

Habitat selection, movement, and home range of largemouth bass (*Micropterus salmoides*) following a habitat enhancement project in Table Rock Lake, Missouri

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The undersigned, appointed by the dean of the Graduate School, have examined the
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Table of contents

Acknowledgments.....	ii
List of tables	v
List of figures.....	vi
List of appendices	viii
Abstract.....	ix
Description of chapters.....	xi
General introduction.....	1
Reservoir aging and management.....	1
Largemouth bass and Table Rock Lake	3
Objectives	6
References.....	7
Chapter 1: Habitat selection of largemouth bass in Table Rock Lake, Missouri following a large reservoir habitat improvement project.....	10
Abstract	10
Introduction.....	12
Methods	15
Study site	15
Largemouth bass collection and tagging.....	17
Radio tracking and collection of habitat variables	18
Analysis	21
Results	25
Mortality and tag detection	25
Habitat selection.....	26

Discussion	28
Habitat selection.....	28
Mortality and tag detection	32
Management implications	33
References.....	35
Chapter 2: Movement and home range of largemouth bass (<i>Micropterus salmoides</i>) in a large Missouri reservoir	49
Abstract	49
Introduction.....	51
Methods	54
Study site	54
Approach	55
Analysis	57
Results	60
Discussion	63
References.....	68
Conclusions	77
Appendices	79

List of tables

Chapter 1

Table 1. Covariates used in resource selection models for largemouth bass habitat selection located in Table Rock Lake, Missouri 2011-2012.	41
Table 2. <i>A-priori</i> models representing hypothesis illustrating habitat selection of largemouth bass in Table Rock Lake, Missouri, 2011-2012. See Table 1 for variable names and definitions.....	42
Table 3. Akaike information criterion (AIC) output for top 5 diel models (see Table 2 for model number and variables) explaining habitat selection of largemouth bass in Table Rock Lake, Missouri from June 2011 to May 2012.	43
Table 4. Akaike information criterion (AIC) output for top 5 seasonal models (summer: June, July, August, fall: September, October, November, winter: December, January, February, spring: March, April, May) explaining habitat selection of largemouth bass in Table Rock Lake, Missouri. See Table 2 for model number and variables.	44

List of figures

Chapter 1

Figure 1. Study site location and distribution of coarse (stump and rock piles) and complex (evergreen and hardwood trees) augmentation structures within the Kings River arm of Table Rock Lake, Missouri. 45

Figure 2. Kriging estimate of slope (degrees) (a) and depth at conservation pool (meters) (b) in the Kings River Arm of Table Rock Lake, Missouri..... 46

Figure 3. Results from our top model in the diel candidate set showing the relative probability (derived from parameter estimates and odds ratios) of largemouth bass selecting a specific depth (a), distance from shore (b), and structure (c), specifically standing timber, natural woody debris, boat docks, rock ledges, complex (evergreen and hardwood trees) and coarse (stump and rock piles) augmentation structure. 47

Figure 4. Results from our top models in the seasonal candidate set showing the relative probability (derived from parameter estimates and odds ratios) of largemouth bass selecting a specific depth (a), distance from shore (b), and structure (c), specifically standing timber, natural woody debris, boat docks, rock ledges, complex (evergreen and hardwood trees) and coarse (stump and rock piles) augmentation structure. 48

Chapter 2

Figure 1. Largemouth bass mean movement rates (m/h) in Table Rock Lake, Missouri from May 2011 through May 2012 by diel period. Low light (gray bars) represent dawn and dusk (2 hours before and after sunrise/sunset) movement rates. Error bars represent one standard error. 73

Figure 2. Observed water level (solid black line) compared to conservation pool (dashed gray line) from May 2011 through May 2012 in Table Rock Lake, Missouri. 73

Figure 3. Mean monthly movement rate (meters per hour) compared to day length (hours) (top panel), mean monthly water temperature (Celsius) (middle panel), and water level (meters) for largemouth bass in Table Rock Lake, Missouri from May 2011 to May 2012. 74

Figure 4. Mean water depth occupied (top panel) and mean distance from shore occupied by largemouth bass (bottom panel) in Table Rock Lake, Missouri from May 2011 through May 2012 by diel period. Low light (gray bars) represent dawn and dusk (2 hours before and after sunrise/sunset) locations. Error bars represent one standard error. 75

Figure 5. Annual core home range (50% least square cross validated fixed kernel estimate) compared to fish length for 12 largemouth bass in Table Rock Lake, Missouri from May 2011 to May 2012. 76

