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Demographics and seasonal abundance of sportfish in three thermal habitats of Coffeen Lake

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Demographics and Seasonal Abundance of Sportfish in Three Thermal Habitats of Coffeen Lake

(TITLE)

BY

Anthony Paul Porreca

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

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IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY
CHARLESTON, ILLINOIS

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DEMOGRAPHICS AND SEASONAL ABUNDANCE OF SPORTFISH IN THREE THERMAL HABTITATS OF COFFEEN LAKE

By

Anthony Paul Porreca

B.S. Eastern Illinois University, 2010

A Thesis

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ABSTRACT

Power generating facilities across Illinois provide electricity to residents of the state, while at the same time offering desirable open water fishing lakes that can be used by anglers during the winter season when other reservoirs are not accessible. Coffeen Lake represents one of the best power cooling fisheries in the state and boasts both excellent largemouth bass and channel catfish populations. The reservoir supplies water to a power station with a generating capacity of 945 megawatts of electricity, with 73% of the surface water affected by heated discharge and a cooling loop covering 4.1 miles. Sampling sport fish species in power cooling reservoirs such as Coffeen Lake presents challenges throughout the year due to fluctuation in temperatures and movement of fish throughout the lake; additionally, a recent rule change by the State of Illinois allows increased thermal loading during May and October to this reservoir. I used AC electrofishing to assess the current sportfish population of Coffeen Lake, and to examine differences in sportfish abundance among three thermal environments within the lake. In addition to AC electrofishing, pulsed DC electrofishing, and modified fyke nets were used to sample this assemblage and for gear comparison. I found AC electrofishing sampled a greater number of fish per hour of electrofishing, and AC electrofishing more effectively sampled sunfishes and channel catfish in Coffeen Lake. Pulsed DC electrofishing, using the Long Term Research Monitoring Program protocol, more effectively sampled largemouth bass. I found largemouth bass to be abundant and in excellent condition in Coffeen Lake. Distribution and abundance of largemouth bass was found to be influenced by thermal effluent, with bass concentration shifting to cooler waters during the fall and summer and into warmer habitats during winter. Crappie species, though in excellent condition, were low in abundance, especially in areas impacted by heated effluent. Channel catfish were found to be in average condition; greater densities of channel catfish were found in the cooling loop of Coffeen Lake during the majority of the year. Overall, spring sampling resulted in more consistent distributions of sportfish, especially largemouth bass, most likely due to relatively cooler water temperatures throughout Coffeen Lake during the early part of the year.

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CHAPTER ONE: GENERAL INTRODUCTION

All power plants, fossil-fueled as well as nuclear require large amounts of water to carry away waste heat (Mattice et al. 1976). Power cooling reservoirs are usually man made bodies of water constructed for the purpose of providing cooling water to a nearby power plant, factory, or refinery. These reservoirs are used as alternatives to earlier power cooling solutions such as cooling towers or discharging heated water into nearby rivers.

Any cooling lake is a massive heat exchanger that takes waste heat from the plant's condenser system and transfers it to the environment (Larimore and Tranquilli, 1981). The high specific heat of water permits the absorption of large amounts of heat with relatively modest increases in water temperature (Larimore and Tranquilli, 1981). By this process, cooling reservoirs act as heat sinks and receive thermal energy from water discharged by the power plant, later dissipated by evaporation. Cooled water is then used again by the power plant, and evaporated water is replaced by "make-up" water added to the system, usually by precipitation (Veil 2007).

Design of the power station and its interface with the environment affects the success of its accompanying cooling source. The obvious environmental problems associated with power cooling are those associated with waste heat from a production process (Larimore and Tranquilli, 1981). Documented cases of entrainment and impingement have occurred at multiple power cooling stations. Entrainment involves fish taken unintentionally with water used for cooling, while impingement is mortality resulting from fish killed on protective screens at the water intake. The largest concern from this is that irreversible damage to fisheries may be caused by barriers and screens present at intake and outflow, or by the design of the intake structure (Chow et. al. 1981).

Management and engineering of the cooling source must consider the effects of thermal effluent on the environment, and size of the water body is important (Diana, 1984). Efficiency of heat exchange also depends on the local climate, basin morphometry, exposure of the lake surface to wind, volume of water moving through the plant and through the lake, and the amount of heat carried away from condenser tubes (Larimore and Tranquilli, 1981). Efficiency of heat-exchanging processes is also related to the physical characteristics of water, such as specific heat, heats of vaporization and fusion, and density at different temperatures (Larimore and Tranquilli, 1981). Power plant electrical output in megawatts and the cooling reservoir surface area also are major factors influencing the amount of water used for cooling purposes and the relative percentage of the reservoir affected by thermal effluent (Galloway and Kilambi, 1988).

The effects of thermal discharges on water quality are more conspicuous in river environments than lakes. This is because of the relatively smaller volume of cooler water available. Cooling lakes more closely parallel marine or estuarine environments in that thermal effects may be less apparent than in rivers (Brezina et al. 1970). As with all bodies of water, cooling reservoirs require management.

Successful management of power cooling reservoirs must consider the primary function of cooling a power station, as well as their secondary uses for recreation. Power generating facilities across Illinois provide electricity to residents of the state, while at the same time offering desirable open water fishing opportunities for anglers during the winter season when other reservoirs are not accessible. For this reason, cooling lakes are seen by many as an especially unique opportunity for fishing northern climates during winter (Larimore and Tranquilli, 1981). Sport fishing represents one of the most popular recreational activities in the state of Illinois and supports nearly 13,000 jobs with workers earning $398 million in salaries and wages. Retail sales from anglers are over $735 million and generate $1.6 billion in economic output for Illinois. Illinois also receives more than 5 million annually for sportfish restoration funds; this money funds fisheries management and research (http://dnr.state.il.us/fish/fishfacts.htm).

Effective management of an aquatic system requires an understanding of environmental quality as well. Rose (2000) defined environmental quality as the suite of abiotic variables (water temperature, dissolved oxygen, depth, etc.) that either exert a direct effect on individuals of the population of interest, or cause an indirect effect mediated by competitors, predators, or prey. Any of these variables may influence growth, reproduction, and mortality in a population. In the case of power cooling reservoirs, water temperature may be one of the most important of these variables.

Water temperatures affect aquatic organisms both directly and indirectly. High temperatures can have direct lethal effects, but sublethal levels operating over long periods of time can be equally harmful. Delayed lethal effects and the production of non-lethal stresses can result in population changes, reduced growth, and the lowering of resistance to disease and parasites (De Stasio et al. 1996). Increased stress from high water temperature will increase mortality, unless thermal refuges are available (De Stasio et al. 1996). Aquatic organisms though have the ability to adapt to environmental changes, and it is possible through acclimation to raise or lower tolerable temperatures in a system (Tarzwell, 1970).

A relatively common phenomenon in waters affected by the input of thermal effluent is a change in species composition and dominance. A prime example of this is a shift in algal communities. Hickman and Klarer (1975) found during spring in a heated site, some algal species' growth is more affected by temperature than light intensity. The temperature of the environment affects all aquatic organisms, fish species being no exception.

Fish generally adapt more rapidly to increasing temperatures than they do to decreasing temperatures (Tarzwell, 1970). Fish have been shown to prefer temperatures that maximize the proportion of metabolism available for growth, activity, reproduction, and other biological functions (Kelsch, 1996). They have a variety of temperature preference relationships that can be categorized into three classes on the basis of whether they are positive, independent, or negative functions of acclimation temperature (Johnson and Kelsch, 1998). Changes in acclimation temperature and the fluctuation of those temperatures may have little to no effect, or greatly impact the success of a fishery.

Fish growth in cooling reservoirs is usually higher than non-thermally impacted lakes. Galloway and Kilambi (1988) found the increased growth of largemouth bass in an Arkansas cooling reservoir could be attributed to almost year-round utilization of water temperatures within or near the thermal preference of largemouth bass, exposure of the largemouth bass to warm-cool cyclic temperatures conductive to growth, daily and seasonal migration patterns, and the abundance of prey fish (shad and bluegill). Diana (1984) found largemouth bass grew faster when exposed to cyclic temperatures (warm, 29° C and cool, 15° C) than those in constant warm or cool temperatures and during most of the year largemouth bass in the refuge areas or the main portion of the reservoir could undertake horizontal and/or vertical migrations for feeding purposes, thus encountering cyclic temperatures conducive for faster growth.

The effect of thermal effluent on growth is species-specific because of different thermal preference and life history strategies. Largemouth bass is a species that may be exposed to temperature fluctuations on a daily or sub-seasonal basis (Diaz et al. 2007). In an experiment by Guest (1985), two subspecies of largemouth bass, Florida largemouth bass and northern largemouth bass, were found to have sub-specific differences in temperature tolerance not due to condition or size of fish within each species. Bennett (1979) found several studies varied in their reported preferred temperature selection for bass. He suggested that seasonal variation in selected temperatures may be the result of acclimation temperatures being possibly linked to photoperiod. Thermal resistance in many fish species is affected by photoperiod and it may also affect temperature selection in bass (Bennett, 1979). In a temperature acclimation experiment, Diaz et al. (2007) found largemouth bass exhibit a temperature preference relationship that is independent of the acclimation temperature. Temperature preference also affects seasonal and daily movements of fish.

Largemouth bass are capable of moving long distances (McCann and Carlander, 1970). Distance traveled and the amount of movement are functions of the individual reservoir, with different habitats showing different rates of movement. Quinn et al. (1978) found that long distance movement by largemouth bass in Par Pond, a cooling reservoir in South Carolina, was common, but movement between thermal and ambient locations occurred infrequently. In contrast, bass influenced by thermal discharge in a study by Zimmerman et al. (1989) were observed to move away from hotter temperatures and toward cooler temperatures, moving in a direction of improving thermal conditions.

This effectively reduced the rate of temperature change they experienced, improving the quality of their thermal environment. This may be of great importance considering most cooling reservoirs are stocked with largemouth bass.

Adding new species to cooling reservoirs may also present challenges. Some species are well suited for living in cooling reservoirs; the mosquitofish for example, is well-known for its ability to survive in very warm waters. Golden shiner is not as tolerant as mosquitofish (Robinson and Buchanan, 1988), though studies indicate that they are approximately as tolerant to high temperatures as largemouth bass (Talmage and Opresko, 1981). The usually high growth rates of already established species such as bluegill and largemouth bass cause greater competition for food and reduced food intake per new individual (Paller et al. 1992). Food available to forage fishes may also be affected by thermal effluent, resulting in altered distributions of bass prey. In addition, thermal effluent may alter the distribution of forage fishes, separating bass more distinctly from prey with different thermal preferences (Rice et al. 1983).

Coffeen Lake represents one of the best power cooling fisheries in the state and boasts both excellent largemouth bass and channel catfish populations. The reservoir supplies water to a power station with a generating capacity of 945 megawatts of electricity, with 73% of the surface water affected by heated discharge and a cooling loop covering 4.1 miles. Twenty-two species of fish are present in the lake, with most anglers seeking largemouth bass, channel catfish and white crappie. Over 50% of game fish (i.e. largemouth bass, white and black crappie, and channel catfish) are over legal size limit, and the lake is well known to produce bass up to 8 pounds (http://dnr.state.il.us/lands/landmgt/parks/r4/coffeen.htm). Because of this, Coffeen is a desirable site for largemouth anglers and tournament fishing. Along with fishing, the site provides the public with other recreational opportunities such as hunting, picnicking, and camping (http://dnr.state.il.us/lands/landmgt/parks/r4/coffeen.htm).

Sampling sport fish species in power cooling reservoirs such as Coffeen Lake presents challenges throughout the year due to fluctuation in temperatures and movement of fish throughout the lake. In addition to this, a site specific rule change granted to Ameren Energy Generating Co. by the Illinois Pollution Control Board (IPCB 09-38) allows increased thermal loading in May and October to Coffeen Lake. This rule change may impact populations and their densities throughout the year.

OBJECTIVES

- Determine the post rule change density, size structure, and condition of sportfishes in Coffeen Lake.
- Determine the post rule change age structure, mortality, and growth of sportfish populations in Coffeen Lake.
- Assess the impact thermal effluent has on sportfish populations in Coffeen Lake on a seasonal basis.
- Assess the sampling efficiency of pulsed DC boat electrofishing a thermally altered reservoir.

CHAPTER TWO: GENERAL METHODS

Study Site

Coffeen Lake is an 1100 acre reservoir located in Montgomery County, approximately three miles east northeast of Donnellson, Illinois and State HWY 127, and approximately two miles west southwest of Coffeen, Illinois and State Highway 185; GPS coordinates for the site are N39° 03. 396 ', W089° 24. 836' (dnr.state.il.us/lands/landmgt/parks/r4/coffeen.htm). The lake is deeper than most Illinois lakes, averaging 5.8 m with a maximum depth of 18 m. Sampling was done at five separate sites on the reservoir (Figure 2.1). Sites included the Discharge Cooling Loop (Site 1), Intake Cooling Loop (Site 2), Cemetery Cove (Site 3), the reach between the intake and railroad bridge (Site 4), and the section north of the bridge (Site 5).

Species of Concern

Sport fish species focused upon were largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), redear sunfish (*Lepomis microlophus*), black crappie (*Pomoxis nigromaculatus*), white crappie (*Pomoxis annularis*), and channel catfish (*Ictalurus punctatus*). These species are the most targeted by anglers in Coffeen Lake.

Electrofishing

Sampling began during fall 2010 and continued over the next 2 years. I sampled by three-phase AC boat electrofishing four times each year (winter, spring, summer, fall), and sampling consisted of at least two fifteen minute transects from five separate sites on the reservoir (Figure 2.1); data from these sites were combined to form three zones: cooling loop, transition zone, and ambient zone (Figure 2.2). I AC electrofished using an unbalanced single dropper array, identical to the rig used by the Illinois Department of Natural Resources. In addition to AC electrofishing, I used pulsed DC boat-electrofishing during fall 2011. Sampling by DC electrofishing was done using a rig consisting of dropper electrodes suspended at equal intervals from a horizontal ring (Reynolds, 1996); we DC electrofished using the Long Term Resource Monitoring Program Protocol. Our control unit for was set at 60 pulses/second at a duty cycle of 24 (LTRMP sampling protocol; Gutreuter et al. 1995). This sampling protocol is currently used for multi-species DC electrofishing in Illinois.

I sampled random transects of shoreline within each designated site of the lake; these transects were marked using a Garmin GPSmap43s GPS unit during AC electrofishing runs and on a Lowrance Elite-5DSI GPS map unit during DC electrofishing runs. All fish collected were held in an aerated livewell during each transect, then weighed to the nearest 1 g and measured to the nearest 1 mm before being released. Boat electrofishing always consisted of 1 boat operator and a 2-person dipping crew targeting only sportfishes.

Fyke Netting

Fyke netting was done during the fall to sample fish species that use shoreline structure; species targeted were black crappie, white crappie, bluegill, and redear sunfish. I used 3 ft X 6 ft, 13mm bar mesh modified fyke nets with 50 ft lead lines (Nichols Net and Twine Inc.) for sampling; a mesh size of 13 mm (≈0.5 in) has been shown to more effectively sample crappies and bluegills smaller than stock length (Jackson and Bauer, 2000). Nets were set at depths of 3 m or less off shoreline points in random locations throughout the 5 separate sites on the reservoir (Figure 2.1). All fish collected were held in an aerated livewell after retrieving nets, then weighed to the nearest 1 g and measured to the nearest 1 mm before being released.

Water Quality

At the center of each site, we measured temperature (°C), conductivity (µS/cm), and dissolved oxygen (mg/L) at 1 m increments from surface to bottom using a calibrated YSI-85 multi-meter (Appendix A). These data were collected each time a sampling effort (e. g. electrofishing surveys and fyke netting) was conducted. Collection points were always kept constant and marked with a Garmin GPSmap43s GPS unit.

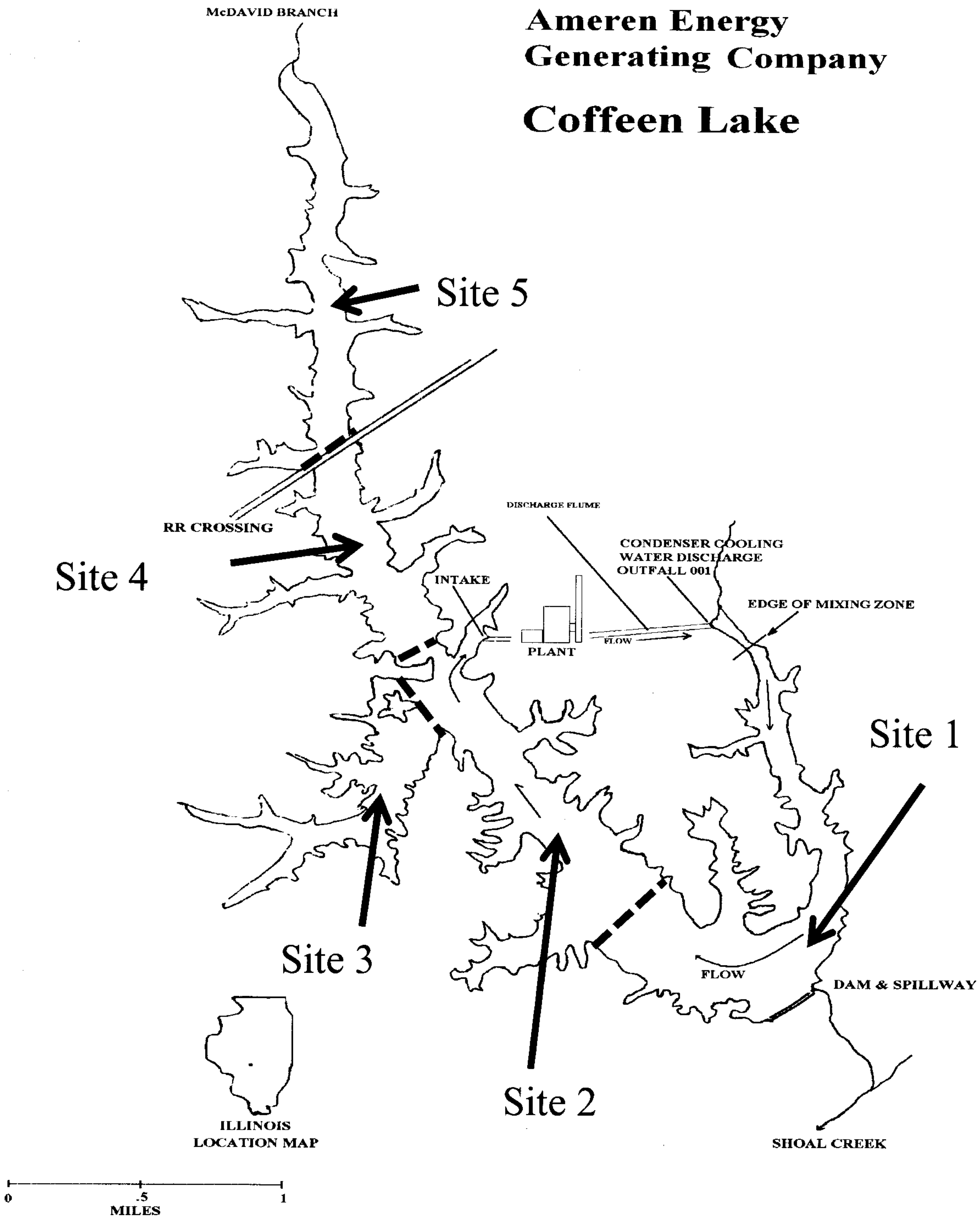

Figure 2.1. Map of Coffeen Lake showing sampling sites number 1-5. Dashed black lines depict extent of the site.

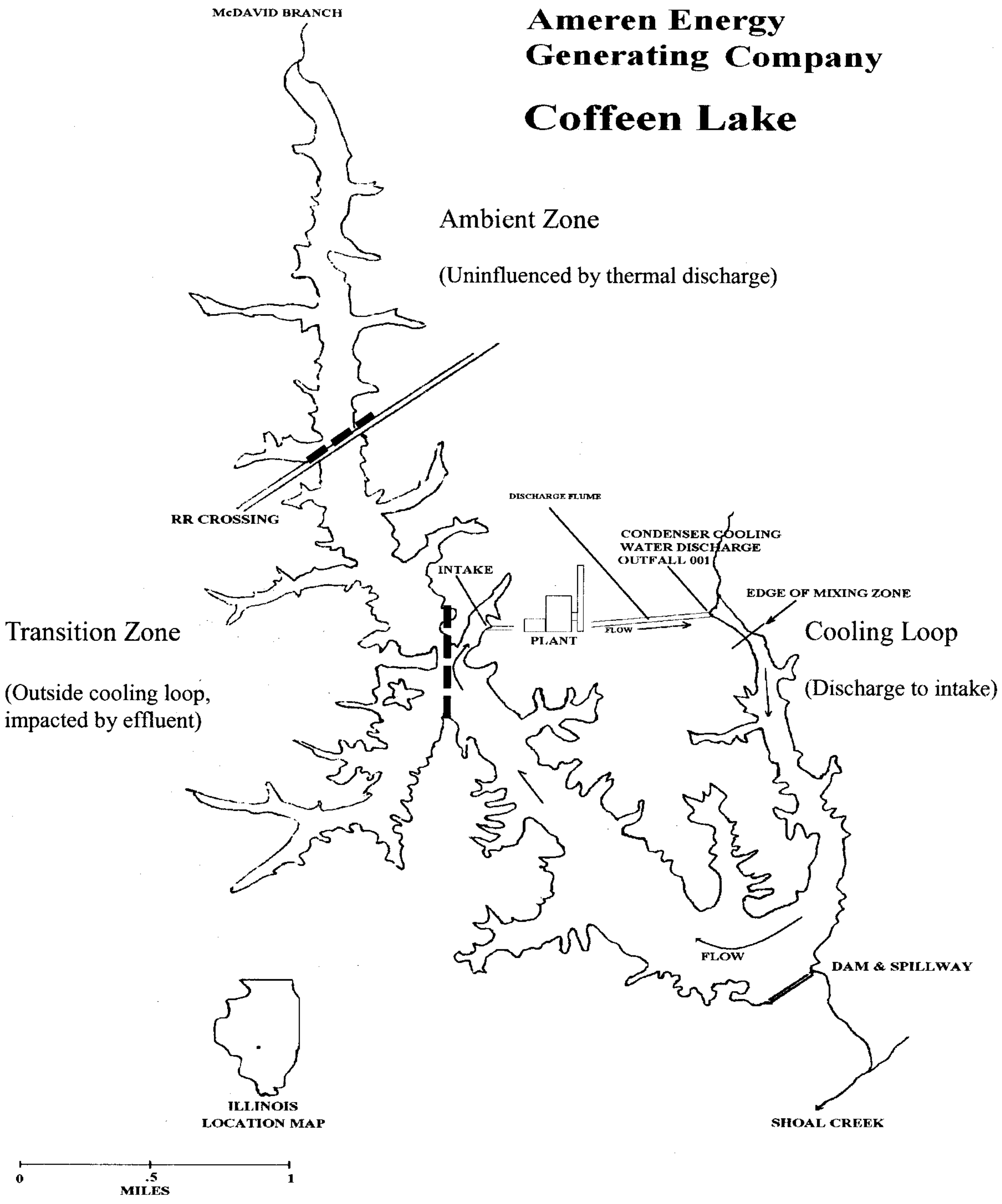

Figure 2.2. Map of Coffeen Lake showing sampling zones (Cooling Loop, Transition Zone, and Ambient Zone). Dashed black lines depict extent of the site.

CHAPTER THREE: STATUS OF THE SPORTFISH POPULATIONS IN COFFEEN LAKE, A MIDWESTERN POWER COOLING RESERVOIR

INTRODUCTION

Effective management of cooling lakes involves the consistent monitoring of sportfish populations existing within a given reservoir. Understanding the effects thermal discharge has on fish populations has been a goal of fisheries biologists since the first power cooling reservoirs were constructed. Similar to other aquatic systems, several important variables are assessed by managers to monitor the status of sportfish populations within cooling lakes. These include assessing relative abundance, size structure, condition, age structure, growth, and mortality within a specific population.

