Burns, J.W. 1966. Threadfin shad. Pages 481-488. *in* A.Calhoun ed. Inland fisheries management. California Fish and Game, Sacramento, California.

Coble, D. W. 1988. Effects of angling on bluegill populations: management implications. North American Journal of Fisheries Management 8:277-283.

Dendy, J.S. 1963. Farm Ponds. Pages 595-620 *in* D.G. Frey, editor. Limnology in North America. University of Wisconsin Press, Madison.

DeVries, D.R. 1989. Complex interactions in aquatic communities: trophic-level interactions, ontogenetic niche shifts, and the role of an open-water planktivore. Doctoral Dissertation. The Ohio State University, Columbus.

DeVries, D.R. and R.A. Stein. 1990. Manipulating shad to enhance sport fisheries in North America: and assessment. North American Journal of Fisheries Management 10: 209-223.

DeVries, D.R., R.A. Stein, J.G. Miner, and G.G. Mittelbach. 1991. Stocking threadfin shad: consequences for young-of-year fishes. Transactions of the American Fisheries Society 120: 368-381.

DeVries, D.R. and R.A. Stein. 1994. Assessing the role of shad in our waters: can we draw any conclusions? Lake and Reservoir Management 9: 68.

Eggleton, M.A, and H.L. Schramm, Jr. 2002. Caloric densities of selected fish prey organisms in the lower Mississippi River. Journal of Freshwater Ecology 17:409-414.

Fast, A.W., L.H. Bottroff, and R.L. Miller. 1982. Largemouth bass, Micropterus salmoides, and bluegill, *Lepomis macrochirus*, growth-rates associated with artificial destratification and threadfin shad, Dorosoma pretense, introductions at El Capitan reservoir, California. California Fish and Game 68: 4-20.

Fisher, R. 1979. Interim report of the supplemental spot feeding to improve bluegill in Dolan Lake. Farm Pond Harvest 13(2): 12-13, 28-29, 32-34.

Gabelhouse, D. W., Jr . 1987 . Response of largemouth bass and bluegills to removal of surplus largemouth bass from a Kansas pond. North American Journal of Fisheries Management 7:81-90.

Garvey, J.E. and R.A. Stein. 1998. Competition between larval fishes in reservoirs: the role of relative timing of appearance.

Garvey, J.E., N.A. Dingledine, N.S. Donovan, and R.A. Stein. 1998. Exploring spatial and temporal variation within reservoir food webs: Predictions for fish assemblages. Ecological Applications 8: 104-120. Transactions of the American Fisheries Society 127: 1021-1039.

Goodson, L.F. 1965. Diets of four warmwater game fishes in a fluctuating, steep-sided California reservoir. Calif. Fish Game 51(4): 529-269.

Griffith, J.S. and D.A. Tomljanovich. 19765. Susceptibility of threadfin shad to impingement. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 29: 16-18.

Guest, W.C., R.W. Drenner, S.T. Threlkeld, F.D. Martin, J.D. Smith. 1990. Effects of gizzard shad and threadfin shad on zooplankton and young-of-year white crappie production. Transactions of the American Fisheries Society 119: 529-536.

Guy, C. S., and D. W. Willis. 1990. Structural relationships of largemouth bass and bluegill populations in South Dakota ponds. North American Journal of Fisheries Management 10:338-343.

Hambight, K.D., R. J. Trebatoski, R. W. Drenner, and D. Kettle. 1986. Experimental study of the impacts of bluegill (Lepomis macrochirus) and largemouth bass (Micropterus salmoides) on pond community structure. Canadian Journal of Fisheries and Aquatic Sciences 43:1171-1176.

Hambright, K. D. 1991. Experimental analysis of prey selection by largemouth bass: role of predator mouth width and prey body depth. Transactions of the American Fisheries Society120:500-508.

Hampton, E.L. and R. T. Lackey. 1976. Analysis of angler preferences and fisheries management objectives with implications for management. Proceedings of the Southeastern Association Game and Fish Commission 29:310–316.

Heidinger, R.C. 1983. Life history of gizzard shad and threadfin shad as it relates to the ecology of a small lake fisheries. *in* Pros and Cons of Shad (Bonneau, D. and Radonski, G., eds), pp. 1-13. Des Moines, Iowa: Iowa Conservation Commission.

Irwin, B.J., D.R. DeVries, and R.A. Wright. 2003. Evaluating the potential for predatory control of gizzard shad by largemouth bass in small impoundments: a bioenergetics approach. Transactions of the American Fisheries Society 132 (5): 913-924.

Jackson, J.R., J.M. Phillips, R.L. Noble, and J.R. Rice. 1991. Relationship of planktivory by shad and diet shifts by young-of-year largemouth bass in a southern reservoir. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 44(1990): 114-125.

Johnson, J.E. 1970. Age, growth, and population dynamics of threadfin shad, *Dorosoma petenense* (Gunther) in central Arizona reservoirs. Transactions of the American Fisheries Society 99: 739-753.

Kilgen, R.H. 1974. Food habits of white amur, largemouth bass, bluegill, and redear sunfish receiving supplemental feed. *In* Proceedings of the 27th Annual Meeting of the Southeast Association of Game and Fish commissioners.

Kimesy, J.B., R. Hagy, and G.W. McCammon. 1957. Progress Report on the Mississippi threadfin shad in the Colorado River for 1956. Calif. Dep. of Fish Game, Inland Fish Admin. Rep. No. 57-23, pp.