List of appendices

Appendix 1. Top discrete choice diel model parameter estimates for variable (β), with standard error (SE) and odds ratios (e^x).	79
Appendix 2. Top discrete choice seasonal model parameter estimates for variable (β), with standard error (SE) and odds ratios (e^x). Fall values were model averaged, reporting the unconditional standard errors for this model. See Table 1 for variable definitions... 80	
Appendix 3. Table of largemouth bass implanted with radio transmitters, showing the radio frequency, length (millimeters), weight (grams), floy tag number, date implanted, and the number of relocations per fish per month over the 14 month habitat selection study (Chapter 1) in Table Rock Lake, Missouri.....	81

Habitat selection, movement, and home range of largemouth bass (*Micropterus salmoides*) following a habitat enhancement project in Table Rock Lake, Missouri

Jason M. Harris

Dr. Craig P. Paukert, Thesis Supervisor

Abstract

Deteriorating reservoir fish habitat is a concern throughout the United States so the Missouri Department of Conservation and cooperators placed approximately 2,000 augmentation structures (trees, stumps, and rock piles) throughout Table Rock Lake, Missouri to improve fish habitat for largemouth bass (*Micropterus salmoides*). Our objectives were to determine habitat selection, movement, and home range of largemouth bass following this enhancement. Seventy largemouth bass (>380 mm total length) were implanted with radio transmitters and relocated monthly for one year. Results from our discrete choice models suggest largemouth bass select intermediate depths (2-7 m) in areas near shore (<25 m) regardless of diel period and season, however structure was only selected during summer and fall. During these seasons, complex (tree) augmentation structures were selected at the same rate as natural woody structure, which suggests the addition of augmentation structures may be able to supplement habitat loss in large reservoirs. Movement rates were higher during day than night across all months, with peak movement rates during June and July (mean=83.5 m/h) when water temperatures were greatest. Annual core (50%) home range estimates averaged 7.9 ha with longer fish having smaller home ranges ($r = -0.64$,

P = 0.03). However, home range size did not differ in the presence of augmentation structure compared to those without. This project was a pilot program of the National Fish Habitat partnership and will help identify areas that may be most suitable for habitat augmentation structures to improve reservoir fish populations through reservoir habitat enhancements.

Description of chapters

The two chapters of this thesis were written as independent manuscripts to be submitted to peer-reviewed journals. Because of this some introductory information is repeated throughout the chapters and an individual literature cited section follows each chapter. Co-authors were listed after each chapter title and the thesis was written using plural nouns to include co-authors who helped on this project.

General introduction

Reservoir aging and management

Reservoirs are a relatively new occurrence on the landscape and often create highly productive aquatic ecosystems after their initial impoundment (Pegg and Chick 2010). This extremely productive period termed the trophic upsurge, creates a newly flooded littoral environment which provides high quality habitat and food from organic matter and nutrients (Kimmel and Groeger 1986), which can create a “boom” fishery in newly constructed reservoirs (Miranda and Bettoli 2010). The trophic upsurge is often temporary and followed by a trophic depression (Kimmel and Groeger 1986) and decline in fish harvest (Jenkins 1967) caused by a number of sources. Anthropogenic factors such as urbanization and agricultural practices (e.g., runoff) can increase phosphorus and nitrogen (Vitello and Armstrong 2008). This nutrient loading can influence the trophic state of reservoirs, altering water temperatures and dissolved oxygen levels (Miranda and Bettoli 2010). Increased shoreline erosion and sedimentation can increase turbidity (Neel 1963), which can reduce light penetration and water clarity, thereby reducing species richness of phytoplankton (Holz et al. 1997), zooplankton (Popp et al. 1996), and the benthic invertebrate community (Popp and Hoagland 1995), all of which comprise the base of reservoir food webs. Over 50% of small impoundments (<100 acre-feet) could completely fill with sediment in as little as 67 years, and it would only take half that time for these dams to be considerably impaired (Kimmel and Groeger 1986). Existing habitat structure used by fishes (e.g., woody debris, gravel/rubble substrates)

will eventually become “carpeted” by layers of fine sediment, reducing habitat heterogeneity throughout the reservoir (Miranda and Bettoli 2010).

In the United States reservoirs cover more surface area than natural lakes, excluding the Great Lakes (Moyle and Cech 1982). The majority of dam construction in the U.S. occurred between 1920 and 1960 (Miranda and Bettoli 2010), with most of these reservoirs now approaching 100 years post impoundment. However, little thought was given to sustaining fisheries production in newly created reservoirs; if fishing slowed in one reservoir, anglers could move to one of the newly constructed reservoirs (Miranda and Bettoli 2010). The majority of dams built in the early part of the century were created for hydropower, flood control, navigation, and water supply (Doyle et al. 2003), with sustainable fisheries being a distant second objective. However, researchers began to notice a decline in sport fish harvest that was inversely related to reservoir age (Jenkins 1967). As these reservoirs continue to age, research and management actions working to restore these systems have emerged as a priority for fisheries agencies.