The absolute abundance of fish in a population is often of fundamental interest to fish managers (Pope et al. 2010). Catch per unit effort (CPUE) is commonly used as an estimate of the relative abundance of a targeted species. A basic assumption of this method is that CPUE is proportional to stock density (Hubert, 1996). In many cases, extensive sampling may be required to provide a reasonable estimate of CPUE (Parkinson et al. 1988). Distributions of certain species should be understood before undertaking an abundance estimation, especially for species that are rare or poorly sampled (Pope et al. 2010). Because power cooling effluent can have a significant impact on location and abundance of fish species, accurate estimations of sportfish abundance are needed in making management decisions.

Many management decisions are based on indices of size and age structure, which rely on estimates of length, weight, and age from a random sample of individual fish (Anderson and Neumann 1996; DeVries and Frie 1996; Pope et al. 2010). Indices of population structure commonly used are proportional stock density (PSD), currently referred to as proportional size distribution, and relative stock density (Guy et al. 2007; Pope et al. 2010). These calculations are numerical representations of the size structure of a population. Proportional stock density is simply the percentage of fish in a sample at minimum quality length (minimum size targeted by anglers; Gabelhouse, 1984a; Anderson and Neumann, 1996), while relative stock density is the percentage of fish of any designated length-group in a sample (Anderson and Neumann, 1996).

While length is commonly used in determining weight of fishes, there can be great variation in weight between fish of the same length within and between populations. Indices of condition, or well-being, may be more easily interpreted, and are calculations from length-weight relationships. Relative weight (W_r) is an index of condition calculated by dividing the weight of a fish by a length-specific standard weight for that species (Anderson and Neumann, 1996). In the case of power cooling lakes, size structure and condition may be impacted greatly by the physiological limitations the thermal environment has on fish growth.

Age and growth information is extremely important in almost every aspect of fisheries (DeVries and Frie, 1996). Examination of hard parts is the most frequently used method for aging fishes, and ages determined from otoliths are usually more precise than other structures like scales (DeVries and Frie, 1996). Age composition of a representative sample of fish can be used to assess recruitment to sampling gear, compare relative abundance of age-groups, and estimate total mortality from a catch curve (Van Den Avyle, 1993; DeVries and Frie, 1996). Additionally, age structure of a population can be used in modeling incremental growth, often assessed via the von Bertalanffy equation (DeVries and Frie, 1996).

The von Bertalanffy model is commonly used to estimate growth parameters that can be compared among populations (Van Den Avyle and Hayward 1999; Haddon 2001; Colombo et al. 2007) - the Brody growth constant (K) and the theoretical maximum length ($L\infty$) allows for the determination of theoretical maximum size. Due to its flexibility, simplicity, and similarity to the actual growth trajectory the von Bertalanffy approach is the preferred model of fisheries scientists (Haddon 2001; Colombo et al. 2007).

Along with growth, estimates of mortality are an essential part of assessing fish populations, and managing fishing mortality is one of the most common practices of fisheries managers (Allen and Hightower, 2010). Once the age structure of a population is estimated, instantaneous mortality, and subsequently total annual mortality, can be calculated from a catch curve. A catch curve is a simple regression of age against the log-transformed frequency. The descending slope of this plot estimates instantaneous mortality (Z) (Ricker 1975). While management is limited in controlling natural mortality, estimates of the natural mortality level in a fishery are important for establishing harvest criteria (Allen and Hightower, 2010). Given the impact an altered thermal environment can have on fish, mortality estimates in power cooling reservoirs may be of special importance.

METHODS

Relative Abundance, Size Structure, and Condition

As an index of relative abundance, I calculated catch per unit effort (CPUE) for each targeted species for the reservoir as a whole; CPUE was calculated as number of fish/hour. To provide a numerical representation of the length frequency of the sportfish populations, I calculated traditional (PSD) and incremental stock density indices (RSDs). They were calculated for each species using the formula given in Anderson and Neumann (1996). Proportional stock density = (number of fish at minimum quality length (by species) / number of fish at minimum stock length) x100. Relative stock density was calculated in the same way but with a variable specified length over stock length. Stock length is the approximate length at maturity, minimum length effectively sampled by traditional fisheries gears, and the minimum length of fish that provide recreational value. Quality length is the minimum size of fish most anglers like to catch (Anderson and Neumann, 1996). Length classes for largemouth bass (Stock ≥ 200 mm, Quality ≥ 300 mm, Preferred ≥ 380 mm, Memorable ≥ 510 mm, and Trophy ≥ 630 mm), black crappie and white crappie (Stock ≥ 130 mm, Quality ≥ 200 mm, Preferred ≥ 250 mm, Memorable ≥ 300 mm, and Trophy ≥ 380 mm), and channel catfish (Stock ≥ 280 mm, Quality ≥ 410 mm, Preferred ≥ 610 mm, Memorable ≥ 710 mm, and Trophy ≥ 910 mm) were used from Willis et al. (1993). I developed length frequency (LFD) histograms for every species for the entire lake.

Additionally, as an index of fish condition, I calculated relative weight for each species sampled by AC electrofishing for the entire lake (Anderson and Neumann, 1996). Standard weight equations for each species:

$\mathrm{Log}_{10}(Ws) = -5.316+3.191\mathrm{Log}_{10}(TL)$ for largemouth bass;

$\mathrm{Log}_{10}(Ws) = -5.618+3.345\mathrm{Log}_{10}(TL)$ for black crappie;

$\mathrm{Log}_{10}(Ws) = -5.642+3.332\mathrm{Log}_{10}(TL)$ for white crappie;

$\mathrm{Log}_{10}(Ws) = -5.800+3.294\mathrm{Log}_{10}(TL)$ for channel catfish (Murphy and Willis, 1996).

Aging

A random subsample of largemouth bass, white and black crappie, and channel catfish was taken to determine age and growth; each fish taken from the population was given a unique identification number. For bass and crappie species, I removed the sagittal otoliths for aging; numerous studies have shown that age estimates from otoliths are more accurate than those from scales (Maceina and Betsill, 1987). Otoliths were removed by disconnecting the operculum and accessing the cranial chamber anteriorly. Otoliths were placed in immersion oil and viewed with a stereo microscope under low magnification (7-40x) using reflected light. Age of fish was estimated by counting the number of annuli (visual growth bands), using two independent readers. For channel catfish, I estimated ages from annual rings on the pectoral spine. Spines were removed from catfish and dried for 24 hours. Two, 700-µm sections of the articulating process of each spine were made using a Beuhler low speed Isomet® saw. Spines were placed in immersion oil, and viewed under low magnification with a stereo microscope. Spines were aged by counting the number of annuli. Disagreements on ages were corrected by a consensus among the two readers. Images of all structures used for aging were taken using a top mounted digital camera.

Mortality

To determine mortality of sportfish populations in Coffeen Lake, I used catch curve analysis. Catch curve data were generated using Fisheries Analysis and Simulation Tools software (FAST; Slipke and Maceina, 2000). The slope of the catch curve estimates the instantaneous mortality of the population (Z). This estimate of Z was used to determine the total annual mortality (A) from the equation $A = 1 - e^{-Z}$.

Growth

Using ages from hard parts and known lengths, I was able to calculate mean lengths at age for each species sampled. These data were then used to estimate growth using a von Bertalanffy model with the Fisheries Analysis and Simulation Tools software (FAST; Slipke and Maceina, 2000). The von Bertalanffy model assumes that growth is asymptotic, reaching a theoretical maximum value (L_∞) at a constant growth trajectory (K). These parameters are used to compare growth among populations.

RESULTS

Relative Abundance, Size Structure, and Condition

Catch per unit effort for sportfishes in Coffeen Lake sampled by AC electrofishing varied considerably among species (see Chapter 4). Largemouth bass were found to be the most abundant sportfish (average CPUE = 42.8 ± 8.48 fish/hour; Table 3.1). Channel catfish were the second most abundant sportfish sampled (32.0 ± 7.4 fish/hour; Table 3.1); average CPUE for channel catfish varied though among sampling sites, with higher catfish CPUE found in areas of warm water (See Chapter 4). Crappie species were both low in abundance compared to other sportfishes, but white crappie were caught at a much higher rate (14.8 ± 7.61fish/hour; Table 3.1) than black crappie (2.4 ± 0.88 fish/hour; Table 3.1).

Proportional stock density (PSD) and relative stock density (RSD) also varied among sportfish species in Coffeen Lake. More than 50% of all largemouth bass sampled were quality length ($\geq$ 300 mm; PSD = 58, Figure 3.1). I found a high proportion of preferred length largemouth bass using AC electrofishing (RSD-P = 18; Figure 3.1), but no memorable- or trophy-sized bass were collected. Over all electrofishing surveys, largemouth bass ranged from 65 mm to 492 mm; average length of largemouth sampled by AC electrofishing was 284.9 ± 3.44 mm (Figure 3.1). I found higher proportions of greater sized white crappie than black crappie in fish sampled by AC electrofishing (BLC PSD = 53, RSD-P = 6; WHC PSD = 85, RSD-P = 42, RSD –M = 6; Figures 3.2 and 3.3). I found AC electrofished black crappie ranged in size from 119-290 mm (Mean TL = 200.9 ± 4.7 mm; Figure 3.3), white crappie 159-327 mm (Mean TL = 233.6 ± 3.72 mm; Figure 3.2), and channel catfish ranged 180-511 mm (Mean TL = 332.4 ± 4.81 mm; Figure 3.5). A low proportion of channel catfish greater than or equal to quality length (410 mm; PSD = 7; Figure 3.4) was sampled; no preferred, memorable, or trophy catfish were found.

Mean relative weight (W_r) of largemouth bass sampled by AC electrofishing from fall 2010 to 2011 was 94.62 ± 0.41 (Table 3.2); indicating this population is in good condition. I found both black and white crappie to be in excellent condition for the entire lake (BLC W_r = 98.25 ± 1.53; WHC W_r = 96.20 ± 1.30; Table 3.2). Channel catfish were in average condition, with a mean relative weight of 88.94 ± 0.78 (Table 3.2).

Age Frequency

Mean age was estimated using fish sampled by AC electrofishing; subsamples were taken from fall 2010 to fall 2011 (Figures 3.5-3.8). Largemouth bass fully recruited to the gear between ages 0 and 1 (Figure 3.5). Over 85% of the subsample I used for age estimation was 0 to 2 years old (Figure 3.5). White crappie were fully recruited to AC electrofishing between ages 2 and 3 (Figure 3.6). Nearly 50% of white crappie were estimated at 2 years old; the oldest individual I sub-sampled was estimated at 5 years old (Figure 3.6). Black crappie fully recruited to the gear between ages 2 and 3; no individuals older than 3 years old were sampled (Figure 3.7). Channel catfish were found at older ages than any other sportfish sampled; the oldest channel catfish sampled was estimated at 8 years old (Figure 3.8). Channel catfish fully recruited to the gear between ages 3 and 4; nearly 40% of all catfish sampled were 3 years old (Figure 3.8).

Mortality

I estimated mortality (A) using subsamples of fish sampled by AC electrofishing using catch curves; black crappie were not included in mortality estimates because of low sample size (Figures 3.9-3.11). Largemouth bass annual mortality was calculated at 54.4% (Figure 3.9). White crappie mortality was high (A= 72.6%; Figure 3.10). Channel catfish had the lowest calculated mortality (A= 47%; Figure 3.11).

Growth

Von Bertalanffy growth models were generated for sportfishes sampled using AC electrofishing from fall 2010 to fall 2011; black crappie growth was not modeled due to low sample size in electrofishing surveys (Figures 3.12-3.14). My calculated theoretical maximum length for largemouth bass (L_∞) was 490.8 mm, about 20 mm less than memorable size (510 mm) for largemouth bass (Figure 3.12). White crappie growth was determined with the aid of an age length key (Figure 3.13). My model predicts a maximum length of only 241.9 mm, even with larger individuals caught; this was due to low average size of all individuals sampled. My channel catfish model shows steep, almost linear, growth with no leveling out (Figures 3.14).

DISCUSSION

Relative Abundance, Size Structure, and Condition

Abundance of largemouth bass may be one of the most useful indicators of the sport fishery of a cooling lake (Tranquilli et al. 1981). The Illinois Department of Natural Resources targets a CPUE of 60 fish/hour using AC electrofishing in impoundments (Mike Mounce, personal communication); my CPUE for largemouth bass is considerably lower than this figure, though it is an average of all sites, including those impacted by heated discharge where densities are lower (See Chapter 4).

Similar to other cooling lakes, channel catfish are abundant in Coffeen Lake, especially in warmer areas of the cooling loop. Channel catfish have been shown to reside in areas of thermal discharge, but rarely spend a great amount of time in one area (Cooke and McKinley, 1999). Catfish activity in heated channels is influenced by temperature fluctuations, with greater fluctuation leading to significantly lower activity level (Cooke and McKinley, 1999). Creel surveys from Illinois cooling lakes support the hypothesis that channel catfish prefer the thermal effluent (McNurney and Dreier 1981;

Tranquilli et al. 1981). In a 1973-1974 study of Lake Sangchris, 65.2 percent of all channel catfish caught by fishermen were from the discharge arm and 31.0 percent of those were captured there during the summer (Tranquilli et al. 1981). Channel catfish in Coffeen Lake clearly prefer the warmer water of the discharge channel, even during the fall, when water temperatures are still elevated.

Crappie abundance using electrofishing was low throughout Coffeen Lake, especially black crappie. Populations of black crappie and white crappie have historically been difficult to assess due to variable catchablility and gear selectivity (Allen et al. 1999). Low abundances of black crappie may be attributable to this species being a relatively new addition to Coffeen Lake. Given these species prefer submerged structure and cooler water temperatures, crappie are most likely moving to and staying in cooler water in the fall (See Chapter 4).

While abundances of most sportfish are high, proportions of preferred, memorable, and trophy sized fish in most species are low in Coffeen Lake. Largemouth bass sampled with AC electrofishing are averaging roughly 285 mm TL in Coffeen Lake; 15 mm below a quality length fish. Though my average LMB was under quality length (300 mm), over 50% of bass captured during electrofishing surveys were greater than 300 mm; a size desirable to anglers (Gabelhouse 1984; Paukert and Willis 2004). Only 18% of fish caught using AC electrofishing were preferred length or greater, which is considerably lower than the site specific target by Illinois DNR (target RSD-P = 35-45, RSD-M = 10-20; Jeffrey Pontnack, personal communication). No large (trophy or memorable) sized largemouth bass were found in this population. A lack of large fish in this population may be due to a variety of factors. Increased density of largemouth bass typically leads to reduced growth, size structure, and condition (Paukert and Willis 2004). High densities of largemouth bass in areas of preferred temperature in Coffeen Lake may be influencing size structure with increased intraspecific competition for food or habitat. Habitat, specifically submerged vegetation and structure, has been shown to influence size structure of largemouth bass as well (Paukert and Willis 2004). Cover has actually been shown to reduce size in bass; with a lack of submerged vegetation, bass become piscivorous at smaller sizes, thus increasing growth (Bettoli, Maceina, Nobel and Betsill 1992; Paukert and Willis 2004). While I did not specifically assess habitat in Coffeen Lake, all sites do have vegetation, both submerged and emergent, and a relatively high amount of cover in the form submerged trees. Additionally, I know through historical data that the largemouth bass fishery of Coffeen Lake has changed over time, with abundance of large fish (> 400 mm) decreasing over the last 10+ years. Angling mortality may be having the greatest impact on the fishery, especially with the popularity of this reservoir as a trophy bass fishery, leading to increased fishing pressure by recreational fishers and through weekly tournaments.

Size structure of other sportfish populations in Coffeen Lake may be more impacted by increased water temperatures from the discharge of thermal effluent. I can assume the great impact thermal effluent has on density in these populations also is influencing size distributions to some extent. Size structure for black and white crappie differs substantially. Smaller sizes and densities in black crappie though may be due to this species being a relatively recent addition to Coffeen Lake. Similar to the findings of Tranquilli et al. (1981), I found channel catfish size structure to be poor, with the majority of catfish caught below quality length. Though I did not target sunfish, size structure in these species was poor as well, a common trend with cooling reservoirs.

Largemouth bass in Coffeen Lake are in excellent condition. Relative weight calculations for bass sampled by AC electrofishing averaged 94.62 ± 0.41, indicating this population is healthy. Crappie species are both in excellent condition, which indicates that even though these fish are not as abundant, especially black crappie, they are healthy. Catfish were also found to be in average condition, even though size structure indicates there are not many large fish in this population. My relative weight values for channel catfish were lower than the target value for IDNR (Jeffrey Pontnack, personal communication). Historically, channel catfish populations in Illinois are normally less successful in large reservoirs not fed by a major stream and containing substantial populations of predatory game fish (Tranquilli et al. 1981).

Age Frequency, Mortality, and Growth

Age structure in the sportfish populations sampled in Coffeen Lake varies by species, but all subsamples indicate these populations are composed of a higher percentage of younger fish compared to older fish. Average ages for all sportfish were low, especially bass and crappie species. Mean age for every species except channel catfish was less than 3 years old.

Largemouth bass and white crappie species are exhibiting relatively fast growth, even though I did not find high percentages of old ages. Largemouth bass have been found to have much more rapid growth early in life in cooling reservoirs than in non-heated reservoirs (Tranquilli et al 1981). Age 0 largemouth bass in Lake Sangchris were found to reach 190 mm, and age 1 fish up to 290 mm TL (Tranquilli et al. 1981).

Largemouth bass I subsampled for aging display a very similar trend with the majority of individuals aged at 0 or 1 year old, and averaging total lengths greater than 300 mm.

My growth model for white crappie predicts a relatively low theoretical maximum length; this is due to the oldest ages of our subsample averaging smaller total lengths than younger age classes, and is likely a result of greater year class strength of those younger fish. Total annual mortality estimates are also fairly high for white crappie, though many populations in North America have a high rate of natural mortality (Boxrucker and Irwin, 2002). In crappie, high mortality estimates are most likely due to harvest, especially considering the desirable sizes and number of white crappie that can be caught by anglers in Coffeen Lake. Largemouth bass mortality was found to be greater than 50%. While this estimate is higher than average mortality rates for black bass populations in North America, which average 35%, higher growth rates and the thermal environment of Coffeen Lake may be increasing mortality rates in Coffeen Lake (Beamesderfer and North, 1995). It is important to note again that largemouth bass size structure has changed over time, with previous size distributions estimating a larger amount of fish greater than 400 mm in the population than I am currently finding. These data may be due to a variety of factors such as greater angling mortality from tournament fishing or harvest of largemouth bass in Coffeen Lake.

Table 3.1. Catch per unit effort (CPUE) for sportfish in Coffeen Lake sampled by AC electrofishing fall 2011; CPUE=fish/hour

Species	CPUE (±SE)
Largemouth Bass	42.80 ± 8.48
White Crappie	14.80 ± 7.61
Black Crappie	2.40 ± 0.88
Channel Catfish	32.00 ± 7.40

Table 3.2. Average condition, relative weight (*Wr*), for sportfishes in Coffeen Lake sampled by AC electrofishing fall 2010-Fall 2011

Species	*Wr* (±SE)
Largemouth Bass	94.62 ± 0.41
White Crappie	96.20 ± 1.30
Black Crappie	98.25 ± 1.53
Channel Catfish	88.94 ± 0.78

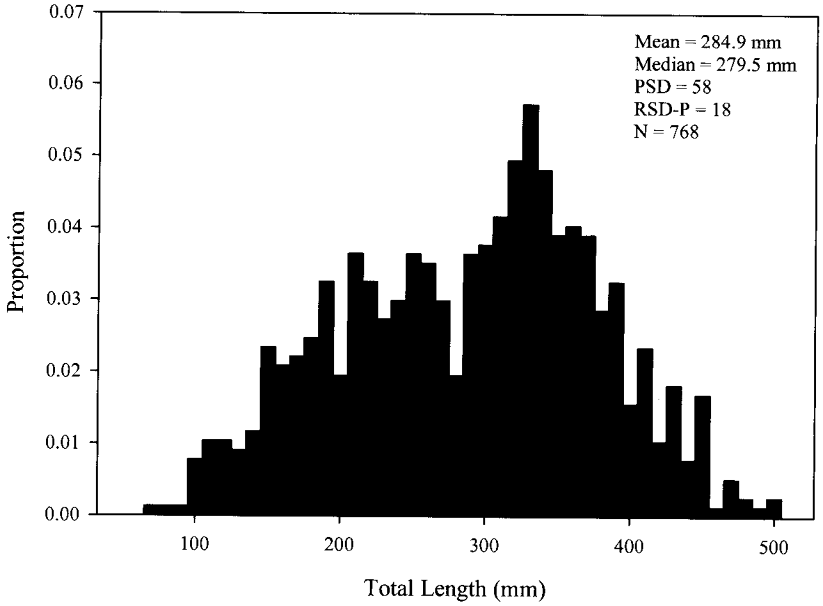

Figure 3.1. Length frequency distribution for largemouth bass sampled by AC electrofishing in Coffeen Lake 2010-2011.

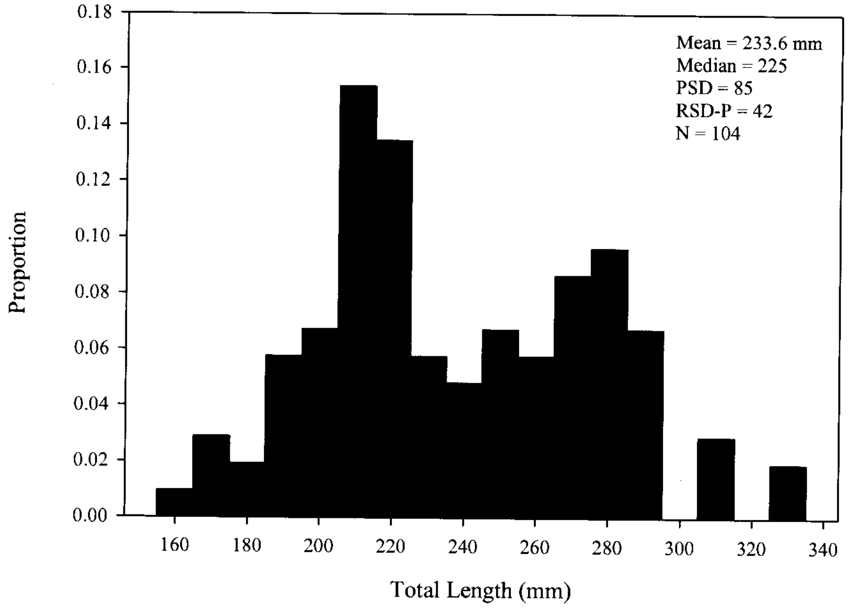

Figure 3.2. Length frequency distribution for white crappie sampled by AC electrofishing in Coffeen Lake 2010-2011.

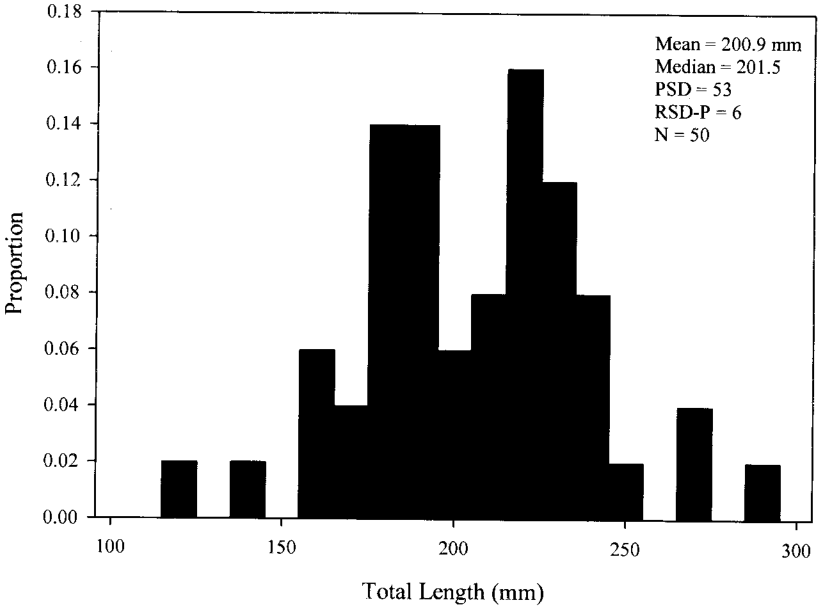

Figure 3.3. Length frequency distribution for black crappie sampled by AC electrofishing in Coffeen Lake 2010-2011.