Le Cren, E. D. 1947. The determination of the age and growth of the yellow perch (*Perca fluviatilis*) from the opercular bone. Journal of Animal Ecology 16:188-204.

Ligler, W.C. 1971. Salvaging stunted bluegills. Farm Pond Harvest5:1, 22-23.

Miller, E.E. 1971. The age and growth of centrarchid fishes in Millerton and Pine Flat reservoirs. California. Calif. Fish and Game, Inland Fish. Admin. Rep. No. 71-4 17 pp.

Miranda, L.E. 2008. Extending the Scale of Reservoir Management. In: M. Allen and S. Sammons (editors). Balancing fisheries management and water uses for impounded river systems. American Fisheries Society Bethesda, Maryland U.S.A.

Modde, T. 1980. State stocking policies for small warmwater impoundments. Fisheries 5: 13-17.

Modde, T., and C. G. Scalet. 1985. Latitudinal growth effects on predator–prey interactions between largemouth bass and bluegill in ponds. North American Journal of Fisheries Management 5:227–232.

Murnyak, D.F., M.O. Murnyak, and L.J. Wolgast. 1984. Growth of stunted and nonstunted bluegill sunfish in ponds. Progressive Fish-Culturist 46(2): 133-138.

Murphy, B.R., D.W. Willis, and T.A. Springer. 1992. The relative weight index in fisheries management: status and needs. Fisheries 16(2):30-38.

Nail, M.L. and D.H. Powell. 1975. Observations on supplemental feeding of a 75-acre lake stocked with largemouth bass, bluegill, redear, and channel catfish. Pp.378-384. Proceedings of the 28th Annual Meeting of the Southeast Association of Game and Fish Commissioners.

Neves, R. J. 1975. Factors affecting fry production of smallmouth bass (*Micropterus dolomieui*) in South Branch Lake, Maine. Transactions of the American Fisheries Society 104:83–87.

Ney, J.J. and J.J. Ney. 1981. Forage-fish managements in the United States: evolution of forage-fish management in lakes and reservoirs. Transactions of the American Fisheries Society 110: 725-728.

Nutt, K. 2004. Stocking Gizzard Shad in Ponds. Wildlife Trends 4(1):2-6.

Noble, R.L. 1981. Management of forage fishes in impoundments of the Southern United States. Transactions of the American Fisheries Society 110: 738-750.

Olive, J.A., L. E. Miranda, and W. D. Hubbard. 2005. Centrarchid assemblages in Mississippi state-operated fishing lakes. North American Journal of Fisheries Management 25: 7-15.

Olson, M.H., G. G. Mittelbach, and C. W. Osenberg. 1995. Competition between predator and prey: resource-based mechanisms and implications for stage-structured dynamics. Ecology 76: 1758-1771.

Porath, M.T., L.D. Pape, and J.J. Jackson. 2003. Evaluating supplemental feeding of a bluegill population and validating species utilization by application of a toxic fish food. Journal of Freshwater Ecology 18 (4): 593-597.

Porath, T.P. and K.L. Hurley. 2005. Effects of waterbody type and management actions on bluegill growth rates. North American Journal of Fisheries Management 25: 1041-1050.

Prophet, C.W. 1982. Zooplankton changes in a Kansas lake 1963-1981. Journal of Freshwater Ecology 1:569-575.

Prophet, C.W. 1985. Calanoid population structure in a Kansas lake after introduction of threadfin shad. Southwestern Naturalist 30:162-163.

Prophet, C.W. 1988. Changes in seasonal population structures of two species of *Diaptomus* (Calanoida, Copepoda) subsequent to introductions of threadfin shad. Southwestern Naturalist 33: 41-53.

Reiger, H. A. 1962. On the evolution of bass-bluegill stocking policies and management recommendations. The Progressive Fish-Culturist2 4:99-111.

Savino, J. F. and R. A. Stein. 1982. Predator-Prey Interaction between Largemouth Bass and Bluegills as Influenced by Simulated, Submersed Vegetation. Transactions of the American Fisheries Society 11:255-266.

Schalles, J.F. and T.E. Wissing. 1976. Effects of dry pellet diets on the metabolic rates of bluegill (*Lepomis macrochirus*). Journal of the Fisheries Research Board of Canada 33: 2443-2449.

Schmittou, H.R. 1969. Some effects of supplemental feeding of controlled fishing in largemouth bass-bluegill populations. Pp 311-320. *In* Proceedings of the 22nd Annual Meeting of the Southeast Association of Game and Fish commissioners.

Schultz, R.D., Z.J. Jackson, and M.C. Quist. 2008. Relating impoundment morphometry and water quality to black crappie, bluegill, and largemouth bass populations in Iowa. In: M. Allen and S. Sammons (editors). Balancing fisheries management and water uses for impounded river systems. American Fisheries Society Bethesda, Maryland U.S.A.

Southeastern Pond Management. 2005. The secrets of super lakes. Fish Tales, Spring 2005.

Strawn, K. 1965. Resistance of threadfin shad to cold temperatures. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 17: 290-293.

Stein, R.A., D.R. DeVries, and J.M. Dettmers. 1995. Food-web regulation by a planktivore: exploring the generality of the trophic cascade hypothesis. Canadian Journal of Fisheries and Aquatic Sciences 52 (11): 2518-2526.

Swingle, H.S., and E.V. Smith. 1941. Experiments on the stocking of fish ponds. Transactions of the American Fisheries Society 5: 267-278.