Larger reservoirs create unique challenges for fisheries managers. In many small natural systems harvest regulations and fish stocking may be sufficient to sustain most fisheries. However, in large complex systems, management needs to be accomplished at multiple spatial scales with the help of various state, federal, and non-governmental organizations (Vitello and Armstrong 2008). Reservoir improvements fall into two broad categories: watershed enhancements and within-reservoir enhancements (Pegg and Chick 2010). Watershed enhancements are usually landscape scale and aim to reduce

nutrient loading and soil erosion. Within-reservoir enhancements are generally smaller scale projects and are focused on the physical habitat through the addition of artificial or natural structure. Both types of enhancements are essential to improving reservoir conditions; however our research will be focused on evaluating how a popular sport fish responds to a within-reservoir enhancement, specifically the addition of augmentation structure.

Largemouth bass and Table Rock Lake

Centrarchids *spp.* have been well studied because of their resilience in lab experiments, availability in natural systems, and importance in recreational fisheries (Kieffer and Cooke 2009). Largemouth bass *Micropterus salmoides* can persist in natural lakes, swamps, creeks, rivers, and impoundments (Warren 2009), where they have a strong preference for cover such as woody debris and vegetation (Schlagenhaft and Murphy 1985; Annett et al. 1996). Largemouth bass also can survive in a wide range of conditions, have a high critical thermal maxima around 37°C (Fields et al. 1987), and have the ability to consume a diverse array of food resources (Savino and Stein 1982; Warren 2009). Largemouth bass are currently distributed throughout 49 states in the U.S. (Noble 2002), with much of this expansion occurring in the 1900s, which coincided with construction of many reservoirs and subsequent stockings (Quinn and Paukert 2009). Largemouth bass reproduction varies based on their geographic distribution and size, but usually occurs between ages 2 and 4 at a size of 250-300 mm total length (Warren 2009), when water temperatures reach 12°C (Ludsin and DeVries 1997). Males

will build nests in shallow (<2.8 m) littoral habitats near complex structure (Hunt et al. 2002) and guard them several weeks following egg hatching (Annett et al. 1996; Cooke et al. 2002). With a wide range of life history traits, largemouth bass have adapted and thrive in a number of different environments.

Largemouth bass have quickly become one of the most important economic and recreational fisheries (Quinn and Paukert 2009), and is one of the most sought after sport fish in the United States (Warren 2009). Tournament fishing has also become more popular in recent years with a substantial amount of research being devoted to the effects of tournament fishing on largemouth bass homing tendencies (Richardson-Heft et al. 2000), nest abandonment (Siepker et al. 2009), and angling mortality (Ridgway 2002). As we move away from traditional regulation studies (Novinger 1987), researchers have begun to focus on improving fishing quality of largemouth bass through habitat improvement projects (Quinn and Paukert 2009).

Table Rock lake has established itself as one of the premiere bass fishing destinations in the U.S. due to high densities and catch rates (CPUE of 129 fish \geq 200 mm/hour of electrofishing) of largemouth bass (Bush 2010). Black bass *Micropterus spp.* in Table Rock Lake are pursued by anglers in much greater numbers than other species (Bush 2010), with the annual economic benefit of angling on Table Rock Lake conservatively estimated at \$67 million (Vitello and Armstrong 2008). Besides largemouth bass, Table Rock Lake also supports a variety of other fish species including bluegill *Lepomis macrochirus*, white crappie *Pomoxis annularis*, longear sunfish *Lepomis*

megalotis, channel catfish *Ictalurus punctatus*, flathead catfish *Pylodictis olivaris*, smallmouth bass *Micropterus dolomieu*, and spotted bass *Micropterus punctulatus*.

Table Rock Lake was listed by the National Fish Habitat Partnership as one of the “waters to watch” in 2012, which is a collection of water bodies that can benefit from strategic habitat conservation effort and planning (fishhabitat.org) and can be used as a model for future restoration projects. Table Rock Lake was a prime candidate for listing because of increases in development around the lake and surrounding watershed which have reduced water quality. Lack of structural habitat in Table Rock Lake was listed as one of the limiting factors in fish production and sustainability. Our research efforts will focus directly on the addition of these augmentation structures, and fish response to these changes.