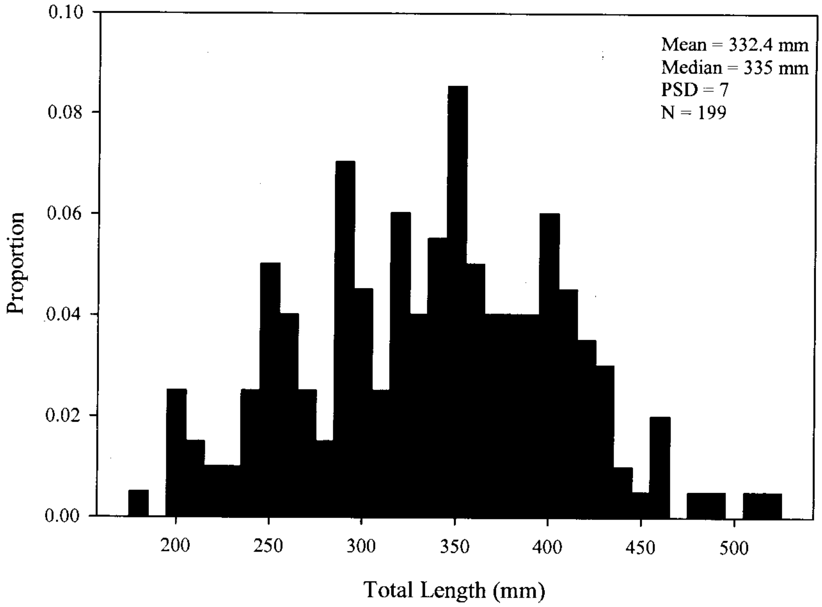

Figure 3.4. Length frequency distribution for channel catfish sampled by AC electrofishing in Coffeen Lake 2010-2011.

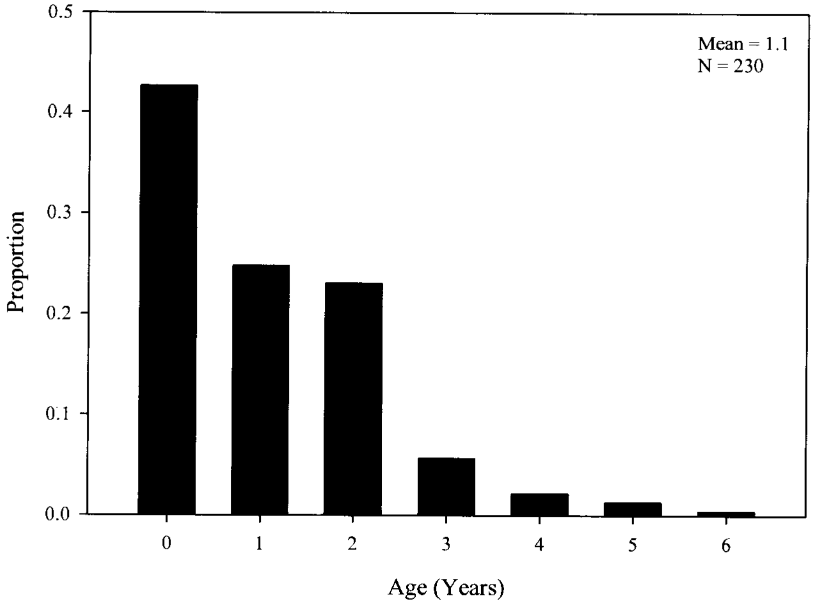

Figure 3.5. Age Structure for largemouth bass sampled by AC electrofishing in Coffeen Lake 2010-2011.

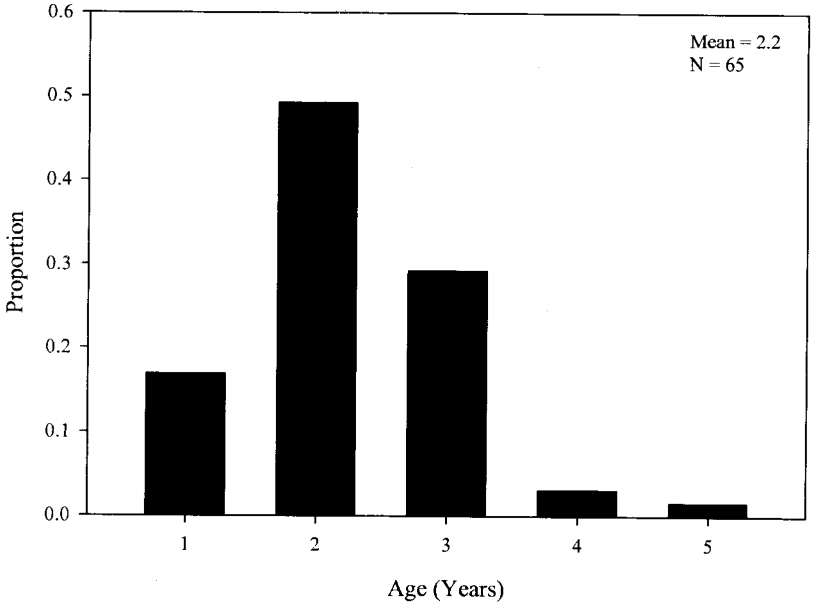

Figure 3.6. Age Structure for white crappie sampled by AC electrofishing in Coffeen Lake 2010-2011.

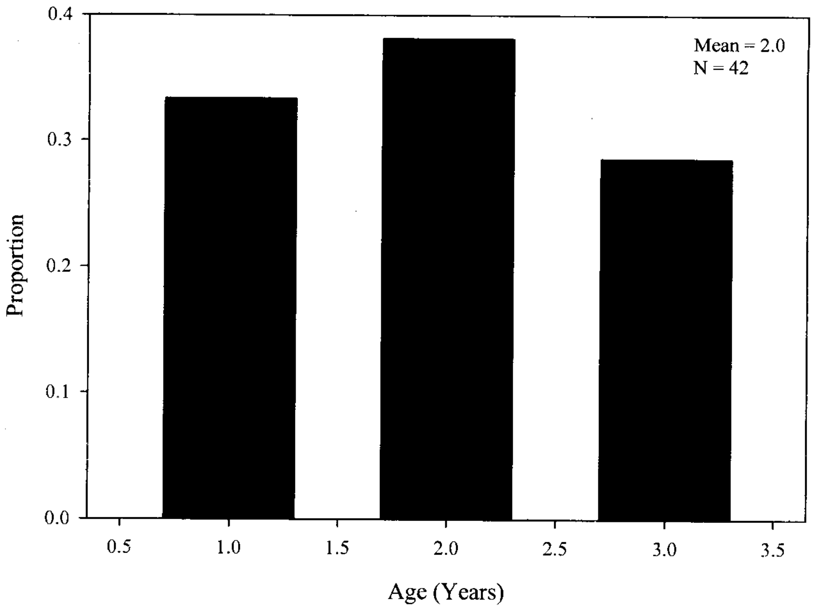

Figure 3.7. Age Structure for black crappie sampled by AC electrofishing in Coffeen Lake 2010-2011.

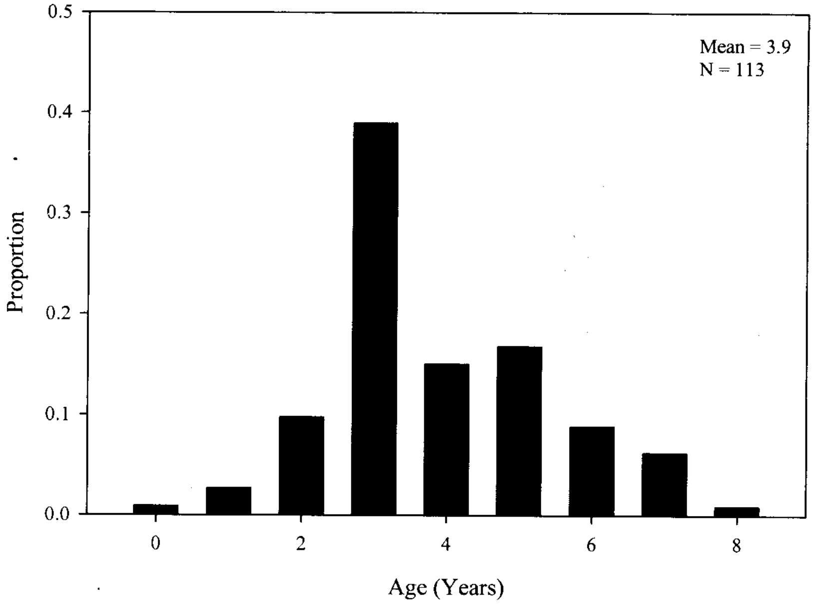

Figure 3.8. Age Structure for channel catfish sampled by AC electrofishing in Coffeen Lake 2010-2011.

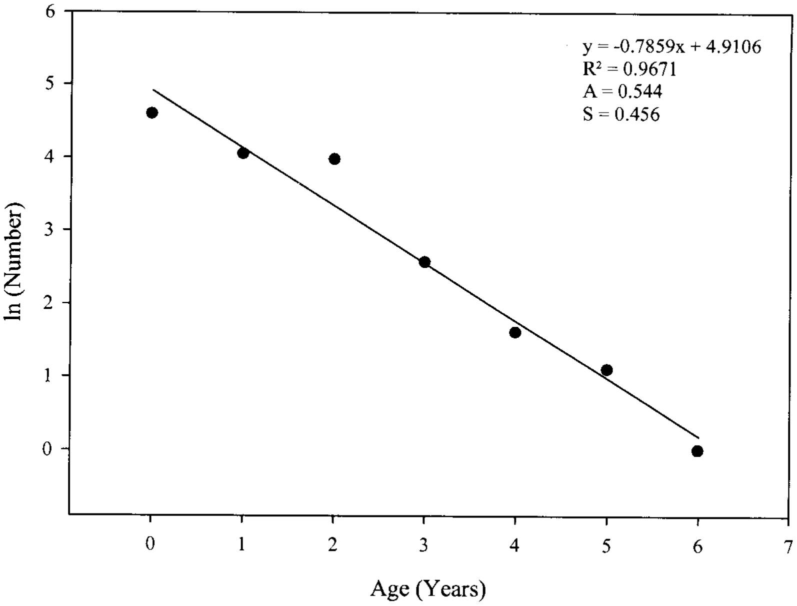

Figure 3.9. Catch Curve for largemouth bass sampled by AC electrofishing in Coffeen Lake 2010-2011.

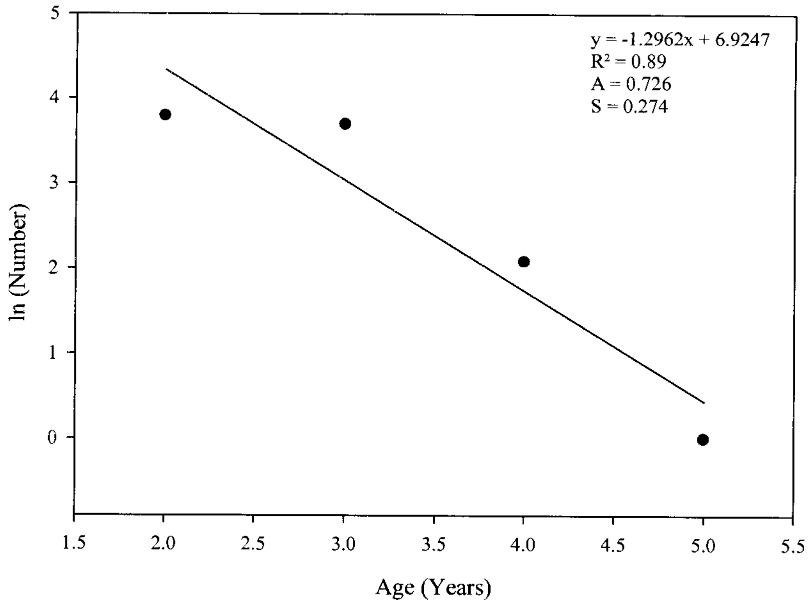

Figure 3.10. Catch Curve for white crappie sampled by AC electrofishing in Coffeen Lake 2010-2011.

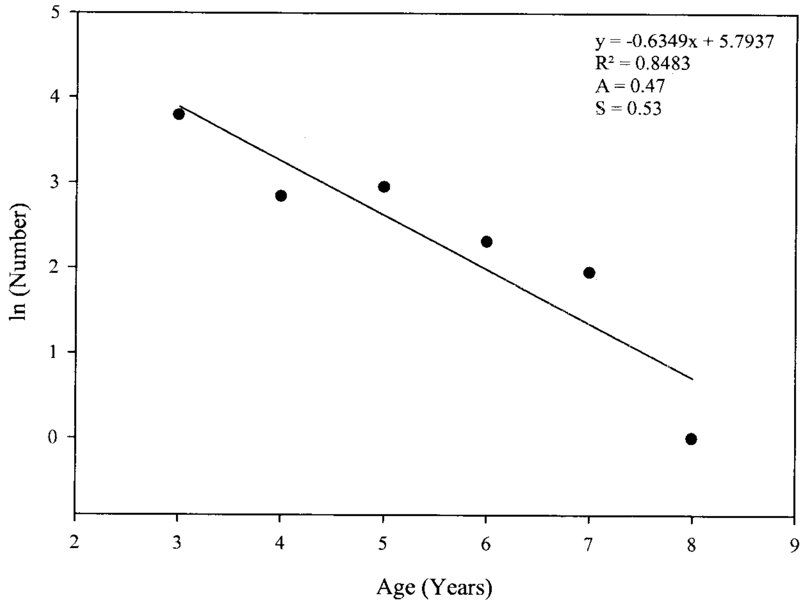

Figure 3.11. Catch Curve for channel catfish sampled by AC electrofishing in Coffeen Lake 2010-2011.

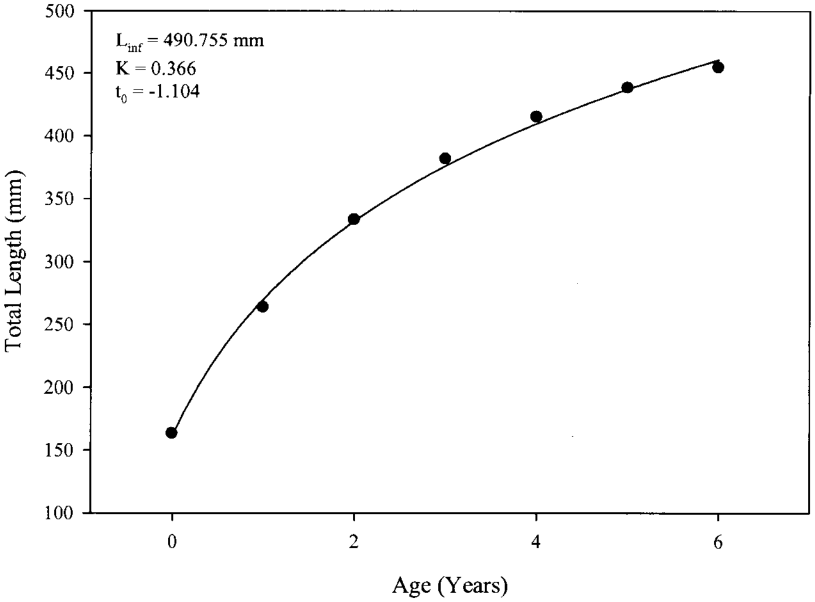

Figure 3.12. Von Bertalanffy growth model for largemouth bass sampled by AC electrofishing in Coffeen Lake 2010-2011.

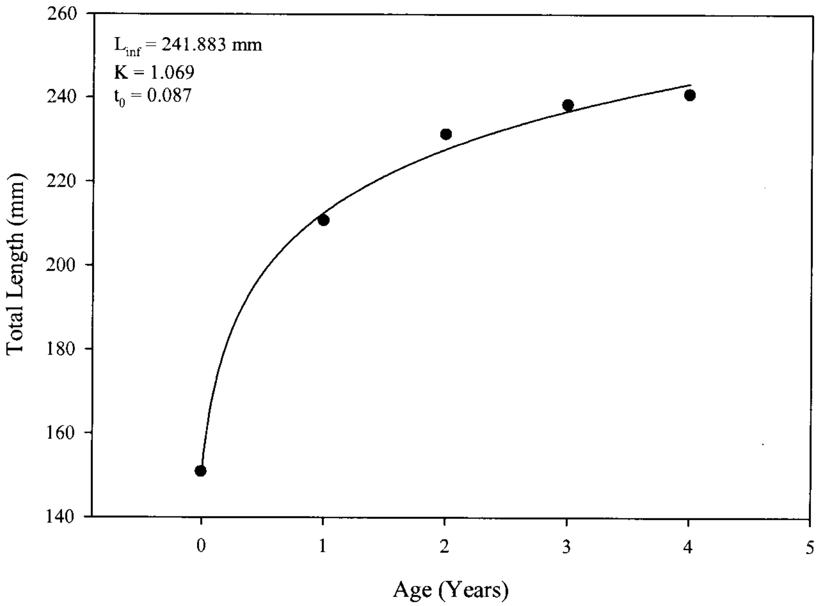

Figure 3.13. Von Bertalanffy growth model for white crappie sampled by AC electrofishing in Coffeen Lake 2010-2011.

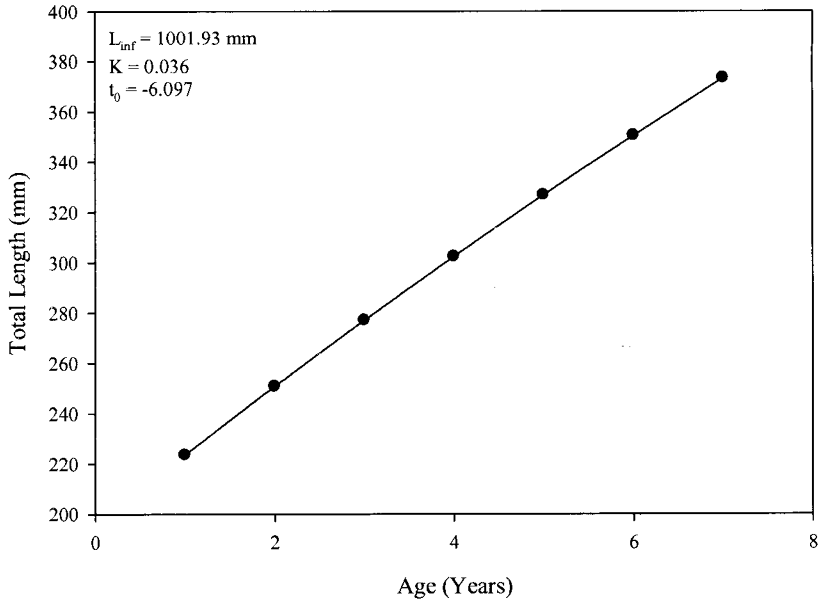

Figure 3.14. Von Bertalanffy growth model for channel catfish sampled by AC electrofishing in Coffeen Lake 2010-2011.

CHAPTER FOUR: SEASONAL DISTRIBUTION AND ABUNDANCE OF SPORTFISHES IN COFFEEN LAKE

INTRODUCTION

Temperature of the aquatic environment affects all organisms, fish species being no exception. Most fish species, as poikilothermic organisms, have body temperatures close to that of their environments because of metabolic heat losses via the skin or gills (Moyle and Cech, Jr. 1996). Temperature impacts metabolism and digestion of fishes, and many species select a particular temperature to conserve energy or to run their metabolic machinery at its most efficient temperature (Moyle and Cech, Jr. 1996).

Water temperatures affect fish species both directly and indirectly. High temperatures can have direct lethal effects, but sub-lethal levels operating over long periods of time can be equally harmful. Delayed lethal effects and the production of non-lethal stresses can result in population changes, reduced growth, and the lowering of resistance to disease and parasites (De Stasio et al. 1996). Additionally, increased stress from high water temperature will increase mortality, unless thermal refuges are available (De Stasio et al. 1996). Thermal impacts though are not necessarily detrimental to fishes (Drew and Tilton, 1970; Gammon 1973; Tranquilli et al. 1979c; Perry and Tranquilli, 1979). In previous studies on the fishery of Coffeen Lake, largemouth bass success was attributable to beneficial effects of thermal loading (Perry and Tranquilli, 1979).

Largemouth bass is a species that may be exposed to temperature fluctuations on a daily or sub-seasonal basis (Diaz et al. 2007). Bennett (1979) found several studies varied in their reported preferred temperature selection for bass. Largemouth bass though are capable of moving long distances (McCann and Carlander, 1970), and have been found to move to areas of preferred temperature in Illinois cooling lakes (Tranquilli et al. 1981). Multiple studies suggest largemouth bass are the most important game fish in Illinois cooling reservoirs (Perry and Tranquilli, 1979), though several other important sportfishes are targeted by anglers in these reservoirs, including white crappie.

Crappie species, like other cooling reservoir sportfish, are also subjected to wide temperature fluctuations. In a study examining crappie temperature tolerance, Baker and Heidinger (1996) found black crappie fingerlings displayed a high tolerance to thermal stress, but with low resistance. They cautioned that laboratory data are not directly related to the field situations of power cooling lakes, but if a lethal temperature is reached, a large proportion of crappie will die, and they will die rapidly. White crappie have been found to tolerate high water temperatures in areas influenced by heated effluent. Gammon (1973), found white crappie near thermal effluent in the Wabash River showed a temperature preference of 26.5 to 27 °C, though no white crappie were found in temperatures above 31 °C in an area of heated discharge (Profitt and Benda, 1971; Edwards et al. 1982). Preferred temperatures for white crappie in laboratory based experiments have been reported as high as 25 °C (Edwards et al. 1982).

In addition to bass and crappie, channel catfish are a common target for anglers in Coffeen Lake (http://www.dnr.state.il.us/). Channel catfish are commonly stocked in Illinois impoundments, but populations are normally unsuccessful in large reservoirs not fed by a major stream (Tranquilli et al. 1981). Success of catfish in power cooling lakes varies; Tranquilli et al. (1981) found the catfish population of Lake Sangchris to be self-sustaining through natural reproduction and without supplemental stocking. Temperature preference of channel catfish in cooling lakes has been studied extensively as well.

Catfish have been found to concentrate in heated discharge channels of power cooling reservoirs during multiple seasons (Cooke and McKinley, 1999). Dryer and Benson (1957) found channel catfish concentrated in a heated discharge harbor on Kentucky Lake, TN during both winter and spring.

Sampling sport fish in power cooling reservoirs such as Coffeen Lake presents challenges throughout the year due to fluctuation in temperatures and movement of fish throughout the lake. In addition to this, a site specific rule change granted to Ameren Energy Generating Co. by the Illinois Pollution Control Board (IPCB 09-38) allows increased thermal loading in May and October on Coffeen Lake. This rule change may impact populations and their location throughout the year. I examined the seasonal distributions of sport fish populations in Coffeen Lake and estimated their relative abundance by season. Additionally, I attempt to identify the best time to sample this thermally altered reservoir.

METHODS

Statistical Analyses

Catch per unit effort (CPUE) was calculated for each targeted species for individual sites during each sampling season; CPUE was calculated as number of fish/hour. I used a one-way ANOVA followed by a Tukey's HSD post hoc test to assess differences in CPUE by season for white crappie and channel catfish. A two-way ANOVA followed by a Tukey's HSD post hoc test was used to assess site and season differences in largemouth bass CPUE. I used ANOVA to assess differences in mean length seasonally (Guy and Brown, 2007). Although size structure is not a normal distribution, ANOVA is robust to deviations from normality (Zar, 1999). I compared mean length for each species for each season using a one-way ANOVA. Site by season differences in largemouth bass were compared using a two-way ANOVA followed by a Tukey's HSD post hoc test.