Swingle, H.S. 1946. Experiments with combinations of largemouth black bass, bluegills, and minnows in ponds. Transactions of the American Fisheries Society 76: 46-62.

Swingle, H.S. 1950. Relationships and dynamics of balanced and unbalanced fish populations. Alabama Agricultural Experiment Station Bulletin (Auburn University) 274.

Swingle, H. S. 1952. Farm pond investigations in Alabama. Journal of Wildlife Management 16: 126-135.

Swingle, H.S. 1956. Appraisal of methods of fish population study – part IV. Determination of balance in farm fish ponds. Transactions of the North American Wildlife Conference 21: 299-318.

Tharratt, R.C. 1966. The age and growth of centrarchid fishes in Folsom Lake, California. Calif. Fish and Game 52(1):4-16.

Timmons, T.J., W.L. Shelton, and W.D. Davies. 1980. Differential growth of largemouth bass in West Point Reservoir, Alabama-Georgia. Transactions of the American Fisheries Society 109: 176-186.

Turner, A. M., and G. G. Mittelbach. 1990. Predator avoidance and community structure: interactions among piscivores, planktivores, and plankton. Ecology 71:2241–2254.

U.S. Department of Agriculture, Soil Conservation Service. 1982. Ponds - Planning, Design, Construction. Agriculture Handbook 590, June 1982.

U.S. Census Bureau, 2001. 2000 U.S. Census Fact Sheet. http://factfinder.census.gov/servlet/ACSSAFFFacts?_submenuId=factsheet_0&_ss=on

von Geldern Jr., C., and D.F. Mitchell. 1975. Largemouth bass and threadfin shad in California, Pages 436-449 *in* R.H. Stroud and H. Clepper, editor. Black Bass Biology and Management. Sport Fishing Institute, Washington, D.C.

Wanjala, B.S., J.C. Tash, W.J. Matter, and C.D. Ziebell. 1986. Food and habitat use by different sizes of largemouth bass (Micropterus salmoides) in Alamo Lake, Arizona. Journal of Freshwater Ecology 3: 359-369.

Wege, G. J., and R. O. Anderson. 1978. Relative weight (Wr): a new index of condition for largemouth bass. Pages 79-91 *in* G. D. Novinger, and J. G. Dillard, editors. New approaches to the management of small impoundments, volume 5. North Central Division, American Fisheries Society, Special Publication, Bethesda, MD.

Wright, R.A., and M. Masser. 2004. Management of recreational fish ponds in Alabama. Alabama Cooperative Extension System, Alabama A&M and Auburn Universities, Circular ANR-557, Auburn.

Ziebell, C.D., J.C. Tash, and R.L. Barefield. 1986. Impact of threadfin shad on microcrustacean zooplankton in two Arizona lakes. Journal of Freshwater Ecology 3:399-406.

APPENDICES

Appendix A. Survey instrument used to obtain pond management information from private pond owners

Pond Management Survey

Surveyor: ___________________ Date: ____________________

Pond Location: County: ________________ Address: ___________________________

GPS coordinates: _________________________ Pond ID# from map: _______

Pond Owner: ______________________________ Phone: _______________________

Interview by telephone/mail/in person: ____________________

<u>Pond Information</u>

1. **Pond area (acres):** _____________ **Pond Age:** _______________

Last time pond was completely restocked: ____________________

2. **What is the pond used for? (Check all that apply)**
recreational fishing
aquaculture
pay-to-fish
livestock watering
irrigation
aesthetics
fire fighting
home heating and cooling
other______________________________________

If the pond is a pay-to-fish or leased for fishing, do anglers buy daily, monthly, annual passes

3. Does your pond currently provide a source of income?

No the pond is strictly for recreational uses______

While the pond is part of a larger facility that sells outdoor recreational activities, the pond itself is not the primary focus for income _________

The pond is used for commercial aquaculture only _________

The pond is used for recreation and commercial aquaculture _______

Appendix A. Cont.

4. What fish are found in the pond? (i.e. catfish, bass, crappie, bream, grass carp, shad, shiners)

Management

5. Who manages the pond?

The pond owner or family member ____________

A pond management consultant? If so who? __________________

A fishing club?________________________

6. Do you fertilize the pond? _________

If you do fertilize how do you determine when to add fertilizer? (a schedule, using water clarity or other)

If you do not fertilize, why? (cost, too much trouble, caused water quality problems, caused weed problems, other)

7. Do you provide supplemental pellet feed to the pond? _______

If there are bass in the pond, do you stock extra forage for them?______
If yes, what forage do you stock? _____________________________

Rate of stocking and how often? **_____________________________**

8. Do you aerate the pond? ______ (fountain, windmill, air pump)

9. How many pounds of bass do you think you take out of the pond each year? ____

Do you keep records of your harvest? ______

10. Where did you get the original fish for stocking the pond?

State ________Private Hatchery _________________ Other ________________

Appendix A. Cont.

11. Where do you get pond management information? (rank from most to least important)
____ county or regional extension agents
____ Alabama Division of Wildlife and Freshwater Fisheries
____ Auburn University
____ local feed and seed store
____ friends and family
____ internet extension/university websites
____ other internet sites
____ other: _______________________________________

12. What is the primary goal or management strategy for the pond?
general balance
trophy bass
trophy bream
enhanced catch rate

13. When is the last time you had your pond checked by a professional for:

balance __________

water quality _________

14. Were you aware that the Alabama Division of Wildlife and Freshwater Fisheries will do balance checks for free?

15. How would you rank your satisfaction with your pond? :

Extremely happy, no problems _______
Generally satisfied _________
I enjoy the pond but it has not lived up to my expectations _______
The pond is unsatisfactory but I am still trying to fix the problems _________
The pond has so many problems that I gave up trying to fix them ______

Appendix A. Cont.