RESULTS

Relative Abundance

I found CPUE for all sportfish sampled varied by season and site on Coffeen Lake ($P < 0.05$); a site by season interaction though was not significant ($P = 0.055$). Largemouth bass were, for most seasons, more abundant in sites outside of the cooling loop, with the only exception being the winter sample (Figure 4.2). In seasons with warm water temperatures (summer and fall, Figure 4.1), largemouth bass showed this trend with our CPUE decreasing with increasing proximity to the discharge channel (Figure 4.2). During the fall, CPUE for largemouth bass in the ambient zone (71.0 ± 5.12 fish/hr) was more than twice that of the cooling loop (29.0 ± 15.53 fish/hr; Figure 4.2). I caught more largemouth bass throughout spring sampling than in both fall and summer ($P < 0.05$). During spring 2011 I sampled greater numbers of largemouth bass in the cooling loop (CPUE = 56.0 ± 3.71 fish/hr), though abundance was still higher in the ambient zone (100.0 ± 1.39 fish/hr). Summer catch rates were considerably lower than any other season ($P < 0.05$; Figure 4.2); largemouth bass CPUE in the cooling loop dropped off substantially (4.0 ± 1.63 fish/hr), while CPUE in the ambient portion of the lake remained high (52.0 ± 5.55 fish/hr; Figure 4.2). During my winter sample I caught more largemouth bass in areas closer to the heated discharge (Figure 4.2). Cooling loop CPUE at this time (40.0 ± 2.683 fish/hr) was greater than that of the ambient zone (20.0 fish/hr; Figure 4.2).

White crappie abundance was consistently lower in areas impacted by heated effluent compared to areas of refuge, throughout all seasons ($P < 0.05$; Figure 4.3). I found significantly more white crappie in the ambient area compared to both the cooling loop and transition zone ($P < 0.05$). White crappie CPUE in the ambient zone during fall 2010 (13.5 ± 2.62) was greater than any other site (transition area CPUE = 1.25 + 1.26; cooling loop CPUE = 0; Figure 4.3). During winter sampling I found more crappie in areas of heated water than other seasons (cooling loop CPUE = 2.0 ± 1.63 fish/hr; transition zone CPUE = 3.0 ± 3.46 fish/hr; Figure 4.3), but abundance was still greater in the ambient zone (22.0 ± 5.97 fish/hr; Figure 4.3). Spring sampling was very similar to winter sampling for white crappie abundance (cooling loop CPUE = 1.33 ± 1.46 fish/hr; transition zone CPUE = 4.67 ± 1.77 fish/hr; ambient zone CPUE = 21.33 ± 0.58; Figure 4.3). Summer catch rates were low in all sites; I only captured white crappie at this time in the ambient zone (CPUE = 2.0 ± 2.83 fish/hr; Figure 4.3).

I found channel catfish CPUE to be impacted by thermal environment. Although channel catfish density was significantly greater in the cooling loop than the transition area ($P < 0.05$), I found the cooling loop and ambient area to not be significantly different for catfish CPUE. During fall 2010, catfish were more abundant in areas of warm water (10.0 ± 1.45 fish/hr in cooling loop; Figure 4.4) than the ambient zone (1.0 ± 1.41 fish/hr; Figure 4.4). Winter and spring were found to have similar trends (Figure 4.4). Summer sampling was the only time I observed higher CPUE in the ambient zone (10.0 ± 1.27 fish/hr) than the cooling loop (0 fish/hr) for channel catfish (Figure 4.4).

Size Structure

To further assess possible movement of sportfishes in Coffeen Lake I examined the size structure of fishes caught in each season. Although not significant, largemouth bass size structure varied considerably among sites ($P > 0.05$). Mean total length in largemouth bass did not vary between seasons ($P > 0.05$; Figure 4.5). I found mean length of white crappie and channel catfish was not different between seasons ($P > 0.05$; Figures 4.6 and 4.7).

DISCUSSION

Differences among seasonal CPUE data suggest that sportfish distribution and abundance is impacted by thermal effluent in Coffeen Lake. Catch per unit effort data from AC electrofishing supports the idea that sportfishes generally are congregating in cooler waters during the warmest months of the year, and may prefer warmer parts of the lake during the winter. Largemouth bass density is indicative of this trend. Largemouth bass CPUE was usually highest in the coolest areas of the lake (Transition/Ambient Zone) in my electrofishing surveys, and only through sampling in spring was I able to see respectable (50+ fish/hr) catch rates for bass in the cooling loop. Tranquilli et al. (1981) found concentrations of largemouth bass in Midwestern cooling lakes changed on a seasonal basis. Differences in size structure of largemouth bass within a given season suggest different proportions of the population are residents of a given area and others are moving to different thermal environments throughout the year. Size structure was not found to be significantly different among seasons, a further indication that largemouth bass may move throughout the lake on a seasonal basis.

A shift in largemouth bass density in a power cooling reservoir may be due to temperature preference, distribution of forage fish, or a combination of these two factors (Tranquilli et al 1981). Some of the most important factors for suitable black bass habitat include food resources and optimal water temperature (Bevelhimer, 1996; Carter et al. 2012). Water temperature affects bass populations because it influences geographic range, migrations, spawning date, success of egg incubation, growth, and habitat selection (Armour, 1993; Cooke et al. 2004). I believe temperature selection is the major factor in this system because forage species are extremely abundant throughout the lake in the form of bluegill, redear sunfish, gizzard shad, and golden shiner. A study done on Lake Sangchris from 1974 to 1976 noted similar findings with temperature selection of bass impacting distribution and abundance more than availability of prey (Tranquilli et al. 1981). My data indicate in similar fashion that a significant portion of the largemouth bass population is moving relatively long distances on a seasonal basis to select preferred water temperatures (Tranquilli et al. 1981). Optimal water temperature may also be more important than other habitat qualities. Black bass in Lake Michigan have been found to inhabit areas of optimal habitat when temperatures are at a preferred level (Creque et al. 2006; Carter et al. 2012). Bass in Coffeen Lake may be exhibiting behavioral thermoregulation by moving to and staying in cooler water in the summer and fall, when water temperatures are at their highest. Furthermore, bass may be using warmer waters of the cooling loop and transition area during the winter, when the ambient area is below their temperature preference.

Some species clearly prefer distinct areas of Coffeen Lake, and are only found in significant numbers in these particular areas throughout the majority of the year. Channel catfish specifically are more abundant in the cooling loop of Coffeen Lake throughout most of the year, the only exception being the summer months. This is a similar trend in other cooling reservoirs, where channel catfish have been shown to reside in areas of thermal discharge (Cooke and McKinley, 1999). One explanation may be that smaller prey fish may be killed, injured, or disoriented in these extremely variable environments, providing increased prey for predators, especially those tolerable of higher water temperatures (Kelso and Milburn, 1979; Cooke et al. 2004). Areas of thermal discharge may provide velocity refugia for fish as well (Cooke et al. 2000; 2004). Creel surveys from Illinois cooling lakes support the hypothesis that channel catfish prefer the thermal effluent (McNurney and Dreier 1981; Tranquilli et al. 1981). In a 1973-1974 study of Lake Sangchris, 65.2 percent of all channel catfish caught by fishermen were from the discharge arm and 31.0 percent of those were captured there during the summer (Tranquilli et al. 1981). Catfish activity in heated channels though is influenced by temperature fluctuations, with greater fluctuation leading to significantly lower activity level (Cooke and McKinley, 1999). My data indicate channel catfish in Coffeen Lake favor the warmer water of the discharge channel, even during the fall, when water temperatures are still elevated.

The value of thermal refuge for sportfishes in Coffeen Lake may be best illustrated by its use by crappie. Crappie species are staying in cooler water and are rarely found in high numbers outside of the ambient portion of the lake. During summer I did not catch crappie by AC electrofishing in the cooling loop. Given these species prefer submerged structure and cooler water temperatures, I believe crappie are moving to and staying in these areas in the summer and fall.

Annual sampling of Coffeen Lake is completed by the Illinois Department of Natural Resources in the fall of each year, and while CPUE values for most sportfish are high in fall, I found greater discrepancies in abundance over our three main sampling locations (the cooling loop, transition zone, and ambient zone) during this time of the year. Sampling the cooling loop during this season yields low numbers of all fish. As a result, the DNR does not electrofish the discharge channel, an area that represents about 20% of the entire reservoir, for their annual survey. Alternatively, during cooler seasons (winter and spring), this portion of the lake is used by many sportfish, not only because of lower water temperatures, but because of its exceptional habitat. For these reasons, I suggest sampling Coffeen Lake in the spring of the year. Spring electrofishing would not only survey the lake when abundance is high throughout the reservoir, but also when fish are using all habitat areas offered by Coffeen Lake.

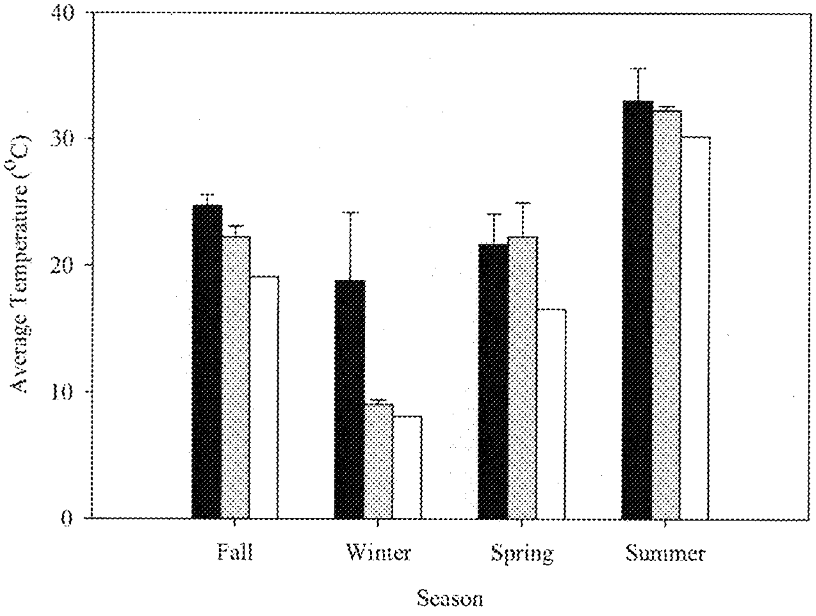

Figure 4.1. Average temperature (±SE) seasonally in cooling loop (black bar), transition zone (gray bar), and ambient zone (white bar) of Coffeen Lake.

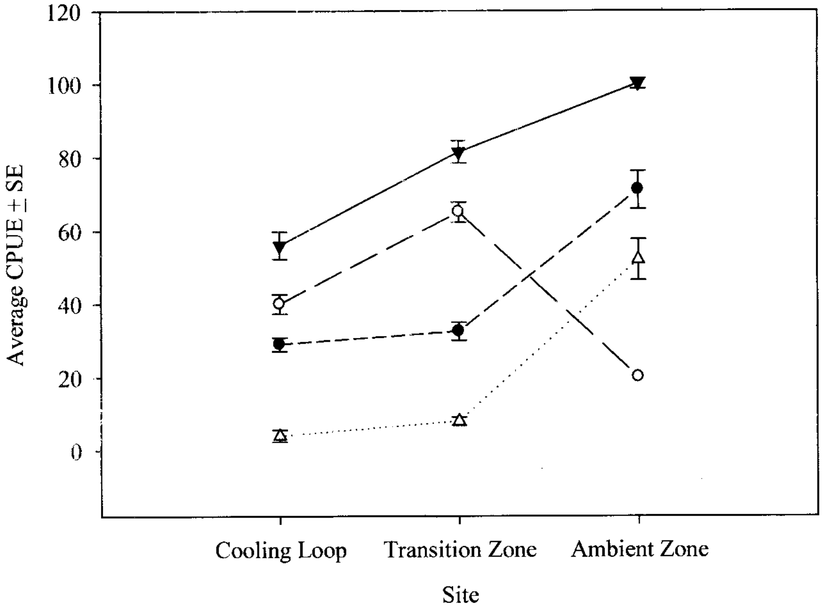

Figure 4.2. Average catch per unit effort (±SE) for largemouth bass in each zone of Coffeen Lake during fall 2010 (black circle, short dash), winter 2011 (white circle, long dash), spring 2011 (black inverted triangle, solid line), and summer 2011 (white triangle, dotted line).

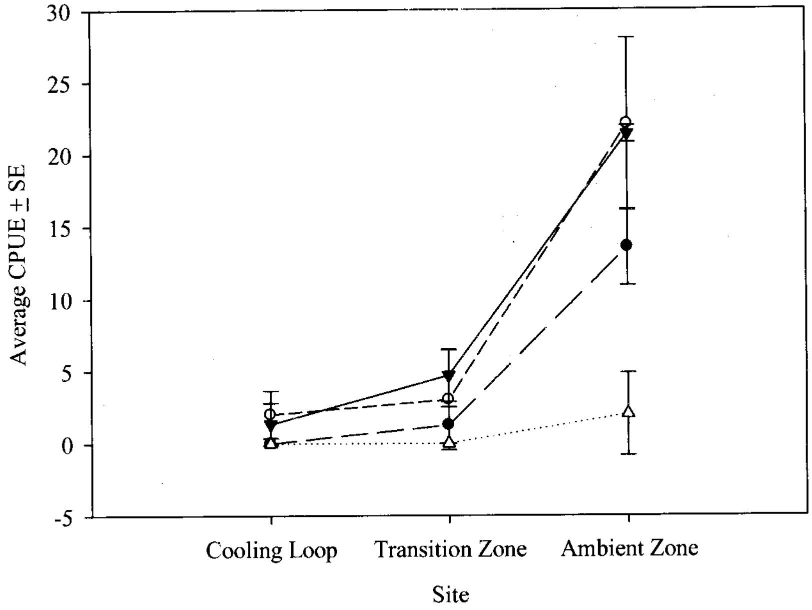

Figure 4.3. Average catch per unit effort (±SE) for white crappie in each zone of Coffeen Lake during fall 2010 (black circle, short dash), winter 2011 (white circle, long dash), spring 2011 (black inverted triangle, solid line), and summer 2011 (white triangle, dotted line).

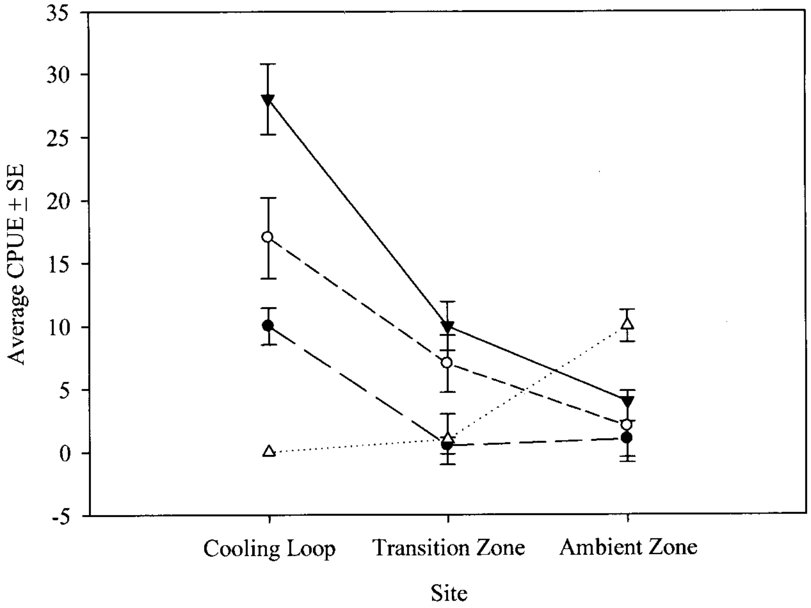

Figure 4.4. Average catch per unit effort (±SE) for channel catfish in each zone of Coffeen Lake during fall 2010 (black circle, short dash), winter 2011 (white circle, long dash), spring 2011 (black inverted triangle, solid line), and summer 2011 (white triangle, dotted line).

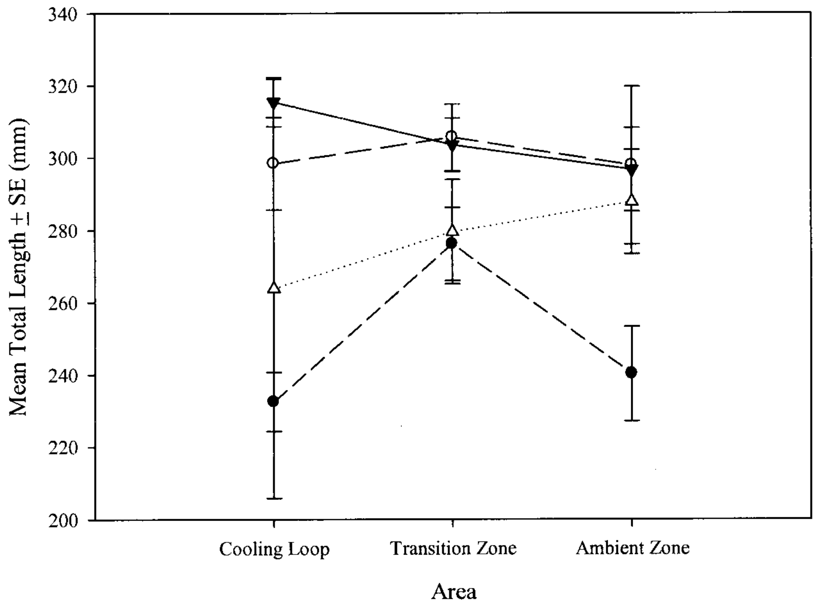

Figure 4.5. Mean total length (±SE) for largemouth bass in Coffeen Lake by site and season; fall (black circle, short dash), winter (white circle, long dash), spring (black inverted triangle, solid line), and summer 2011 (white triangle, dotted line). *Denotes significantly higher mean, $p < 0.05$.

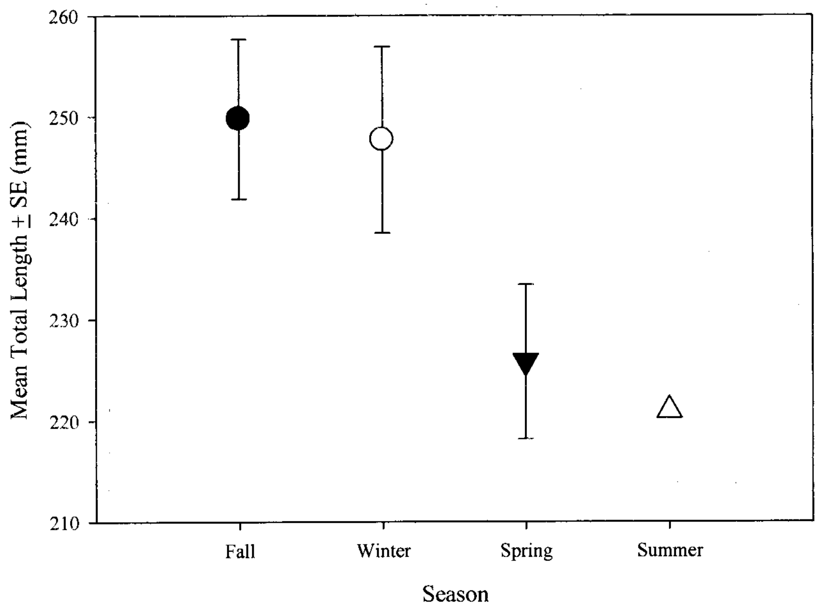

Figure 4.6. Seasonal mean total length (±SE) for white crappie in Coffeen Lake. *Denotes significantly higher mean, $p < 0.05$.

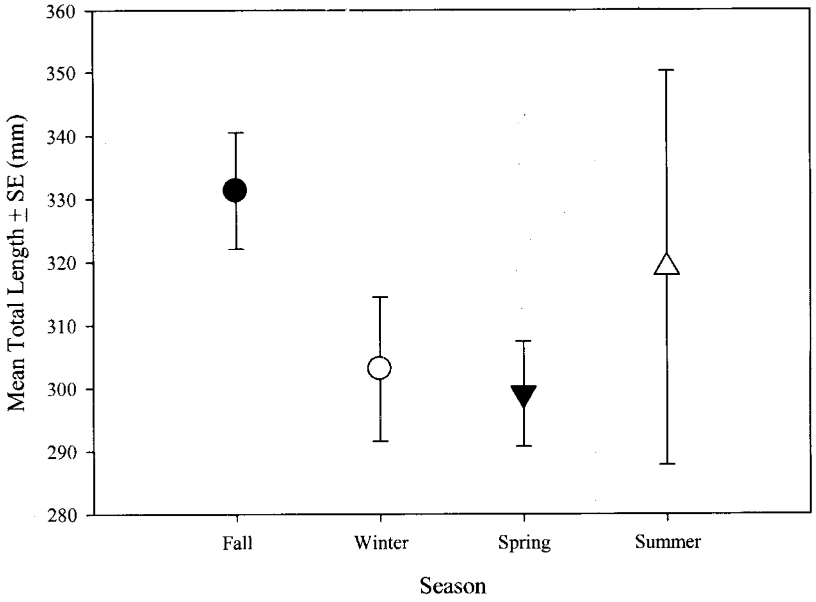

Figure 4.7. Seasonal mean total length (±SE) for channel catfish in Coffeen Lake. *Denotes significantly higher mean, $p < 0.05$.

CHAPTER FIVE: COMPARISON OF MULTIPLE GEAR TYPES IN ASSESSING THE SPORTFISH ASSEMBLAGE OF COFFEEN LAKE

INTRODUCTION

Sampling of multiple species in a lentic environment is a common task for fisheries managers and biologists. Several gears have been developed to sample fishes under a wide range of conditions, with each method having its advantages and limitations. Additionally, methods considered acceptable in some states may be considered unsatisfactory in others (Sullivan and Gale, 1999). In any study, sampling strategies must appropriately and effectively produce needed information about a fishery (Vokoun and Rabeni, 1999), and for this reason, care must be taken when selecting such methods to determine the demographics of a population (Colombo et al. 2008). Because of the bias of any one particular gear type, a multi-gear approach for assessing populations may be beneficial.

Passive sampling techniques involve the capture of fish by entanglement, entrapment, or angling devices that are not actively moved by humans while the organisms are being captured (Lagler, 1978). Entrapment devices capture organisms that enter an enclosed area through one or more funnel- or V-shaped openings and once inside, cannot find a way to escape (Hubert, 1996). A common entrapment gear used in lentic habitats is the modified fyke net (Hubert, 1996).

Modified fyke nets are similar to hoop nets, but have one to three leads or wings of webbing attached to the mouth to guide fish into the enclosure and a rectangular frame to enhance their stability (Hubert, 1996). They are used most often to sample cover-seeking, mobile species that use structure close to shore (Hoffman et al. 1990). Modified fyke nets are less selective than gill nets, but are biased in sampling larger fish of age-groups above the minimum imposed by the physical dimensions of the net (Latta, 1959); they are especially efficient in the capture of black and white crappie (Boxrucker and Ploskey, 1989; McInerny, 1989; Hubert, 1996). For these reasons, modified fyke nets are commonly used to sample sunfish and crappie species in Illinois lakes and reservoirs.

Active sampling gears have the advantage of enclosing or sweeping a specified geometric space and operating over a specified time, thus allowing an accurately defined unit of effort (Hayes et al. 1996). Active gears are also mobile in space and time; samples collected with active gears can typically be obtained in a span of minutes to hours, producing larger sample sizes per unit of time. Additionally, active gears allow for time of capture to be determined more precisely; these data are particularly important in studies of fish diet, feeding rate, behavior, and movement (Hayes et al. 1996). One of the most widely used active gears for sampling fish in warm water impoundments in Illinois is boat electrofishing.

Electrofishing, in the strictest sense, is the use of electricity to capture fish (Reynolds, 1996). Electrofishing tends to be the most efficient technique for sampling a wide variety of fish species and sizes, though effectiveness is limited to relatively shallow waters (< 3 m). As a result, habitat preference among species will affect their vulnerability to the gear, and for this reason, electrofishing is particularly applicable to sampling the littoral zone of lakes and reservoirs (Larimore, 1961; Hayes et al. 1996). Boat electrofishing produces adequate samples of selected fish species over a broad range of littoral habitats and environmental conditions (Miranda and Boxrucker, 2009), which is beneficial considering different habitats generally hold different numbers and sizes of fish (Vokoun and Rabeni, 1999). Additionally, electrofishing requires limited personnel, and uses durable equipment that is easily transported and maintained, all without exceedingly demanding physical activity (Miranda and Boxrucker, 2009). Another advantage to electrofishing is that while multiple species and sizes are susceptible to electrofishing, only target specimens may be retrieved and handled, and all or most of the specimens handled may be released uninjured (Miranda and Boxrucker, 2009). The major disadvantage of electrofishing is that samples are biased against small individuals and species (Miranda and Dolan. 2003; Miranda, 2009). This is most likely due to body voltage increasing with body length, resulting in greater electroshock to larger fish (Reynolds, 1996).

Sampling multiple species within a lentic system most often requires the use of several gear types, both active and passive. Because of known biases existing with these gears, I set out to examine two active gear types: alternating current (AC) and pulsed direct current (DC) boat electrofishing, and one passive gear type: modified fyke netting; all methods are used by state agencies and researchers to sample warmwater lakes in Illinois. Currently, the Illinois Department of Natural Resources employs the use of AC boat electrofishing to sample lakes and reservoirs throughout the state, but a shift towards pulsed DC boat electrofishing is underway (Jim Mick, IDNR personal communication). The objective of this study was to assess relative abundance and size structure of sportfish sampled by AC electrofishing, pulsed DC boat electrofishing, and modified fyke netting in a Midwestern power cooling lake.

METHODS

Statistical Analysis: Relative Abundance

Catch per unit effort (CPUE) was calculated by gear type for each species targeted and for all species as a whole sampled by each gear; CPUE was calculated as number of fish/hour for electrofishing and number of fish/net night for fyke netting. For analyses using CPUE data, black and white crappie were combined into one group: crappie; I also combined bluegill and redear sunfish into one group: sunfish. Mean CPUE for gear type was compared using a t-test.

Statistical Analysis: Size Structure

Mean total lengths (TL, mm) of each species sampled by specific gear types were compared using a one way ANOVA, followed by a Tukey's HSD post hoc test. Because largemouth bass were not effectively sampled by fyke nets, I compared only electrofishing gears for this species using a t-test. Differences in the length frequency distributions of sunfish were compared using a Kolmogorov-Smirnov test (Bonferroni corrected $\alpha = 0.0167$).

RESULTS

Relative Density

Overall, catch per unit effort for all species sampled by AC electrofishing was greater than that of DC electrofishing (df = 16, t = 2.12, $p < 0.05$, Figure 5.1). I found AC electrofishing sampled greater numbers of all targeted sportfishes, except for largemouth bass. Largemouth bass were caught at a significantly higher rate using DC electrofishing (74.8 ± 16.40 fish/hour) than AC electrofishing (42.8 ± 8.48 fish/hour; Figure 5.2; df = 9, t = 2.26 $p < 0.05$). I found a positive correlation between AC and DC electrofishing for largemouth bass CPUE (r =0.84, Figure 5.3).

Channel catfish were sampled at a rate roughly two times greater than that of DC electrofishing using AC electrofishing, though these data were not found to be significantly different (Figure 5.4; df = 14, t = 2.14, $p = 0.053$). Sunfish species sampled by AC electrofishing were also caught at a rate over two times greater than that of DC electrofishing (df = 18, t = 2.10, $p < 0.05$; Figure 5.5). I found AC electrofishing was not correlated to DC electrofishing for sunfish CPUE (r = 0.2, Figure 5.6)

Size Structure

Although not significant, largemouth bass sampled by AC electrofishing were on average smaller than those sampled by DC electrofishing (Mean TL-AC = 287.6 ± 8.15 mm; Mean TL-DC = 303.1 ± 5.40 mm; $p > 0.05$; Figures 5.7 and 5.8). Size structure of crappie sampled by both AC (Mean TL = 223.8 ± 4.88 mm) and DC electrofishing (Mean TL = 217.1 ± 3.13 mm) was not found to be significantly different, though both electrofishing gear types sampled crappie sizes significantly larger than fyke nets (Mean TL = 202.4 ± 1.28 mm, Figures 5.9 and 5.10; $p < 0.016$). Channel catfish size structure did not differ among electrofishing gears, but electrofishing was found to catch significantly larger catfish than fyke nets (Figures 5.11 and 5.12, $p < 0.05$). I found bluegill and redear sunfish length frequency distributions to be significantly different across all gear types (Figures 5.13 and 5.14; $p < 0.0167$). Fyke nets, on average captured bluegill 20 mm larger than DC electrofishing, and 30 mm larger than AC electrofishing

($p < 0.0167$; Figure 5.15). I found fyke nets captured redear sunfish 10 mm larger than DC electrofishing and 20 mm larger than AC electrofishing ($p < 0.0167$; Figure 5.16).

DISCUSSION

Differences in catch per unit effort and mean length between the three gear types used in this study suggest that using a single capture method when sampling multiple sportfish in lakes or reservoirs may result in an inaccurate estimation of population parameters. Size selectivity of sampling gears causes errors in the estimation of population structure (Hilborn and Walters, 1992) and may limit the ability to draw inferences about trends in abundance (Binion et al. 2009). While size structure did not differ significantly between electrofishing gears for all species, relative abundance did. Overall CPUE of AC electrofishing was significantly greater for all species except largemouth bass; additionally AC electrofishing sampled smaller fish and smaller species more effectively than DC electrofishing. This can be seen best with the significantly greater efficiency of AC electrofishing for sampling sunfish, where for bluegill and redear sunfish, AC electrofishing captured fish 10 mm smaller than DC electrofishing and 25 mm smaller than modified fyke nets. The inefficiency of DC electrofishing in sampling sunfish during this study suggests that this gear type may not effectively sample some of the most abundant and important species in Illinois lakes and reservoirs (Willink and Veraldi, 2009). Panfish species such as bluegill and redear sunfish are popular sportfish for recreational angling, but also represent an ecologically important group in many Illinois impoundments as these species are a primary food source for larger, more desirable sportfishes such as largemouth bass and channel catfish (Nyberg, 1971; Werner and Hall, 1977; Shoup et al. 2007). Additionally, lower catch rates and narrower size ranges of sunfish captured by DC electrofishing may impact future management decisions regarding these species once DC electrofishing becomes a state-wide sampling method. Fyke nets, though selective to certain species and sizes of fish (Laarman and Ryckman, 1982), effectively capture sunfish and may significantly increase sample sizes of these species. As a result, I would recommend use of modified fyke nets in the sampling of sunfish species in addition to DC electrofishing.

Populations of black crappie and white crappie have historically been difficult to assess due to variable catchablility and gear selectivity (Allen et al. 1999). Electrofishing, both AC and DC, did not effectively sample crappie, as groups of fish were holding to deeper structure, and it is clear that the most efficient way of sampling crappie species in Coffeen Lake was with the use of modified fyke nets. Several studies of southeastern lakes though have shown fyke nets to be largely ineffective in sampling crappie (Maceina et al. 1998; Sammons and Bettoli, 1998a, Sammons et al. 2002), and even though commonly used to sample crappie species, low catch rates often limit the utility of the data (Sammons et al. 2002). Contrary to this, my results suggest modified fyke nets are an effective gear type for sampling crappie in Coffeen Lake, a system with water temperatures similar to that of southern lakes as a result of the reservoir receiving thermal effluent.

While DC electrofishing did not produce the high numbers of sunfish captured using AC shocking, the gear did more effectively sample largemouth bass, a noteworthy result, given the importance of largemouth bass as a sportfish in Illinois. For Coffeen Lake as a whole, DC electrofishing not only sampled a significantly greater number of largemouth bass, individuals caught with DC were larger than those sampled using AC electrofishing. Little information on electrofishing biases or limitations in sampling largemouth bass exists, but abundance has been shown to affect electrofishing efficiency (Reynolds, 1996). Population density of largemouth bass may be inversely related to efficiency; Simpson (1978) postulated that dense populations may result in offshore distributions, group fight responses, or less effective dipnetting, and thus reduced efficiency. In this study, the discrepancy between AC and DC electrofishing CPUE is most likely due to another factor considering both gear types sampled similar areas, with roughly identical water depths, and dipnetting efficiency was not noticeably different. Environmental factors, especially specific conductivity, have been shown to influence electrofishing efficiency (Reynolds, 1996). Because samples were taken in the same areas of Coffeen Lake on the same day, environmental factors were not significantly influencing catch rate. For these reasons, I believe pulsed DC electrofishing, using the LTRMP parameters, may be more efficient in sampling largemouth bass in warmwater impoundments than the current AC boat electrofishing method.

Several studies, including Colombo et al. (2008), caution that the use of AC electrofishing may provide results that differ from those obtained with DC electrofishing, especially for catfish. The use of pulsed DC electricity is attractive for sampling catfish because variable voltage pulsators (VVPs) allow adjustments to the pulse frequency and pulse width that cannot be accomplished using AC (Vokoun and Rabeni, 1999). Electrofishers equipped with VVPs have been shown to return more catfish than other electrofishing gears (Gilliland, 1988). I found DC electrofishing was not as effective as AC at sampling channel catfish in Coffeen Lake. Contrary to many other studies on catfish and gear selection, AC electrofishing sampled on average twice as many channel catfish than DC electrofishing, and fishes sampled by AC electrofishing averaged greater mean lengths. This may be due to setting our control unit at 60 pulses per second; a lower pulse rate (i.e. 20 pps) has been shown to increase CPUE of many catfish species, including channels (Robinson, 1994). Additionally more recent studies have shown that popular forms of pulsed DC (50-60 Hz, 25-30% duty cycle), roughly the same parameters we used for sampling all species, can lead to greater electroshock injuries (Sharber and Carothers, 1988; Holmes et al. 1990; Reynolds, 1996). The development of low-energy pulsed DC wave forms offers significant reduction of injury incidence in the future (Sharber et al. 1994), something to consider as the state moves towards a standard DC method.

The shift to DC electrofishing in Illinois may be beneficial to future research because it will standardize electrofishing efforts across the state. Standardization of electrofishing can help reduce the variability of survey data and potentially reduce injury to fish (Miranda, 2009). Without standardization, differences among collections can be partially attributed to disparities in electrofishing methodology, intensity of the electrical field, and size of the electrical field rather than to disparities in fish abundance, population structure, or fish community composition (Miranda, 2009). Because electrofishing is an active capture method applied to changing microenvironments that continually distort the electric field and to multiple target species that respond differently to electric fields, complete standardization is not possible with present technology, but standardization of controllable power transferred to fish is advisable (Miranda, 2009).

While pulsed DC electrofishing in this study captured more largemouth bass, it did not sample any other sportfish species as effectively as AC. Smaller species, such as sunfish, were more effectively sampled using AC or modified fyke nets. This is likely due to several factors, but control unit settings had the greatest influence on catch, considering all other variables (i.e. environmental conditions, site locations, and boat operation) were relatively consistent between gear types. Additionally, my samples were taken from a cooling reservoir, where fluctuations in conductivity levels and water temperature due to thermal effluent may have had a greater impact on gear efficiency (Reynolds, 1996). Overall, I suggest if pulsed DC electrofishing is used to sample warmwater lakes and reservoirs, it be paired with a passive entrapment gear such as modified fyke nets to more effectively sample smaller species or those actively using near-shore structure.

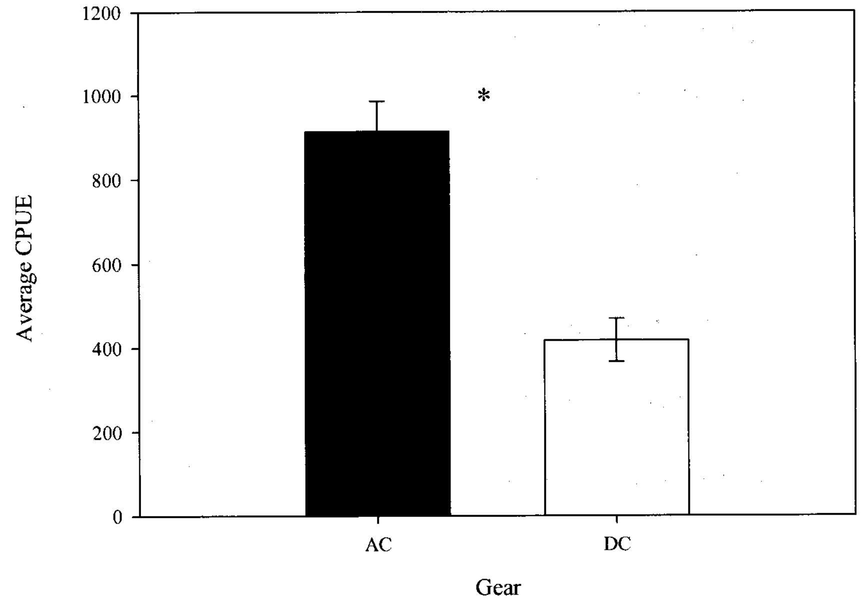

Figure 5.1. Average catch per unit effort (±SE) for all species sampled by AC and DC boat electrofishing during fall 2011. *Denotes significantly higher mean, $p < 0.05$.

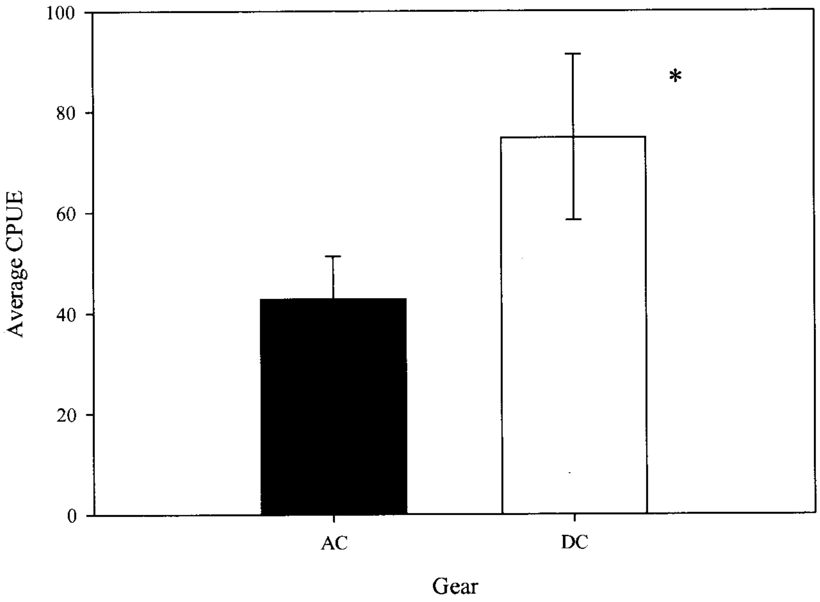

Figure 5.2. Average catch per unit effort (±SE) for largemouth bass sampled by AC and DC boat electrofishing during fall 2011. *Denotes significantly higher mean, $p < 0.05$.

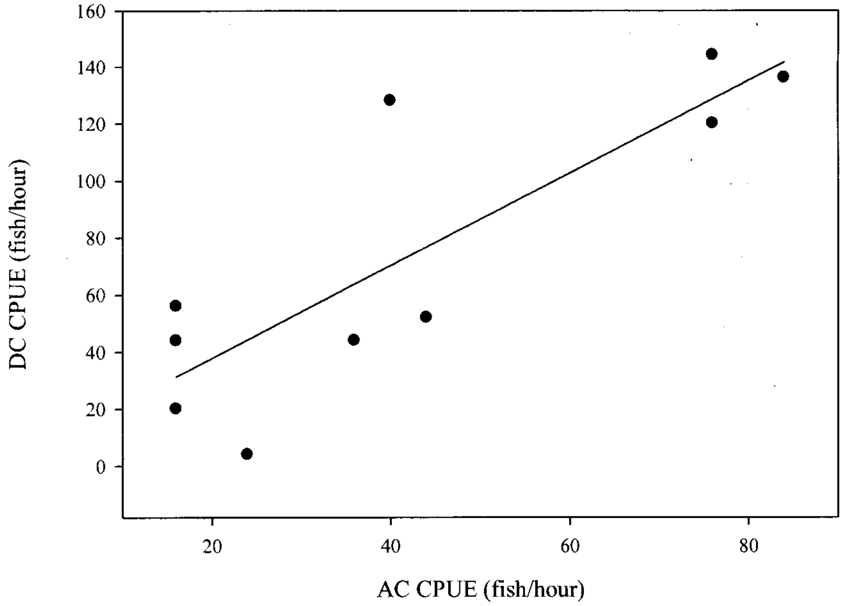

Figure 5.3. AC electrofishing vs. DC electrofishing for largemouth bass in Coffeen Lake during fall 2011.

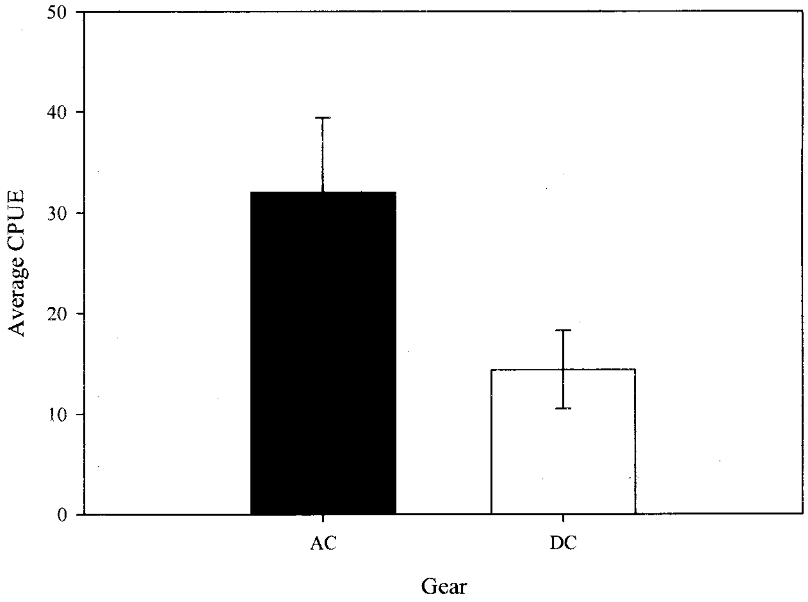

Figure 5.4. Average catch per unit effort (±SE) for channel catfish sampled by AC and DC boat electrofishing during fall 2011. *Denotes significantly higher mean, $p < 0.05$.

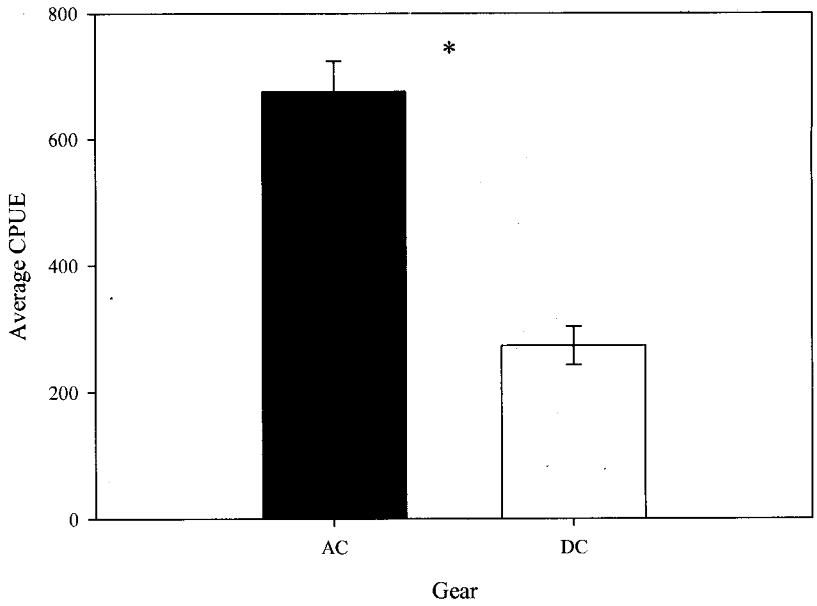

Figure 5.5. Average catch per unit effort (±SE) for sunfish (bluegill and redear sunfish) sampled by AC and DC boat electrofishing during fall 2011. *Denotes significantly higher mean, $p < 0.05$.

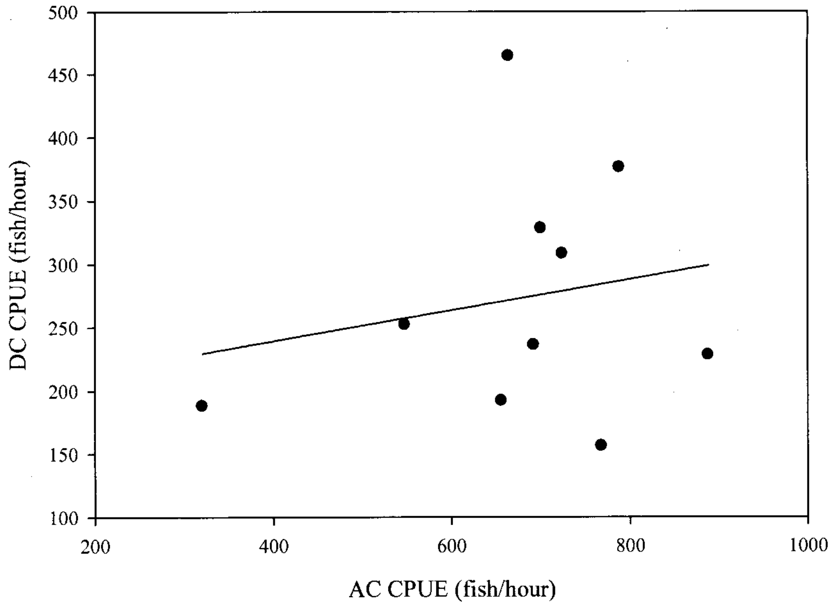

Figure 5.6. AC electrofishing vs. DC electrofishing for sunfish in Coffeen Lake during fall 2011.

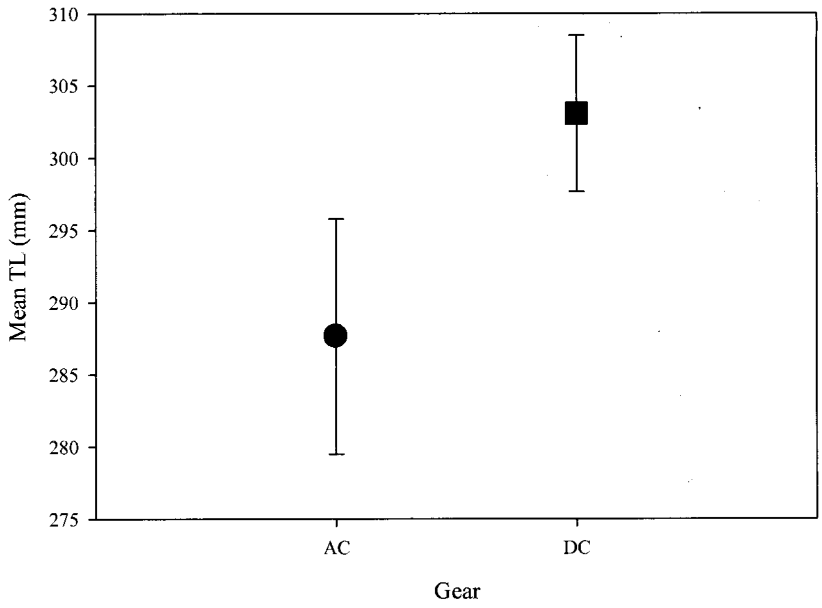

Figure 5.7. Mean total length (±SE) for largemouth bass sampled by AC and DC boat electrofishing during fall 2011. AC electrofishing represented by a circle marker, DC electrofishing represented by a square marker. *Denotes significantly higher mean, $p < 0.05$.