16. Of the following problems, give them a score from 1 being not a problem to 5 a serious problem you deal with every year.

Filamentous algae (pond moss)	1	2	3	4	5
Other weeds	1	2	3	4	5
slow bass growth	1	2	3	4	5
poor algae bloom	1	2	3	4	5
slow bream growth	1	2	3	4	5
leaky pond	1	2	3	4	5
fish kills	1	2	3	4	5
fish disease	1	2	3	4	5
Poachers	1	2	3	4	5
Cormorants or other fish-eating birds	1	2	3	4	5
beavers/muskrats	1	2	3	4	5
other__________________________	______________________________________				

17. Would you be willing to allow personnel from Auburn University and The Alabama Cooperative Extension System to sample your pond as part of a project on pond management techniques?

Appendix B. Reasons given by the 16% (n = 25) respondents as to why they were unable to participate in the survey of Alabama Black Belt pond owners.

Reasons for Unavailable Surveys	N
Pond no longer existed	10
Owner unwilling to participate in survey	6
Pond changed ownership	4
Pond was part of waste water treatment facility	3
Pond was connected to local waterway	1
Owner was unaware of the pond	1

Appendix C. Location (county), water quality, and morphological measurements for sites with an unmanaged management strategy sampled in fall 2007 and spring 2008.

Management Strategy	County	Year	Surface Area (ha)	Maximum Depth (m)	Secchi (m)	Turbidity (NTU)	Chl-a (ug/l)	Alkalinity (ppm)	Hardness (ppm)
Unmanaged	Bullock	2008	4.9	4.0	1.50	3.60	97.66	20.0	16.0
(n = 16)	Chambers	2008	1.5	3.0	2.15	2.56	69.49	16.0	12.0
	Choctaw	2007	2.0	2.0	1.25	2.95	77.51	8.5	5.5
	Conecuh	2007	4.2	2.0	1.00	3.73	88.76	10.0	10.0
	Escambia	2007	3.4	4.0	0.75	7.58	127.83	15.0	12.0
	Lee	2008	1.4	4.0	1.30	3.61	126.88	30.0	23.0
	Lee	2008	3.3	6.0	1.50	3.33	80.38	12.0	11.0
	Lowndes	2007	3.6	4.0	0.50	16.20	117.04	86.0	102.0
	Lowndes	2008	22.8	5.0	2.50	1.60	92.08	100.0	55.0
	Lowndes	2008	1.6	3.0	1.10	3.74	180.34	40.0	30.0
	Lowndes	2008	2.4	3.0	3.00	12.36	177.18	55.0	60.0
	Lowndes	2008	4.0	2.0	0.60	11.12	169.04	121.0	108.0
	Lowndes	2008	3.8	3.0	1.25	4.73	384.96	52.0	59.0
	Marengo	2007	2.4	2.0	0.75	8.95	80.15	18.0	22.0
	Pike	2008	2.9	4.0	1.75	N/A	92.02	28.0	31.0
	Sumter	2008	1.5	3.0	2.00	2.33	161.74	18.0	16.0

Appendix D. Location (county), water quality, and morphological measurements for sites with a fertilized management strategy sampled in fall 2007 and spring 2008.

Management Strategy	County	Year	Surface Area (ha)	Maximum Depth (m)	Secchi (m)	Turbidity (NTU)	Chl-a (ug/l)	Alkalinity (ppm)	Hardness (ppm)
Fertilized	Bullock	2008	1.6	4.0	0.50	24.97	160.41	15.0	15.0
(n = 15)	Bullock	2008	6.6	3.0	0.75	8.94	238.83	13.5	12.0
	Clarke	2007	3.0	5.0	1.25	3.65	154.88	75.0	90.5
	Dallas	2007	2.8	4.0	0.50	10.96	190.71	20.0	25.0
	Hale	2007	4.0	4.0	0.75	7.44	155.71	21.0	30.0
	Lowndes	2007	2.7	3.0	0.50	7.55	192.61	100.0	102.0
	Lowndes	2007	3.8	3.0	0.50	10.84	129.87	67.5	70.0
	Lowndes	2008	6.7	4.0	0.40	16.19	195.34	21.0	30.0
	Lowndes	2008	6.9	5.0	1.00	14.97	261.50	101.0	100.0
	Lowndes	2008	5.9	4.0	0.60	14.13	223.09	155.0	147.5
	Lowndes	2008	7.4	5.0	0.85	7.59	372.92	95.0	95.0
	Russell	2007	2.2	5.0	0.25	23.70	328.93	28.0	34.0
	Sumter	2007	3.8	4.0	0.75	6.95	132.61	72.5	72.5
	Sumter	2008	2.3	3.0	0.75	8.23	224.46	33.0	57.5
	Sumter	2008	1.7	3.0	0.75	15.54	319.75	49.0	65.0

Appendix E. Location (county), water quality, and morphological measurements for sites with a fertilized-and-feeder management strategy sampled in fall 2007 and spring 2008.