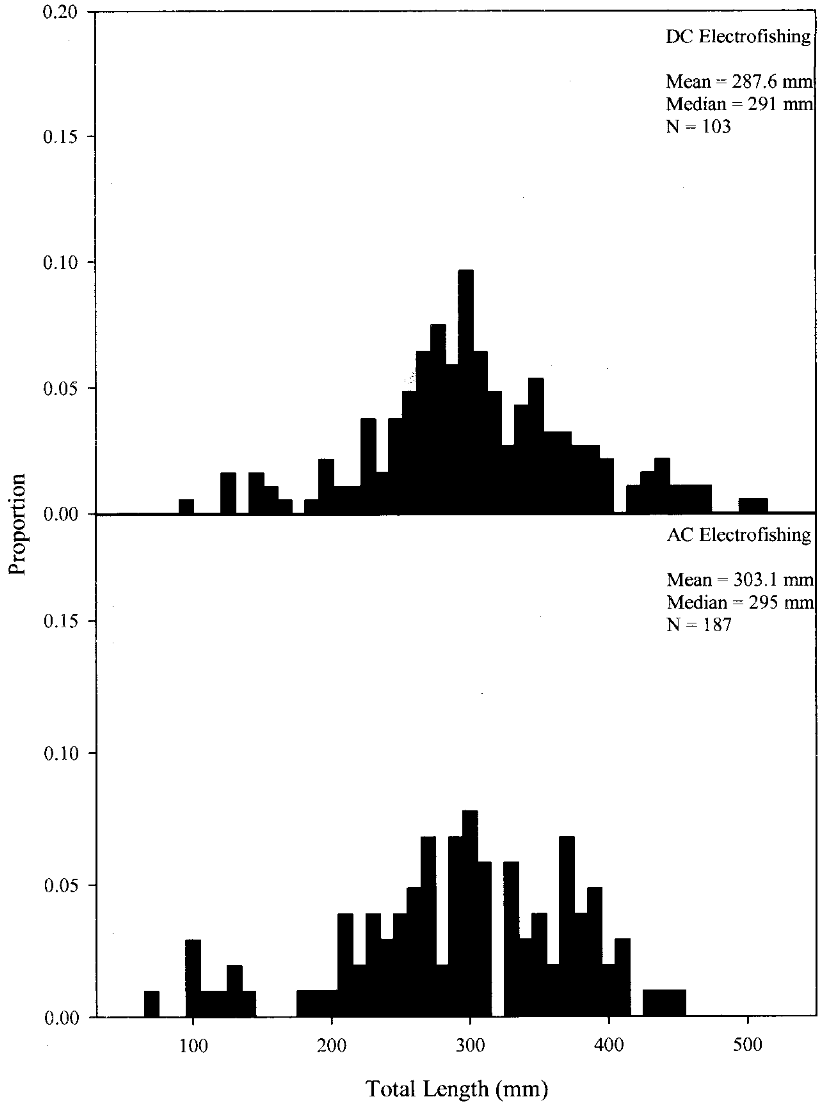

Figure 5.8. Length frequency distribution for largemouth bass sampled by AC and DC boat electrofishing during fall 2011.

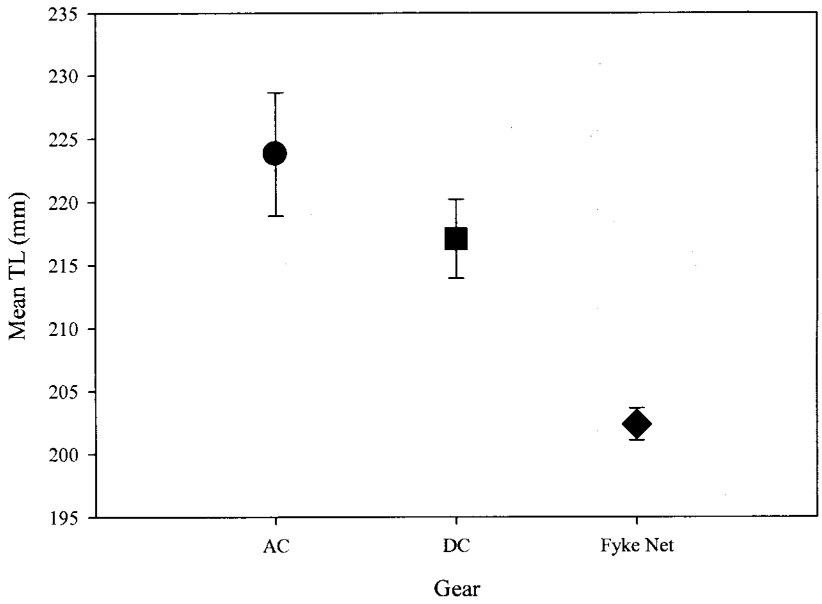

Figure 5.9. Mean total length (±SE) for crappie sampled by AC and DC boat electrofishing, and fyke nets during fall 2011. AC electrofishing represented by a circle marker, DC electrofishing represented by a square marker, fyke nets represented by a diamond marker. *Denotes significantly higher mean, $p < 0.05$.

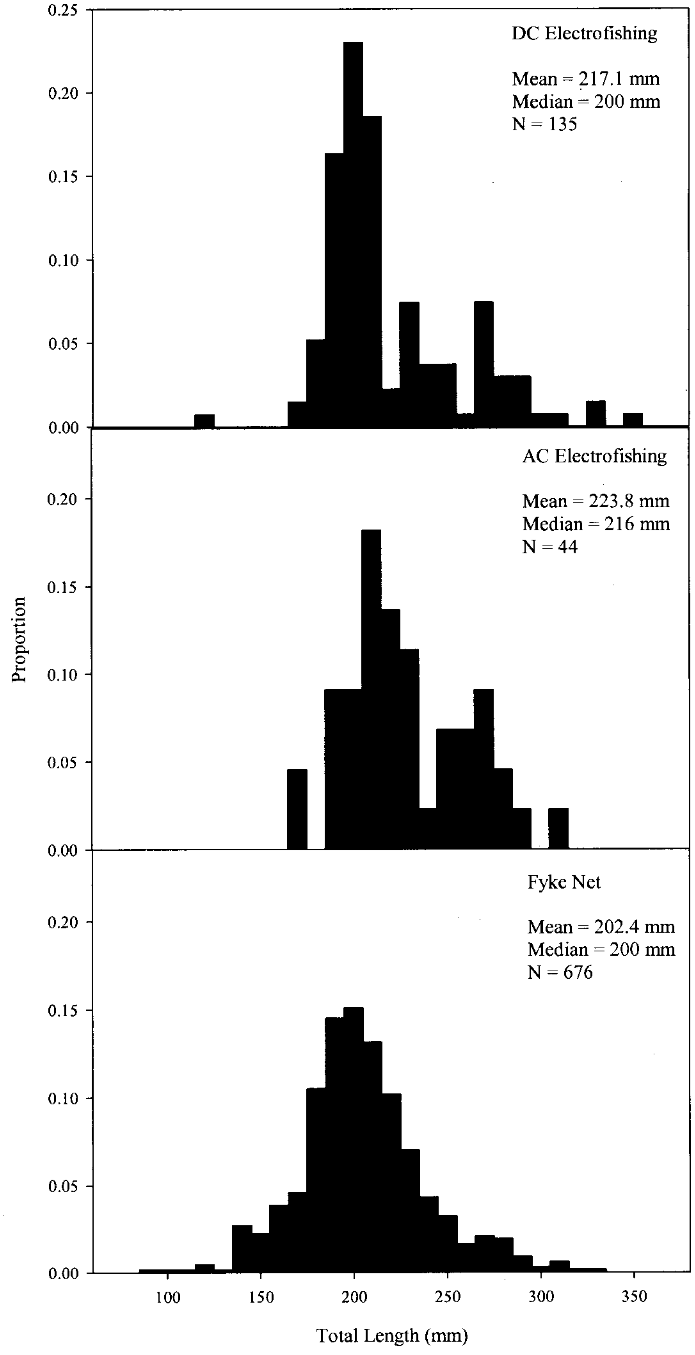

Figure 5.10. Length frequency distribution for crappie sampled by AC and DC boat electrofishing and fyke nets during fall 2011.

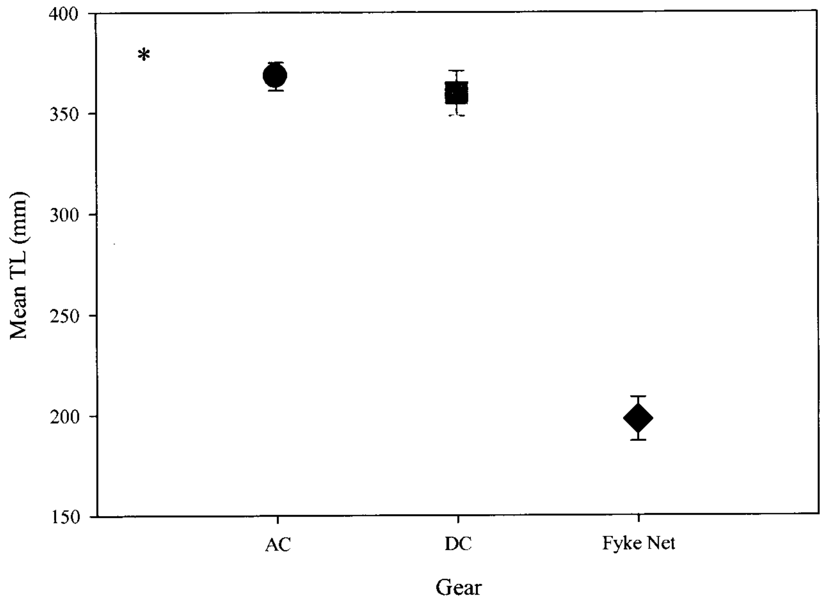

Figure 5.11. Mean total length (±SE) for channel catfish sampled by AC and DC boat electrofishing, and fyke nets during fall 2011. AC electrofishing represented by a circle marker, DC electrofishing represented by a square marker, fyke nets represented by a diamond marker. *Denotes significantly higher mean, $p < 0.05$.

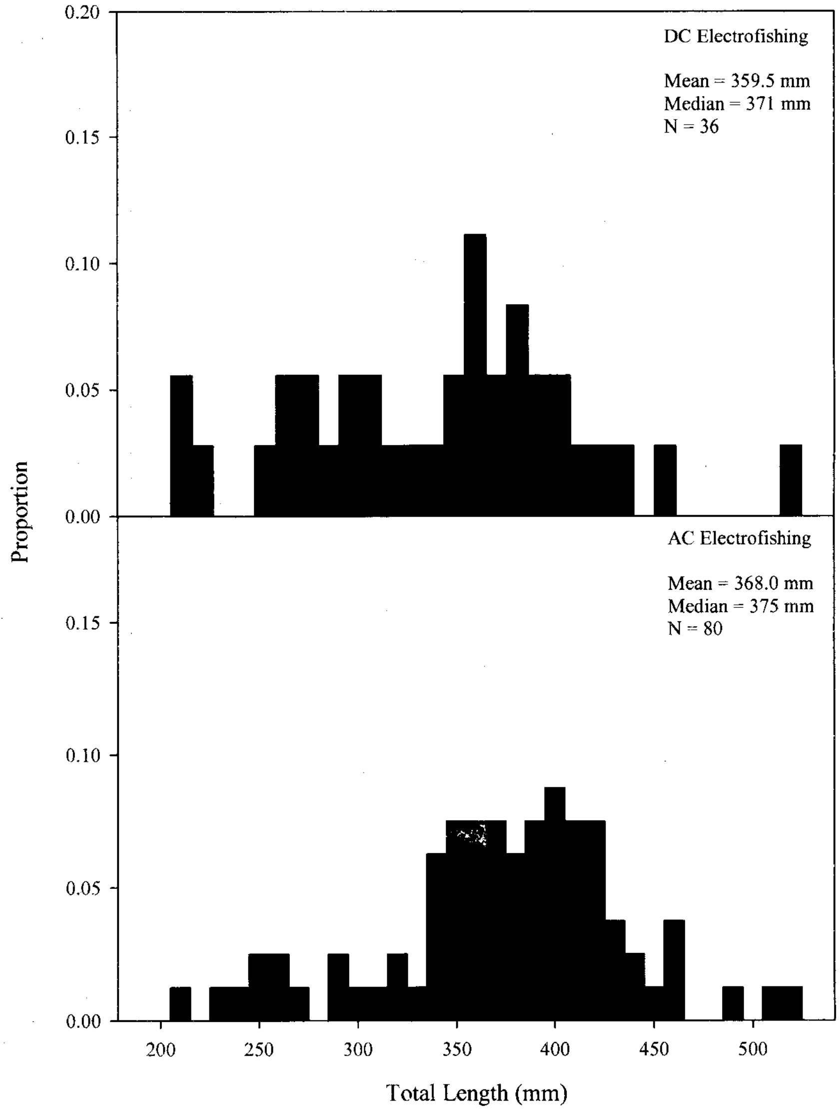

Figure 5.12. Length frequency distribution for channel catfish sampled by AC and DC boat electrofishing during fall 2011.

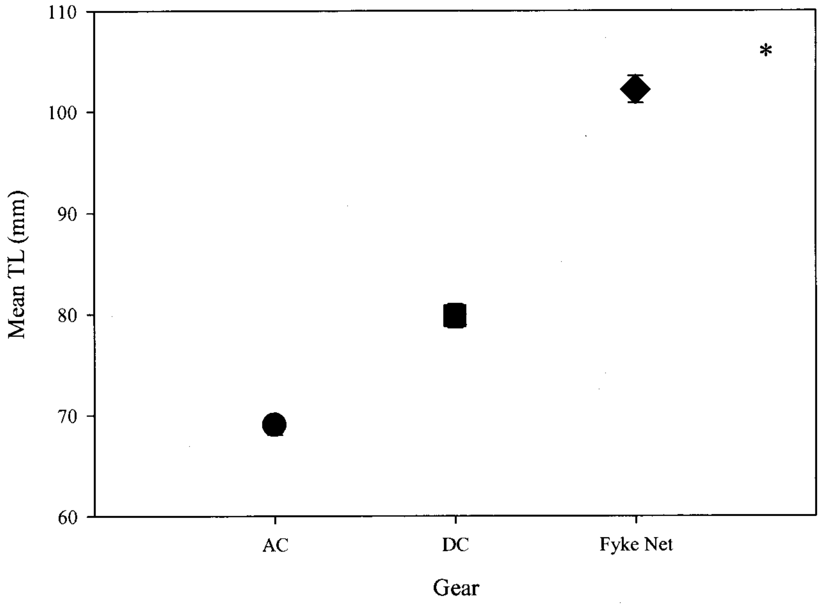

Figure 5.13. Mean total length (±SE) for bluegill sampled by AC and DC boat electrofishing, and fyke nets during fall 2011. AC electrofishing represented by a circle marker, DC electrofishing represented by a square marker, fyke nets represented by a diamond marker. *Denotes significantly higher mean, $p < 0.05$.

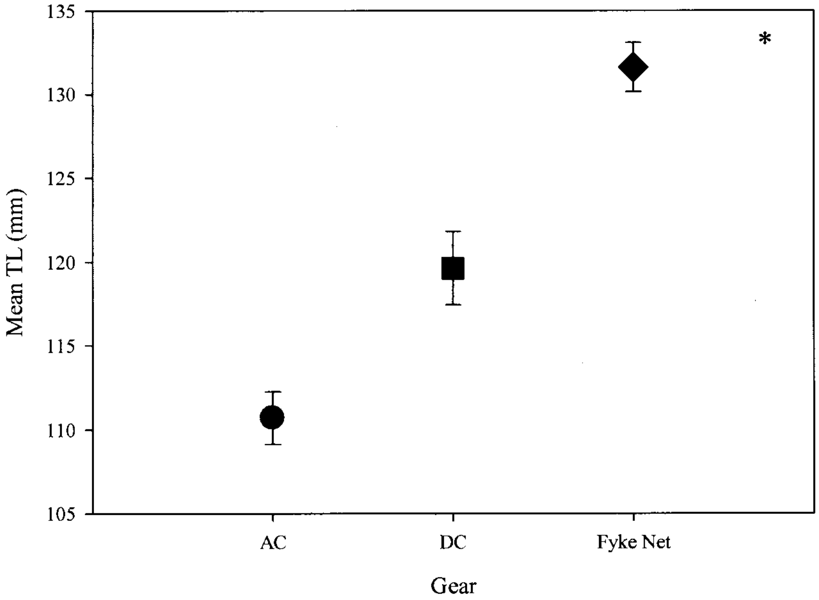

Figure 5.14. Mean total length (±SE) for redear sunfish sampled by AC and DC boat electrofishing, and fyke nets during fall 2011. AC electrofishing represented by a circle marker, DC electrofishing represented by a square marker, fyke nets represented by a diamond marker. *Denotes significantly higher mean, $p < 0.05$.

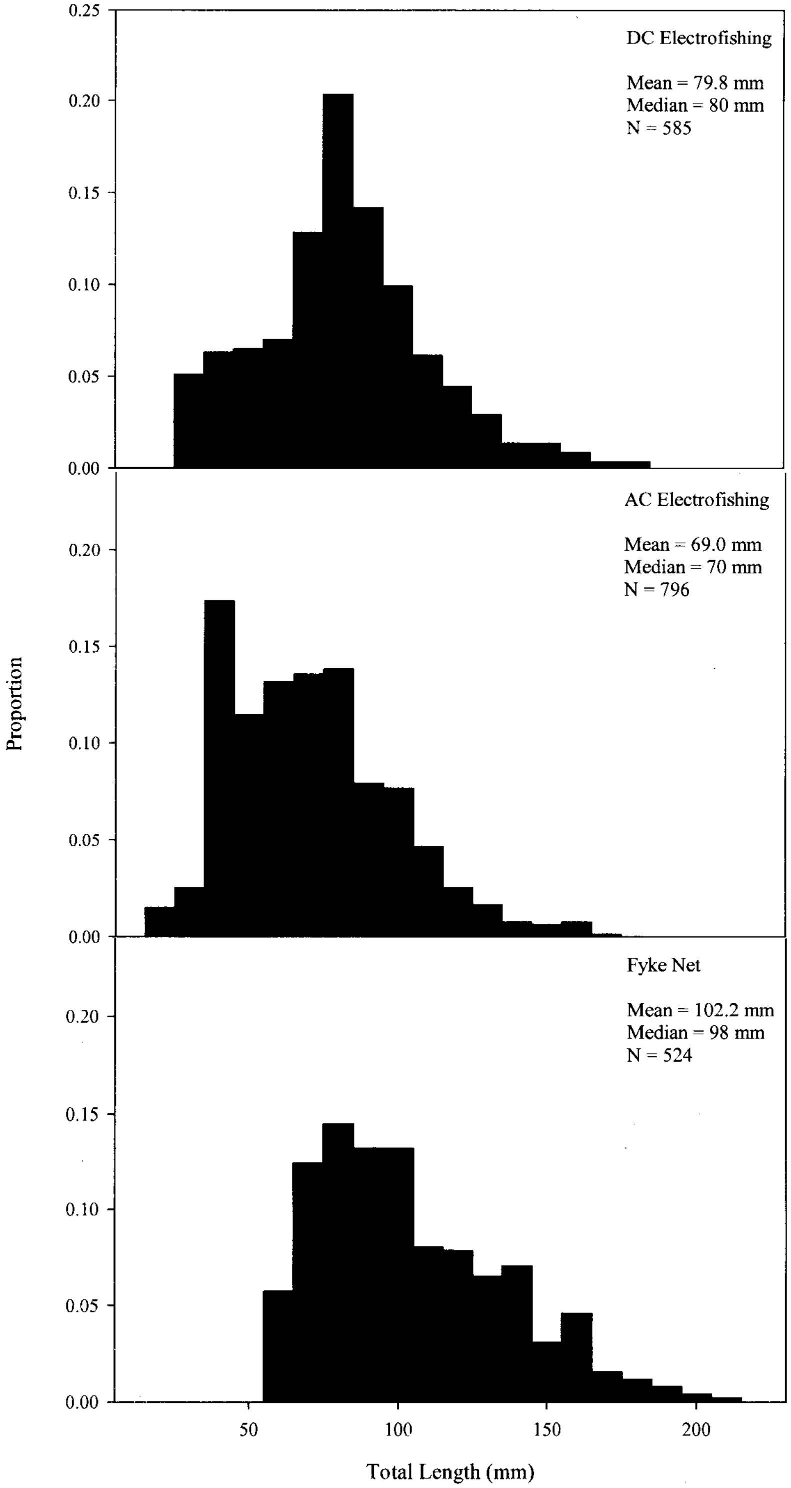

Figure 5.15. Length frequency distribution for bluegill sampled by AC and DC boat electrofishing and fyke nets during fall 2011.

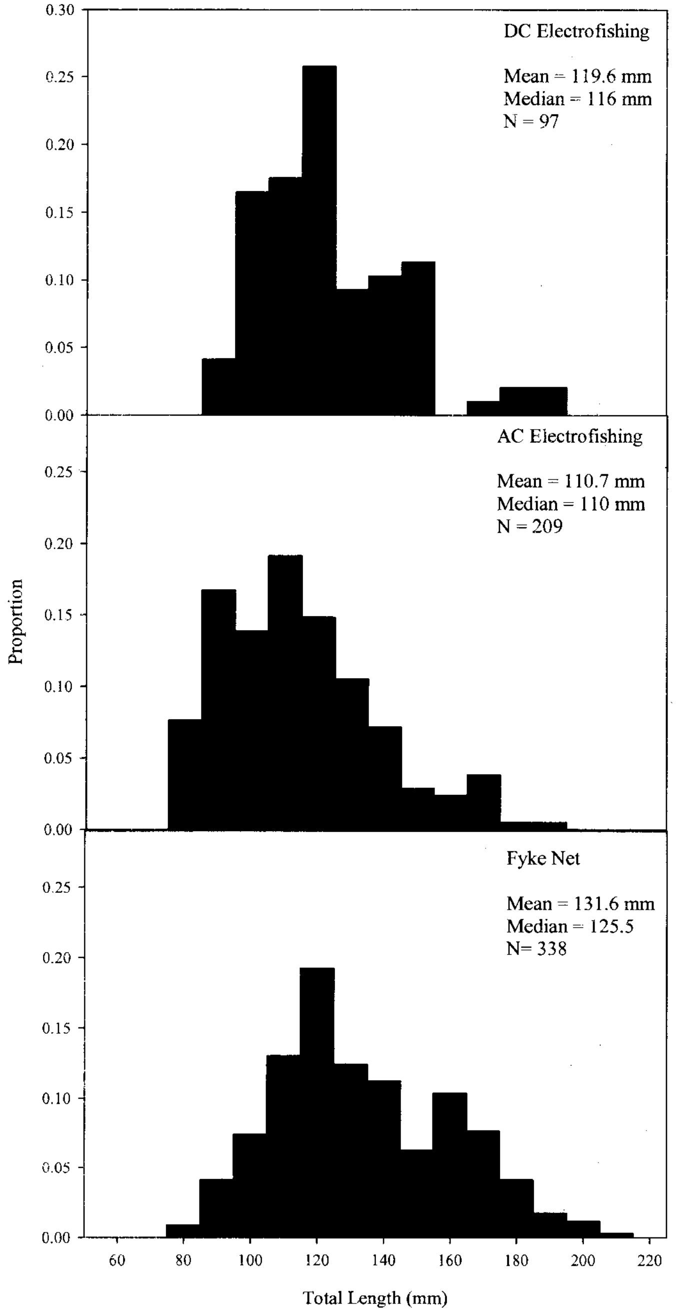

Figure 5.16. Length frequency distribution for redear sunfish sampled by AC and DC boat electrofishing and fyke nets during fall 2011.

CHAPTER SIX: GENERAL CONCLUSION

Sampling Coffeen Lake

Annual sampling of Coffeen Lake during the fall based on my surveys showed greater discrepancies in abundance over our three main sampling locations (the cooling loop, transition zone, and ambient zone) than cooler seasons such as spring. I suggest sampling Coffeen Lake in the spring of the year. Spring electrofishing would not only survey the lake when abundance is high throughout the reservoir, but also when fish are using all habitat areas offered by Coffeen Lake. Additionally, the use of fyke nets may be beneficial to annual surveys on Coffeen Lake. Currently, IDNR only uses AC electrofishing to sample this reservoir. Fyke netting resulted in greater numbers of crappie caught, with little disparity in density among sites.

Relative Abundance, Size Structure, and Condition

Changes in catch per unit effort throughout different seasons and among the different sites on Coffeen Lake indicate that thermal input is affecting sportfish location and distribution in Coffeen Lake. Distribution of the most desirable sportfishes in the lake (i.e. largemouth bass, channel catfish, and crappie species) is affected by heated effluent. Catch per unit effort data from AC electrofishing supports the idea that sportfishes generally are congregating in cooler waters during the warmest months of the year, and prefer warmer parts of the lake during the winter. Largemouth bass density is indicative of this trend, with concentrations of bass shifting throughout the year based on thermal preference. Additionally, the ambient zone represents critical refugia for all sportfishes, especially crappie.

While abundances of most sportfish are high, proportions of preferred, memorable, and trophy sized fish in most taxa are low in Coffeen Lake. Largemouth bass sampled with AC electrofishing are averaging roughly 285 mm TL in Coffeen Lake; 15 mm below a quality length fish. Only 18% of fish caught using AC electrofishing and only 15% of bass caught using DC electrofishing were preferred length or greater. No large (trophy or memorable) sized largemouth bass were found in this population. Size structure for black and white crappie differs substantially, with greater numbers of larger white crappie present. Smaller sizes and densities in black crappie may be due to this species being a relatively recent addition to Coffeen Lake. Out of all gear types used, AC electrofishing was most efficient for sampling larger white crappie; 6% of fish sampled using this gear were memorable size or greater. Channel catfish size structure is poor; the majority of catfish caught were below quality length.

Largemouth bass in Coffeen Lake are in excellent condition. Relative weight calculations for bass sampled by AC electrofishing average 94.62 ± 0.41, indicating this population is healthy. Sunfish species were found to be in average condition; it is important to note, food for bluegill and redear sunfish, which is abundant, does not seem to be influencing condition. Crappie species are both in excellent condition, which indicates that even though these fish are not as abundant, especially black crappie, they are healthy. Catfish were also found to be in average condition, though size structure indicates there are not many large fish in this population.

Age Frequency, Mortality, and Growth

Largemouth bass and crappie species are exhibiting relatively fast growth, even though I did not find high percentages of old ages. Stronger year classes influenced my growth model for white crappie, with younger ages averaging greater lengths than older age classes. Mortality estimates are also fairly high for these species, most notably crappie. In crappie, high mortality estimates are most likely due to harvest, especially considering the desirable sizes and number of white crappie that can be caught by anglers in Coffeen Lake. Largemouth bass mortality was found to be greater than 50%. It is important to note that largemouth bass size structure has changed over time, with previous size distributions estimating a larger amount of fish greater than 400 mm in the population than we are currently finding. These data may be due to a variety of factors including greater angling mortality or harvest of largemouth bass in Coffeen Lake.

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APPENDIX A: TEMPERATURE AND DISSOLVED OXYGEN IN COFFEEN LAKE

FALL 2010—FALL 2011

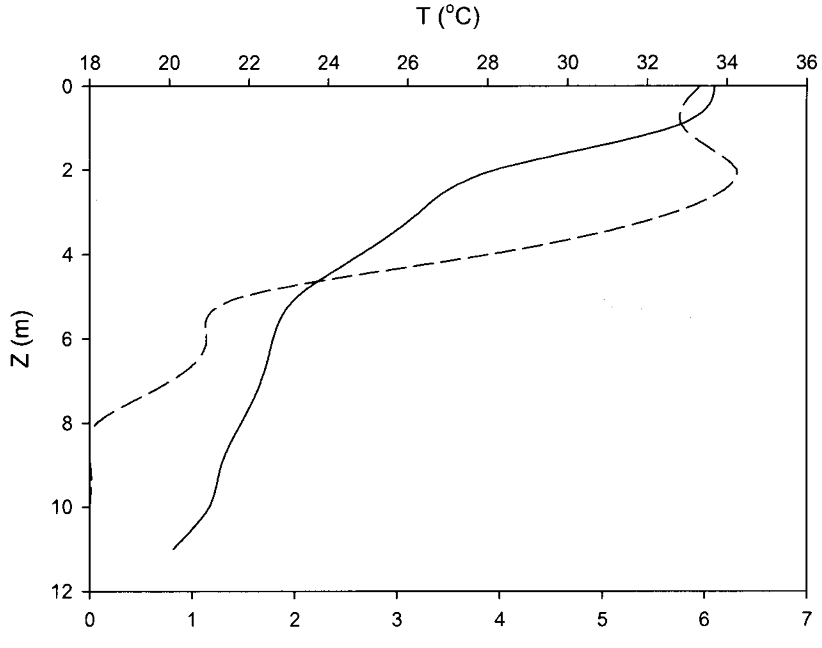

Figure A1. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 1 during Fall 2010.

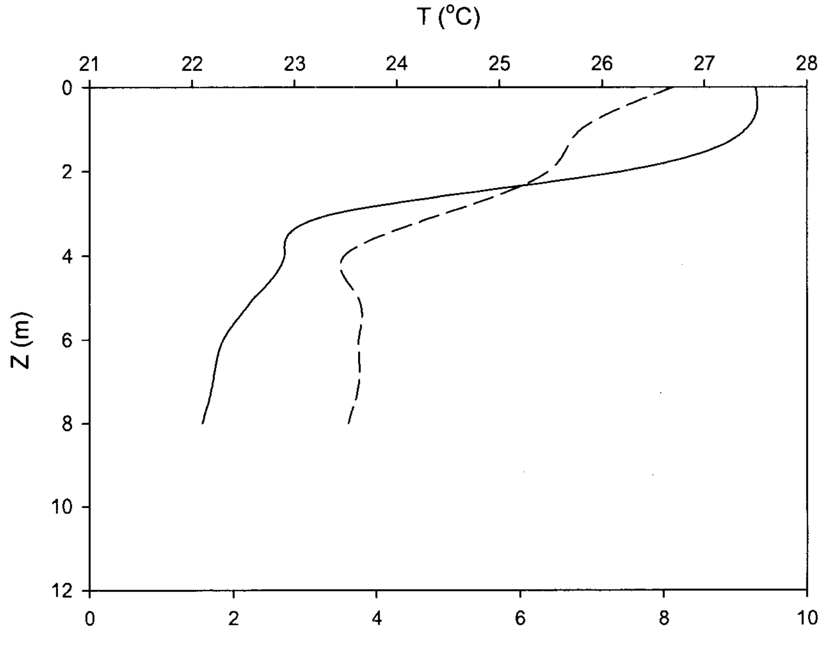

Figure A2. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 2 during Fall 2010.

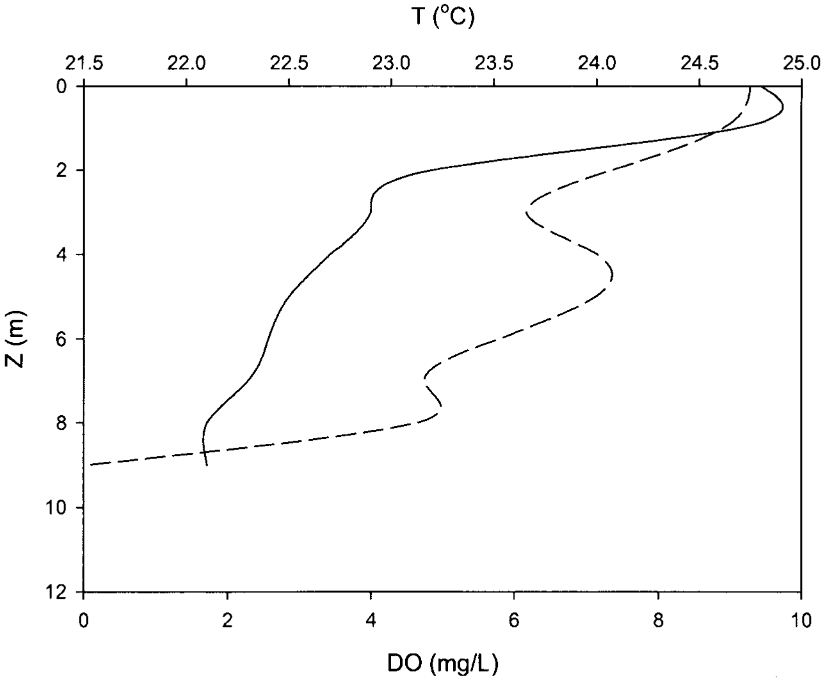

Figure A3. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 3 during Fall 2010.

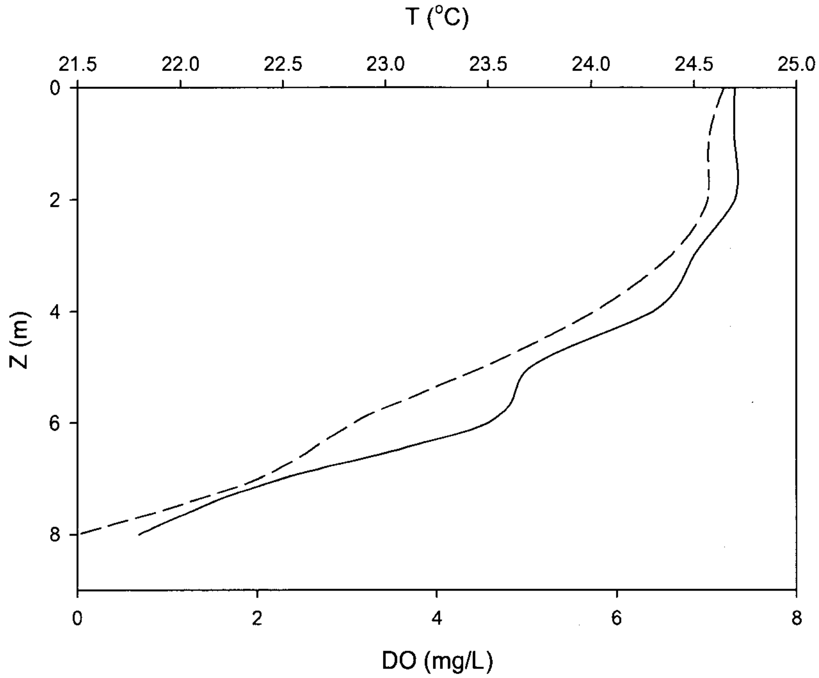

Figure A4. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 4 during Fall 2010.

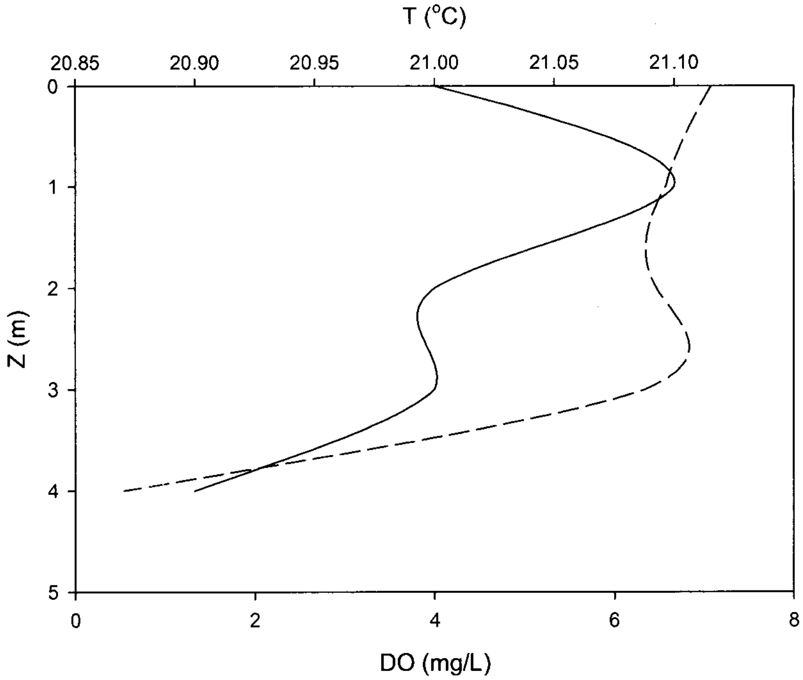

Figure A5. Temperature (°C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 5 during Fall 2010.

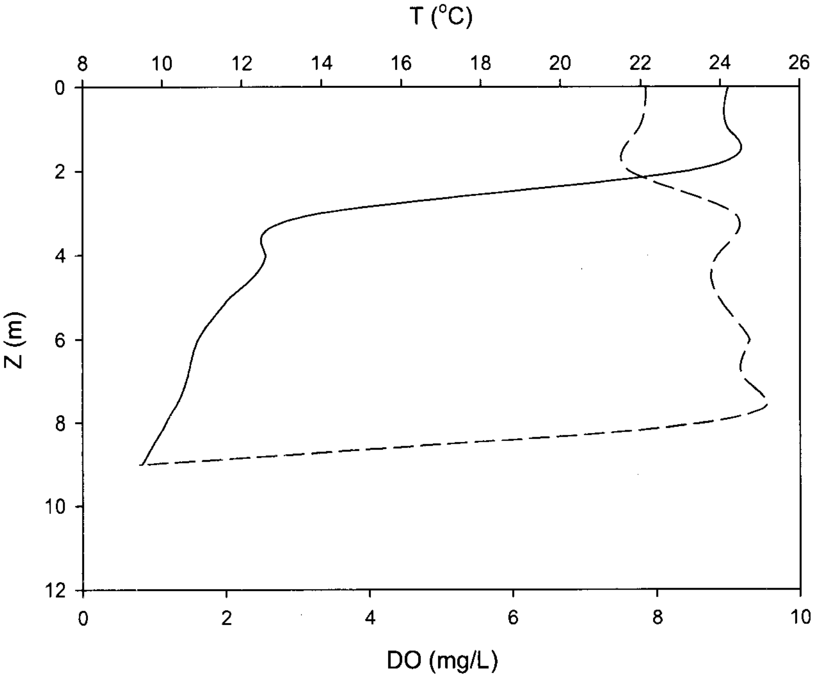

Figure A6. Temperature (°C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 1 during Winter 2011.

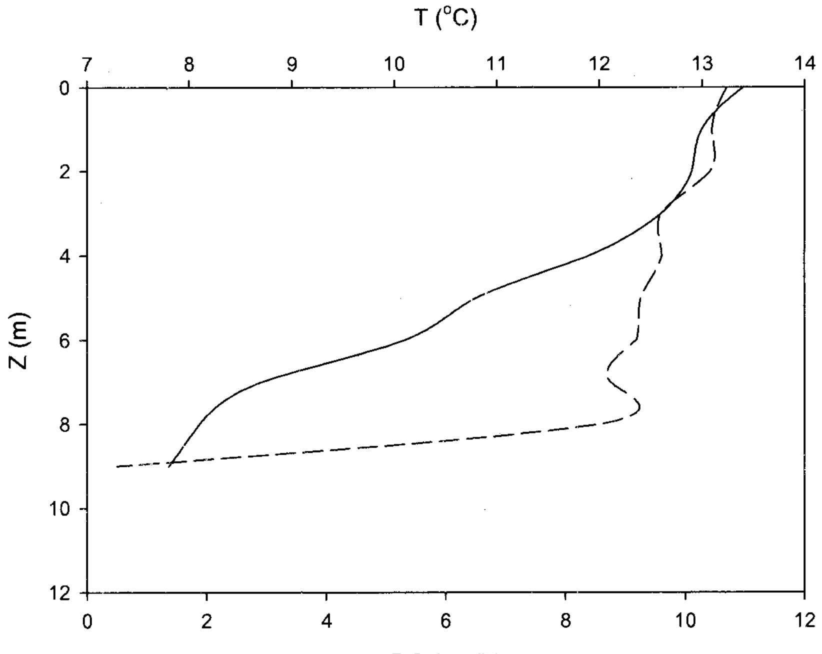

Figure A7. Temperature (°C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 2 during Winter 2011.

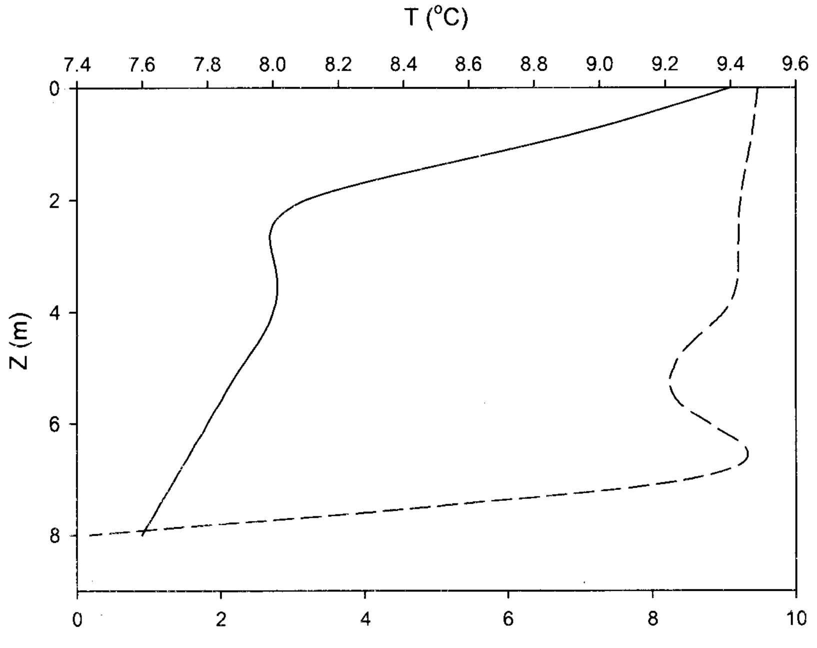

Figure A8. Temperature (°C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 3 during Winter 2011.

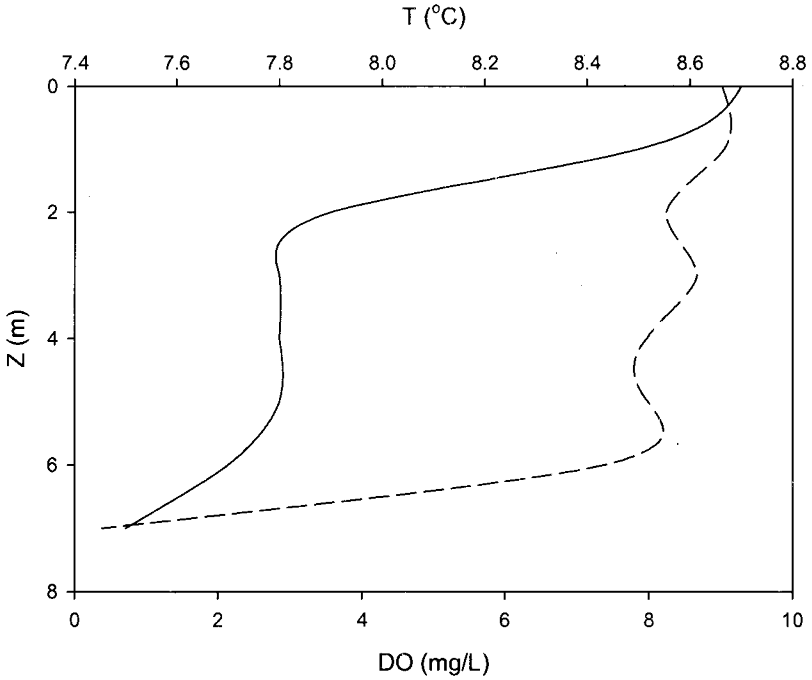

Figure A9. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 4 during Winter 2011.

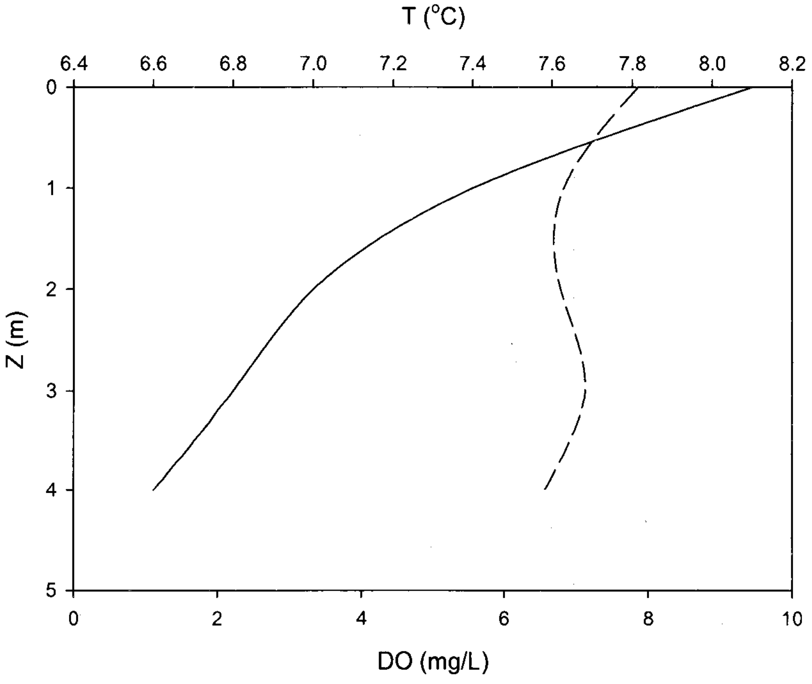

Figure A10. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 5 during Winter 2011.

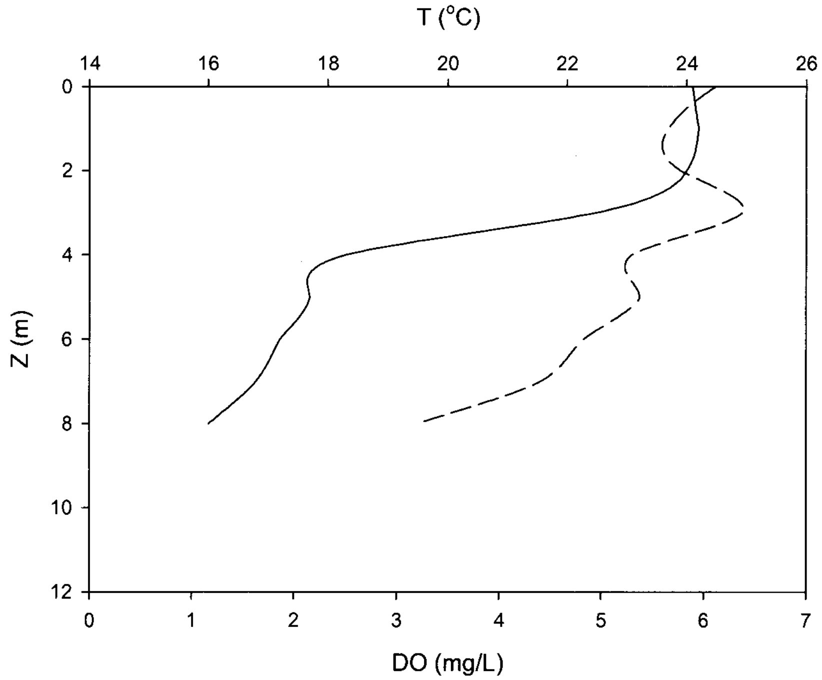

Figure A11. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 1 during Spring 2011.

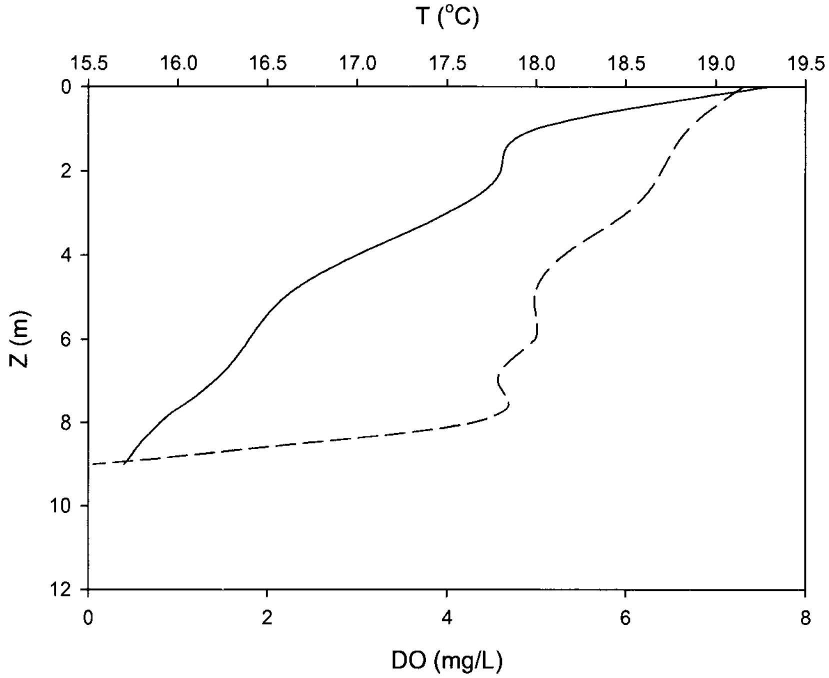

Figure A12. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 2 during Spring 2011.