Management Strategy	County	Year	Surface Area (ha)	Maximum Depth (m)	Secchi (m)	Turbidity (NTU)	Chl-a (ug/l)	Alkalinity (ppm)	Hardness (ppm)
Fertilized & Feeder (n = 11)	Clarke	2007	0.7	4.0	1.00	16.19	155.48	90.0	100.0
	Conecuh	2007	2.1	1.0	0.48	28.76	291.08	47.5	44.0
	Covington	2007	10.5	2.0	0.75	10.67	201.00	20.0	32.0
	Lee	2007	10.4	3.0	0.75	7.20	88.47	56.0	56.0
	Lowndes	2007	1.6	2.0	0.25	33.62	256.84	20.0	13.0
	Lowndes	2008	2.6	3.0	0.75	8.22	312.56	125.0	115.0
	Lowndes	2008	7.0	6.0	0.55	7.25	192.42	22.0	20.0
	Lowndes	2008	2.0	5.0	0.60	16.98	191.46	80.0	64.0
	Lowndes	2008	2.1	4.0	0.45	24.13	190.24	117.5	124.0
	Macon	2007	5.1	5.0	1.25	5.97	204.27	47.5	45.0
	Pickens	2007	1.6	2.0	0.75	7.45	167.50	40.0	36.0

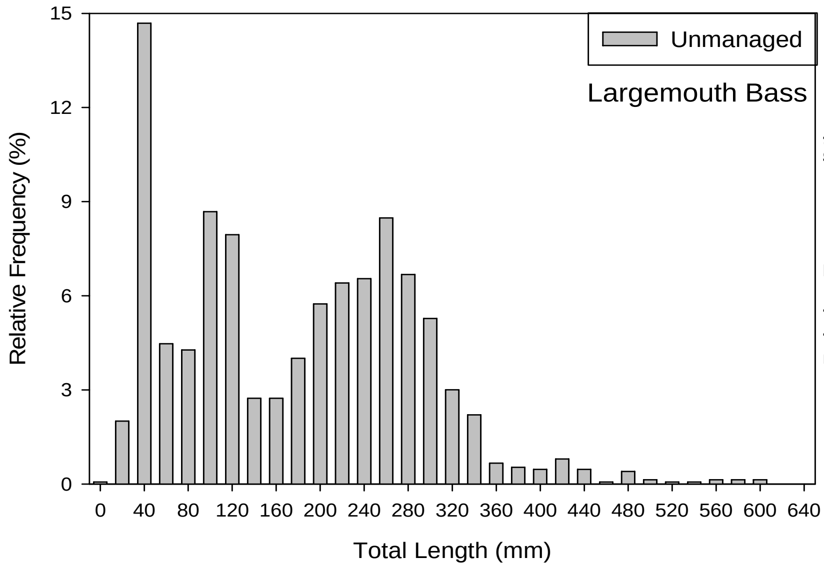
Appendix F. Location (county), water quality, and morphological measurements for sites with a fertilized-and-shad management strategy sampled in fall 2007 and spring 2008.

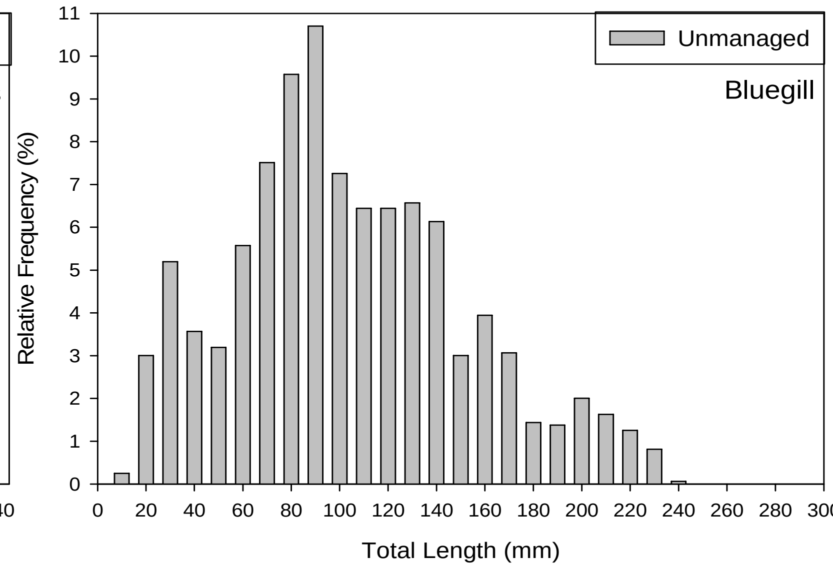
Management Strategy	County	Year	Surface Area (ha)	Maximum Depth (m)	Secchi (m)	Turbidity (NTU)	Chl-a (ug/l)	Alkalinity (ppm)	Hardness (ppm)
Fertilized & Shad (n = 12)	Bullock	2007	19.8	4.0	0.50	10.65	208.41	87.5	90.0
	Bullock	2008	7.3	4.0	0.65	10.72	271.12	48.0	58.0
	Bullock	2008	16.6	4.0	0.75	5.50	136.18	35.0	40.0
	Crenshaw	2008	12.9	4.0	0.95	5.55	197.57	21.0	24.0
	Lowndes	2007	5.5	3.5	0.75	7.08	225.57	80.0	83.5
	Lowndes	2007	7.5	5.0	1.00	6.74	149.50	100.0	105.0
	Lowndes	2007	7.8	1.0	0.65	12.89	89.10	27.5	35.0
	Lowndes	2007	0.9	3.0	0.25	36.43	237.11	84.0	87.0
	Lowndes	2007	2.9	3.0	0.75	5.66	237.36	80.0	84.0
	Lowndes	2007	3.7	3.0	0.35	16.50	262.38	80.0	75.5
	Lowndes	2007	9.0	5.0	0.75	5.84	247.59	100.0	110.5
	Lowndes	2008	31.6	5.0	1.00	5.62	103.20	123.5	118.5

Appendix G. Location (county), water quality, and morphological measurements for sites with a fertilized-shad-and-feeder management strategy sampled in fall 2007 and spring 2008.