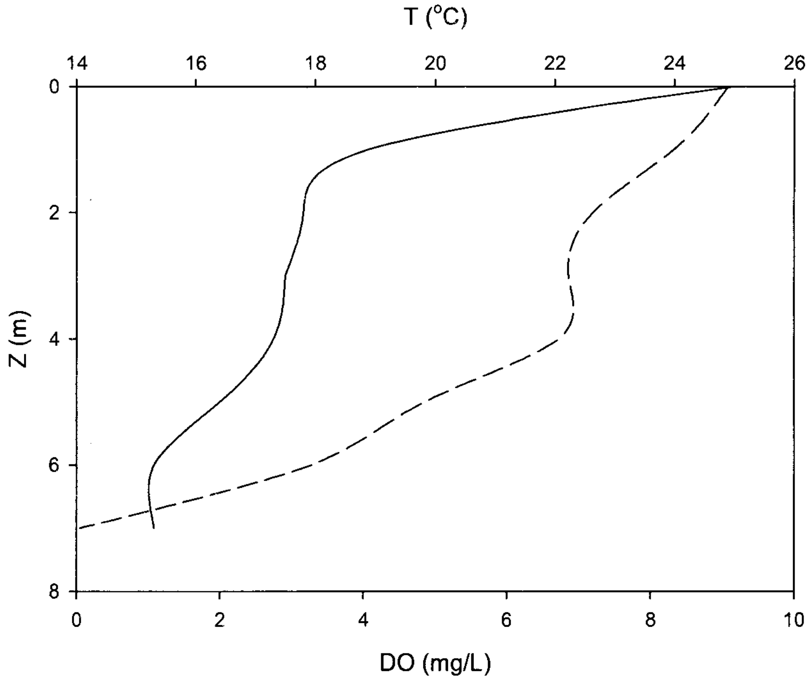

Figure A13. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 3 during Spring 2011.

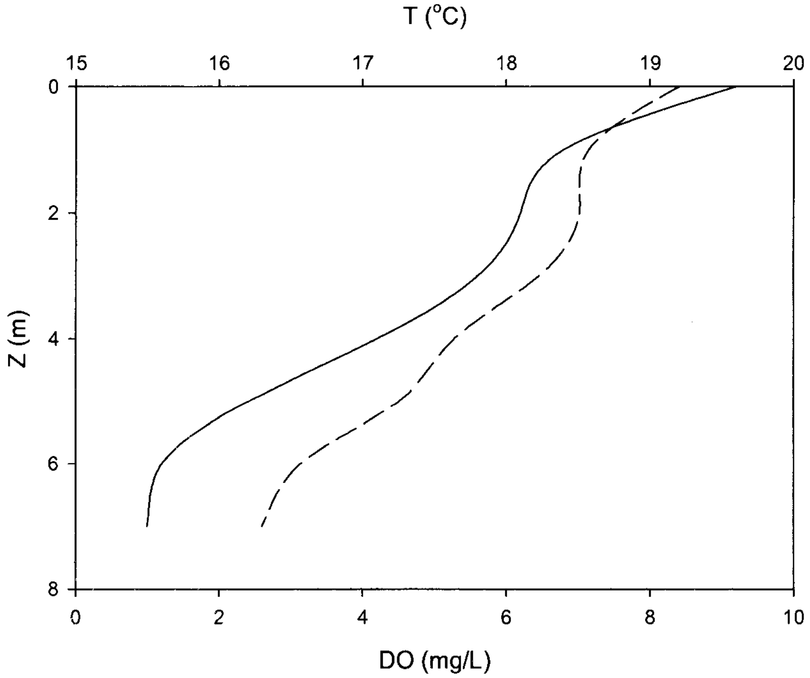

Figure A14. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 4 during Spring 2011.

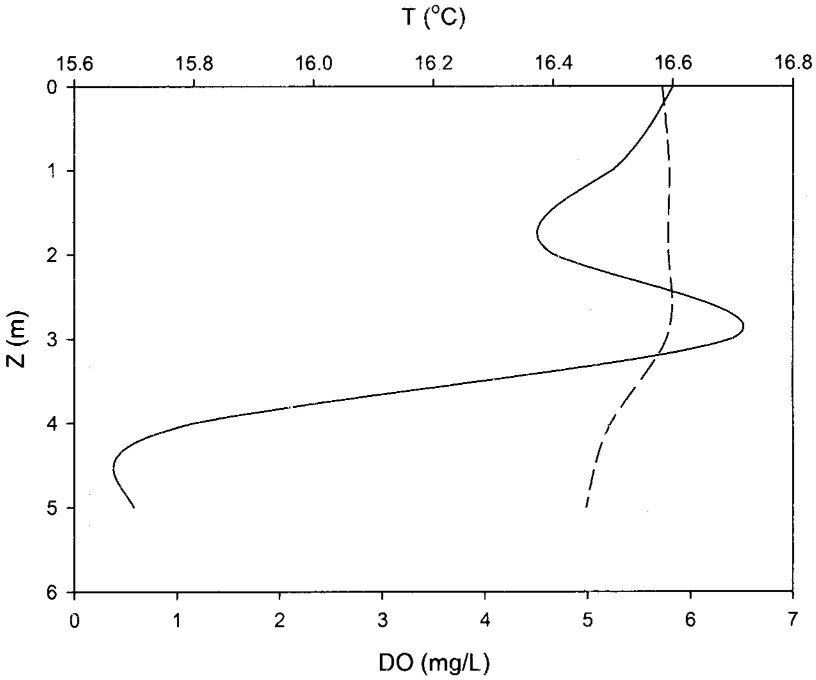

Figure A15. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 5 during Spring 2011.

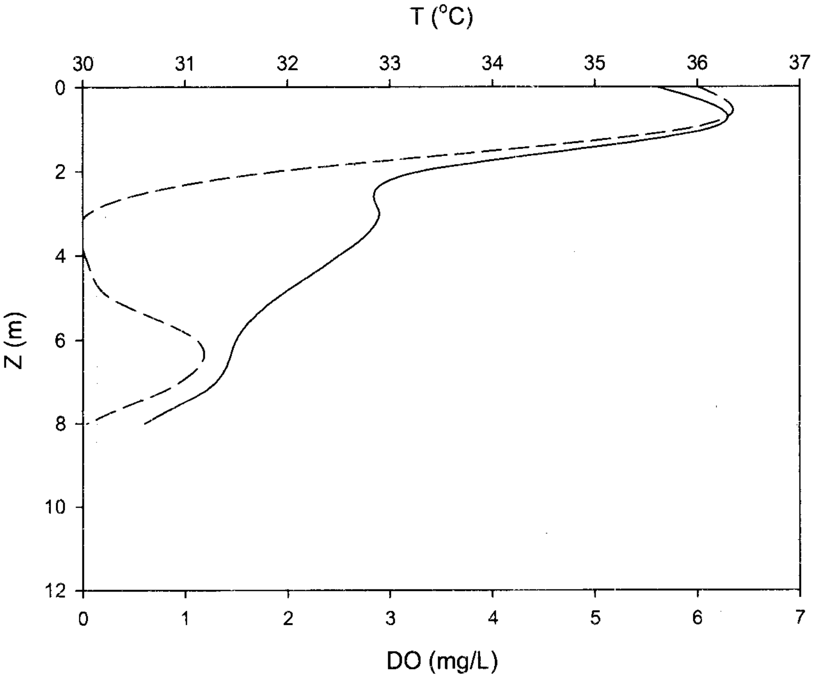

Figure A16. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 1 during Summer 2011.

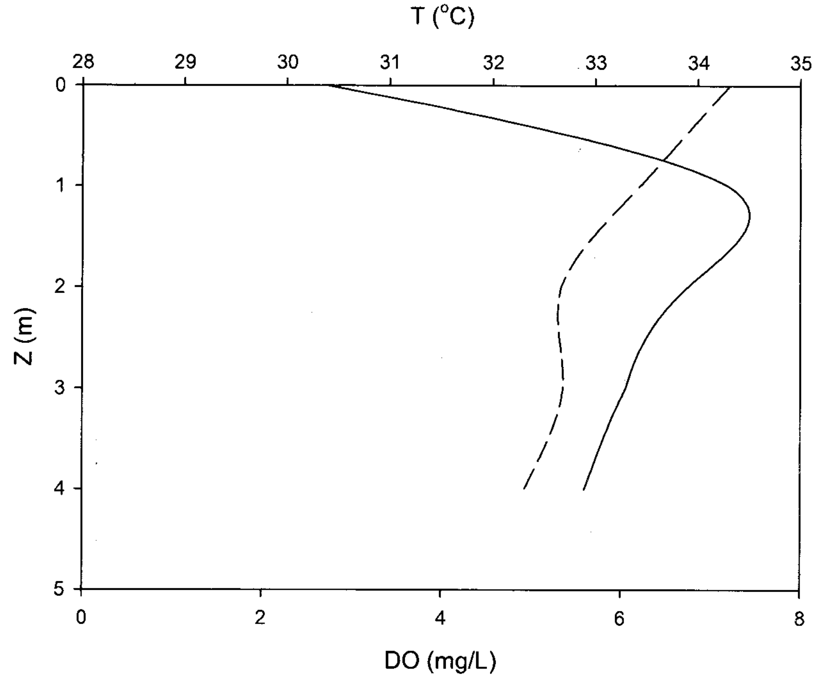

Figure A17. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 2 during Summer 2011.

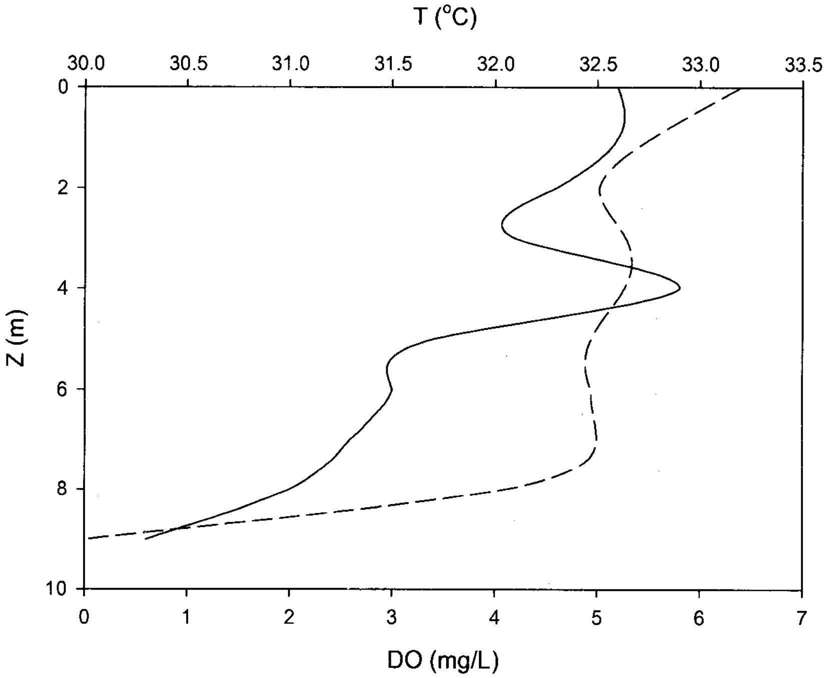

Figure A18. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 3 during Summer 2011.

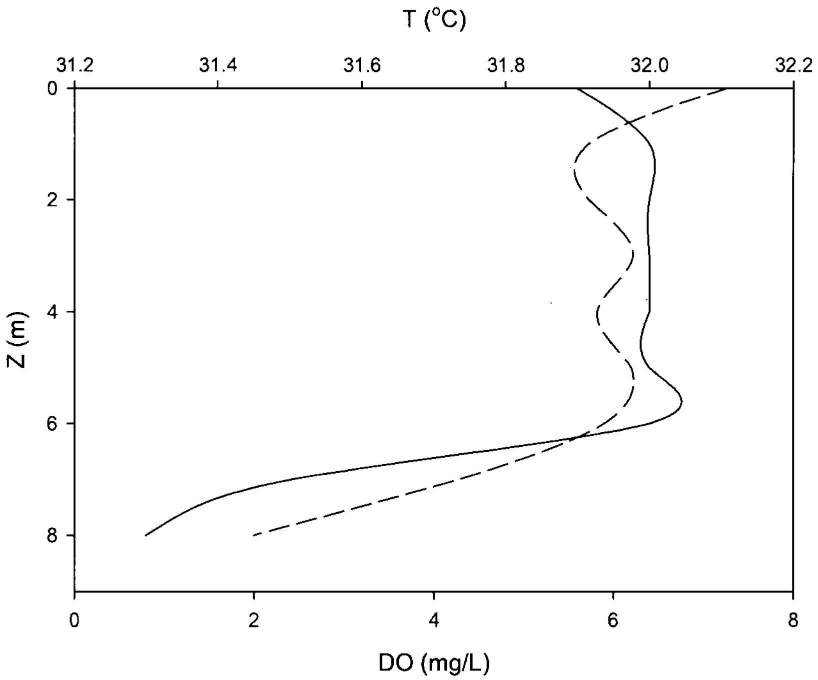

Figure A19. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 4 during Summer 2011.

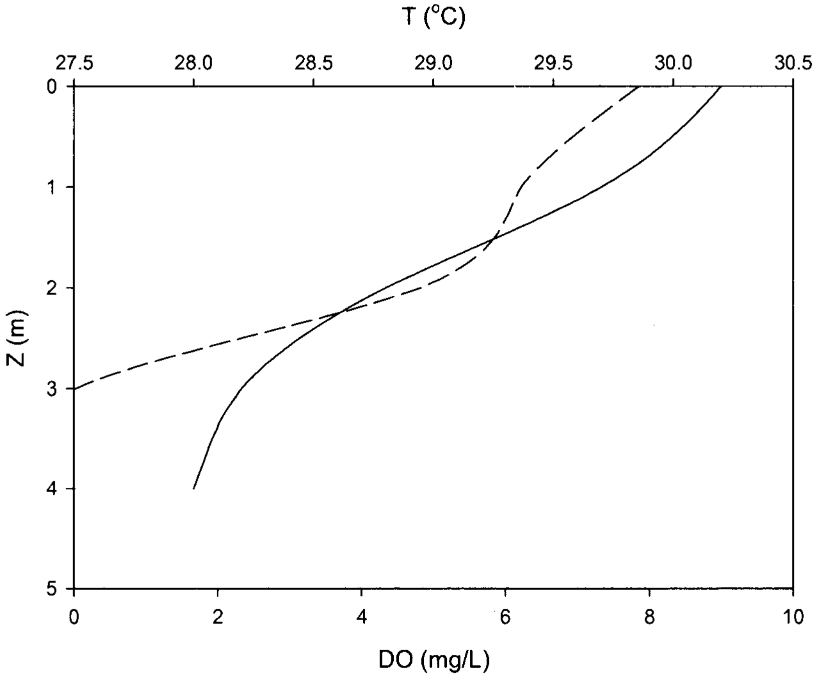

Figure A20. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 5 during Summer 2011.

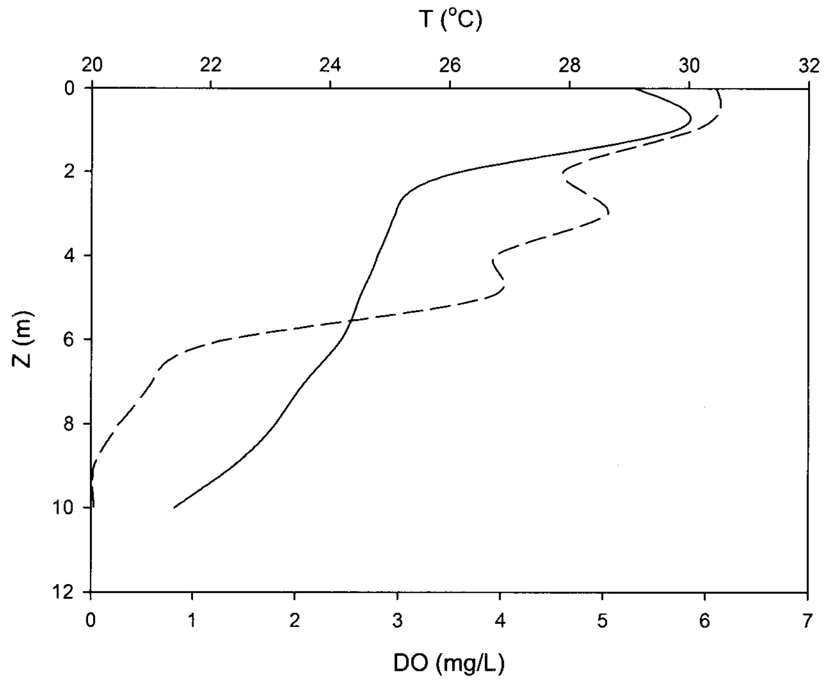

Figure A21. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 1 during Fall 2011.

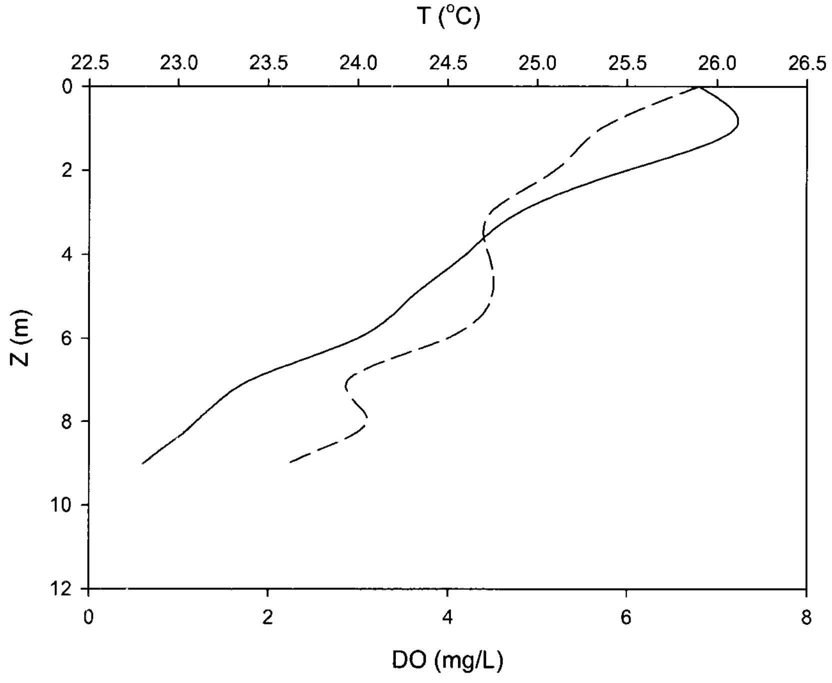

Figure A22. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 2 during Fall 2011.

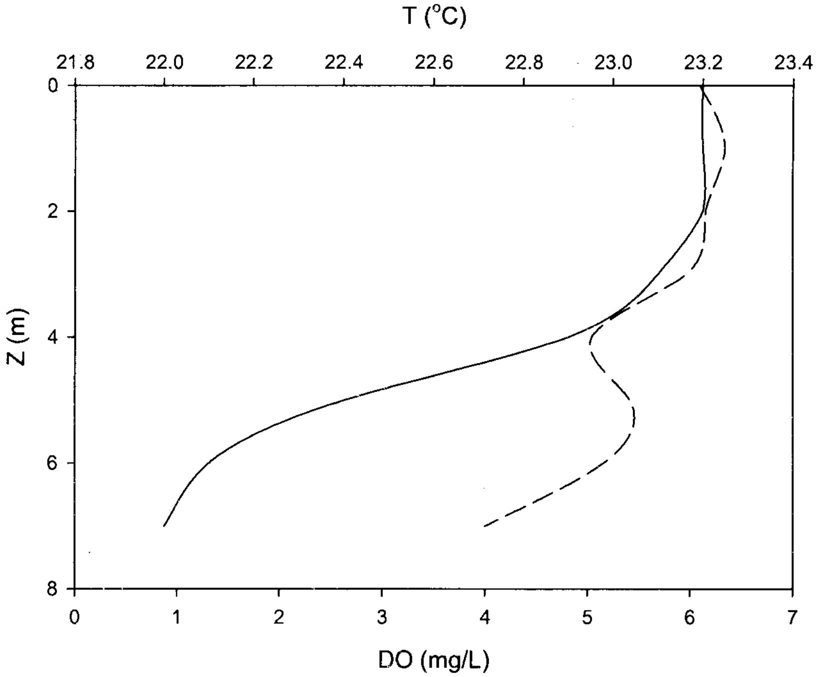

Figure A23. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 3 during Fall 2011.

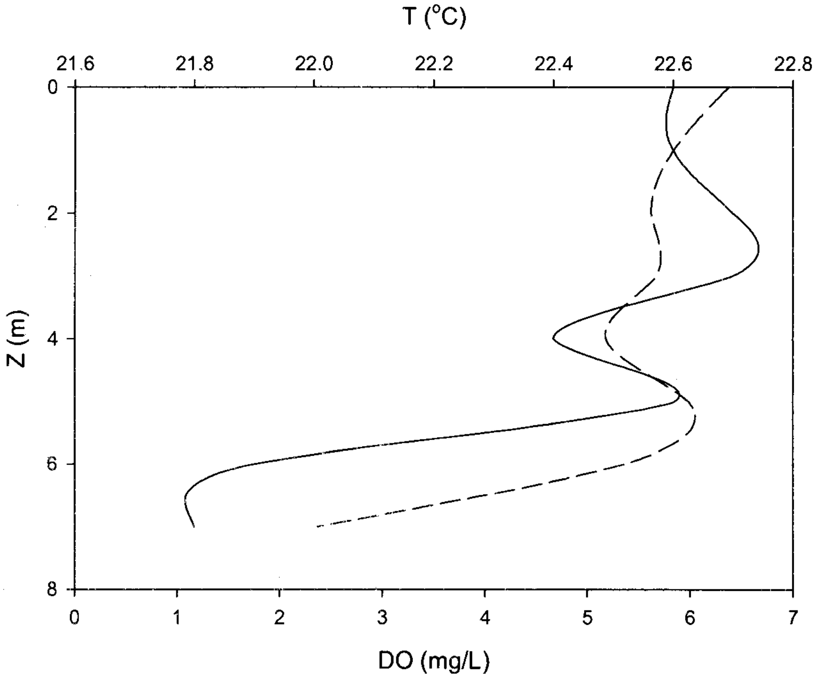

Figure A24. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 4 during Fall 2011.

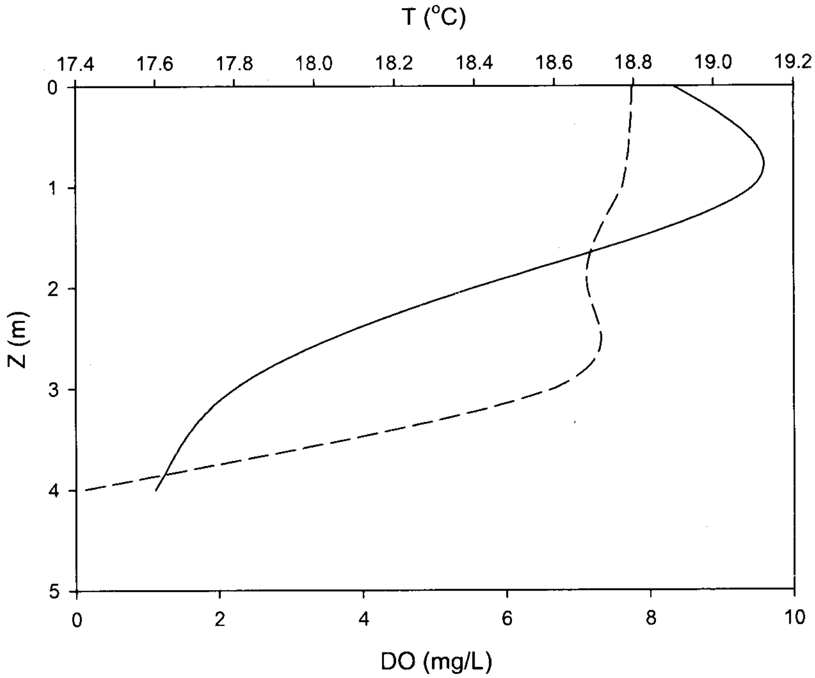

Figure A25. Temperature (˚C, Solid Line) and Dissolved Oxygen (mg/L, Dashed Line) Profile for Site 5 during Fall 2011.

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