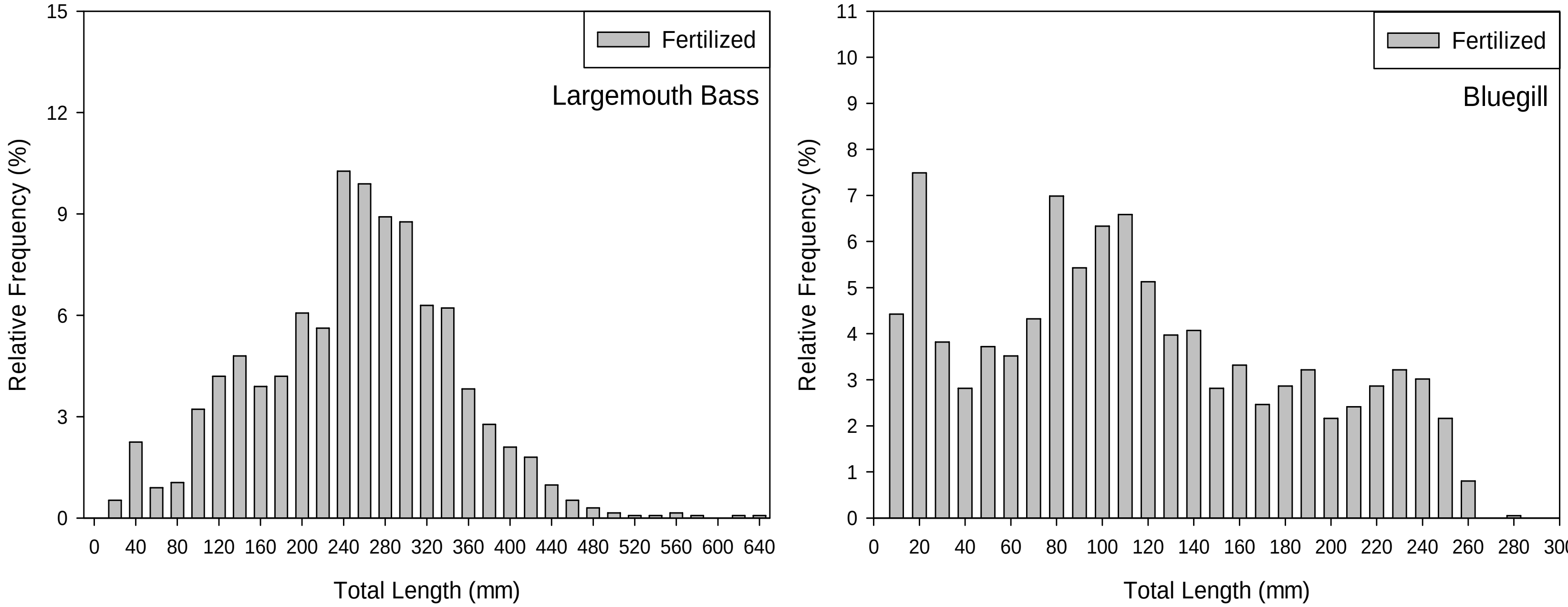
Management Strategy	County	Year	Surface Area (ha)	Maximum Depth (m)	Secchi (m)	Turbidity (NTU)	Chl-a (ug/l)	Alkalinity (ppm)	Hardness (ppm)
Fertilized, Shad, & Feeder (n = 12)	Bullock	2008	4.4	5.0	0.85	5.16	169.00	52.0	60.0
	Bullock	2008	14.4	4.0	0.75	7.24	217.38	28.5	33.0
	Bullock	2008	3.6	4.0	0.85	5.65	167.88	33.0	44.0
	Chambers	2008	1.5	2.0	1.30	6.33	260.04	43.5	60.0
	Crenshaw	2008	4.7	3.0	1.00	5.79	114.74	47.0	50.0
	Greene	2007	11.3	4.0	0.50	15.82	218.40	90.0	64.0
	Greene	2007	12.7	5.0	0.50	16.95	297.50	105.0	64.0
	Lowndes	2007	8.6	4.0	0.50	16.39	176.00	115.5	109.0
	Lowndes	2008	5.8	4.0	1.00	4.22	155.83	100.0	54.5
	Lowndes	2008	5.9	5.0	1.15	3.40	135.95	42.0	37.0
	Lowndes	2008	6.8	6.0	0.40	17.69	147.34	39.0	44.0
	Montgomery	2007	21.9	4.0	0.25	37.03	205.20	36.5	47.5

Appendix H. Combined relative length-frequency distributions for largemouth bass and bluegill collected via electrofishing fall 2007 and spring 2008 in unmanaged management strategies.

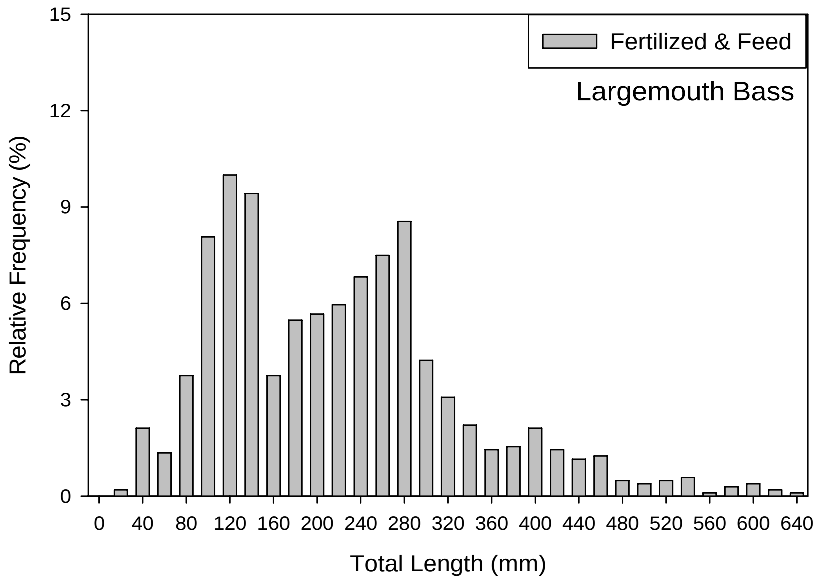


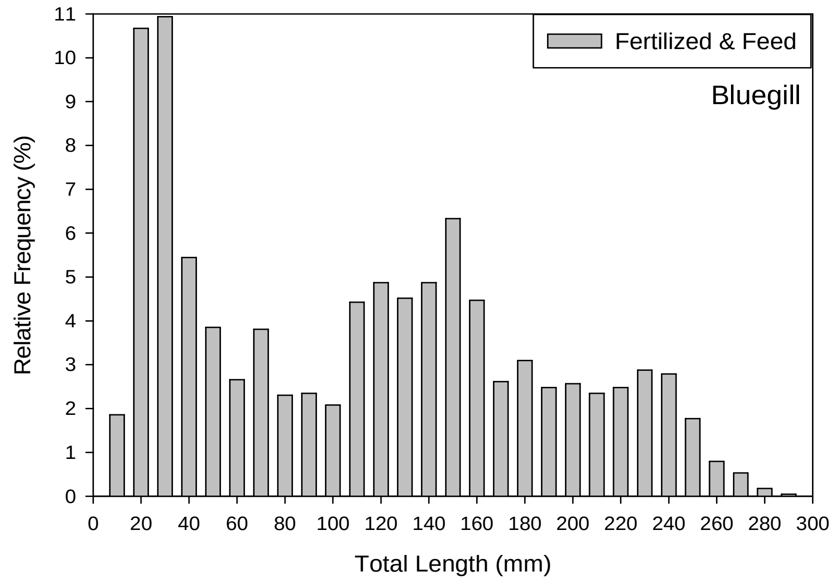


Appendix I. Combined relative length-frequency distributions for largemouth bass and bluegill collected via electrofishing fall 2007 and spring 2008 in fertilized management strategies.

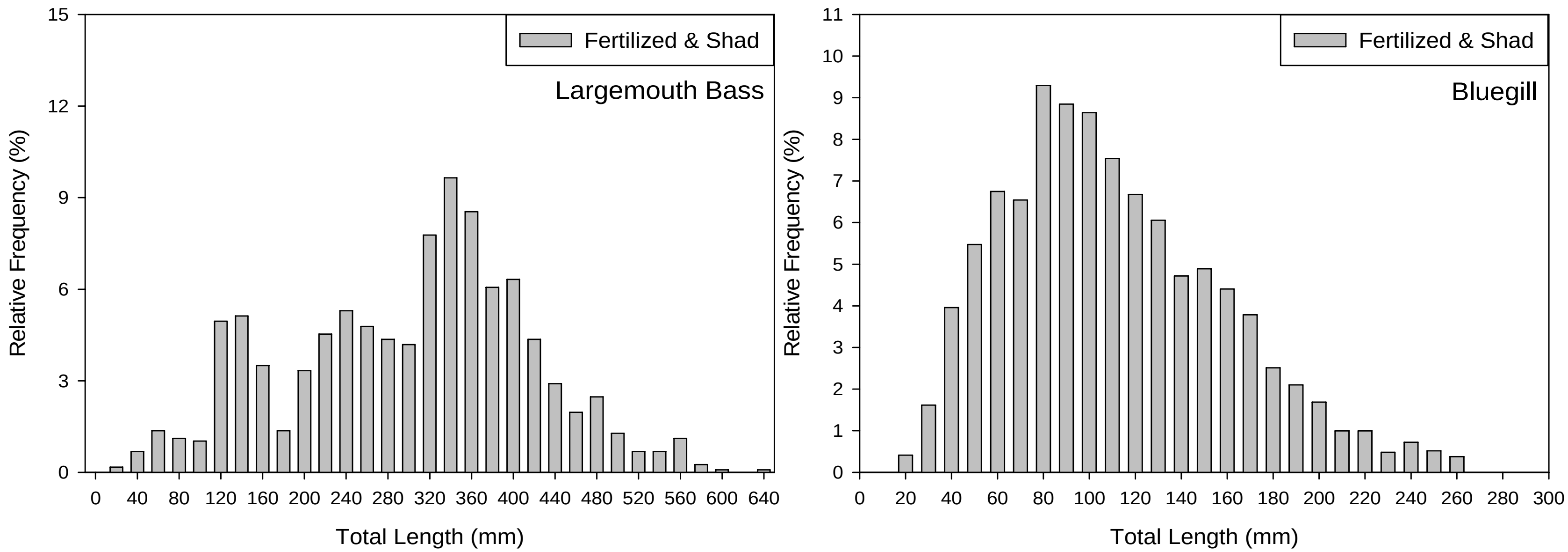


Appendix J. Combined relative length-frequency distributions for largemouth bass and bluegill collected via electrofishing fall 2007 and spring 2008 in fertilized-and-feeder management strategies.

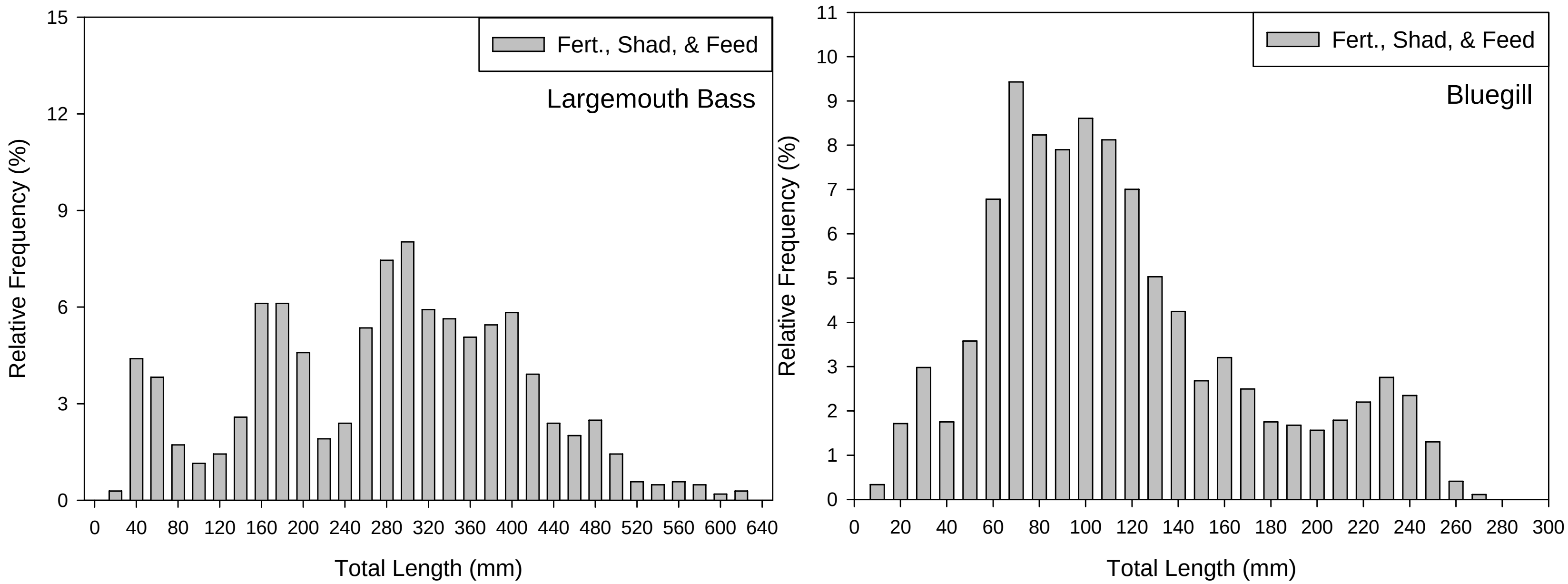




Appendix K. Combined relative length-frequency distributions for largemouth bass and bluegill collected via electrofishing fall 2007 and spring 2008 in fertilized-and-shad management strategies.



Appendix L. Combined relative length-frequency distributions for largemouth bass and bluegill collected via electrofishing fall 2007 and spring 2008 in fertilized-shad-and-feeder management strategies.



Appendix M. Pearson correlation coefficients (r), p-values (P), and number of observations (N) for relationships between bluegill stock size catch-per-unit-effort (CPUE) and mean relative weight (Wr) and between largemouth bass preferred size CPUE and mean Wr, and largemouth bass back-calculated mean length-at-age-2 (MLA-2), and largemouth bass mean MLA-2 and Wr by management strategy.

	Bluegill CPUE by:			Largemouth bass CPUE by:						Largemouth bass MLA-2 by:		
	Wr			Wr			Growth (MLA-2)			Wr		
Management Strategy	r	P	N	r	P	N	r	P	N	r	P	N
Unmanaged	0.17	0.53	16	0.18	>0.05	16	0.33	0.29	12	0.34	0.28	12
Fertilized	-0.2	0.5	13	0.52	<0.05	15	0.67	0.01	13	0.69	< 0.01	13
Fertilized & Feed	-0.3	0.46	11	0.61	<0.05	11	0.02	0.97	8	0.33	0.43	8
Fertilized & Shad	0.05	0.87	12	0.34	0.28	12	0.05	0.91	9	0.19	0.62	9
Fertilized, Shad, & Feed	-0.6	<0.05	12	0.36	0.27	12	0.56	<0.01	10	0.77	<0.01	10
All Ponds Combined	-0.1	0.66	64	0.54	<0.01	66	0.53	<0.01	52	0.64	<0.01	52