Since 2007, approximately 2,000 habitat augmentation structures (trees, sumps, and rock piles) have been distributed by the Missouri Department of Conservation with additional structures being added through 2013. All main lake structures were placed at depths of 3-7.5 m (at conservation pool), while cove structures were placed at 1-4 m depths (at conservation pool). Size of individual structures varied based on materials available, however most wood structures were comprised of a single barge load which measured approximately 6 m x 4.5 m x 1.5 m. Rock and stump piles were made of larger loads of up to 38 metric tons. Two thousand habitat structures may seem trivial in a 17,443 ha reservoir. However, because of the structure size and placement within the littoral zone (which makes up a fraction of the total surface area of the lake), the habitat

structures become a substantial addition to the near shore habitat complexity, where many important game species reside (Moyle and Cech 1982).

Objectives

Our objectives were to use radio telemetry to determine the habitat selection, movements, and home range of largemouth bass in a large aging reservoir that had been recently supplemented with augmentation structures. We will determine if the presence of augmentation structure has an influence on how largemouth bass select habitats, or if these structures influence movements and home ranges. Our study was part of a larger, multi-faceted study that began in 2007 with the Missouri Department of Conservation (MDC) monitoring fish response to the augmentation structures. Standardized electrofishing is being used by MDC to measure fish abundance pre and post habitat augmentation. SCUBA surveys are being used by MDC to determine species composition around augmentation structures, and examining the deterioration rate of introduced trees. A creel survey is also being used by MDC to measure angler catch rates before, during, and after habitat augmentation, and to determine angler's opinions about the study. Collectively, these results will provide managers with recommendations on the effects of habitat augmentation structure in a large reservoir. This project will be used as the pilot study for a national program (National Fish Habitat Partnership) looking to improve habitat in aging reservoirs, with the main goal to improve reservoir fish populations with large-scale habitat enhancements (fishhabitat.org).

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Chapter 1

Habitat selection of largemouth bass in Table Rock Lake, Missouri following a large reservoir habitat improvement project

Jason M. Harris, Craig P. Paukert, Shane C. Bush, Michael J. Allen, and Michael J. Sieper

Abstract

Deteriorating reservoir fish habitat is a concern throughout the United States so the Missouri Department of Conservation and cooperators placed approximately 2,000 augmentation structures (trees, stumps, and rock piles) throughout Table Rock Lake, Missouri to improve fish habitat for largemouth bass *Micropterus salmoides* and other species. Our objective was to determine habitat selection of largemouth bass in a reservoir that had recently been supplemented with augmentation structure. Seventy largemouth bass (>380 mm total length) were implanted with radio transmitters and relocated monthly for one year. A discrete choice analysis was used to determine if largemouth bass selected for certain structure, depth, distance to shore, slope, and aspect. We built a set of 12 *a-priori* models to best predict use of habitat by largemouth bass and ranked these models using Akaike's Information Criterion. Results from our top seasonal models suggest largemouth bass select intermediate depths (2-7 m) in areas near shore (<25 m) regardless of diel period and season, however structure was only selected during summer and fall. Largemouth bass selected boat docks at about 1.5 to

4.0 times more than any other structure type (depending on season). During both summer and fall complex augmentation structure was selected at the same rate as natural woody debris and more than any other structure type, except boat docks. Coarse augmentation structure was also selected more than standing timber or rock ledges but at only half the rate of natural woody debris and complex augmentation structure during both summer and fall. When natural structure is limited, our results suggest the addition of augmentation structure may be able to supplement this loss in large reservoirs.

Introduction

The addition of natural or artificial habitat structures in reservoirs is common practice by resource managers to enhance aquatic biodiversity and create high-quality fisheries (Pegg and Chick 2010). These structures may be particularly important as reservoirs age, which may change abiotic and biotic factors of impoundments through time (Kimmel and Groeger 1986). A highly productive trophic upsurge occurs shortly after initial impoundment (Pegg and Chick 2010), which can create a “boom” fishery (Miranda and Bettoli 2010), but is often followed by a trophic depression (Kimmel and Groeger 1986). The trophic depression may affect existing habitat structure that could become covered by layers of fine sediment, reducing habitat heterogeneity throughout the reservoir (Miranda and Bettoli 2010) and lead to a decline in sport fish production (Jenkins 1967). However, agencies and organizations have been working to improve fish habitat in reservoirs with the addition of supplemental habitat structure (Miranda and Bettoli 2010). Working with the National Fish Habitat Partnership (fishhabitat.org) and the Missouri Department of Conservation (MDC), as part of a larger pilot project focused on habitat restoration in reservoirs, we will be evaluating how largemouth bass *Micropterus salmoides* respond to augmentation habitat structures.

The addition of natural or artificial materials has been used to supplement reservoir habitat with differing goals and results. Reservoir managers seek to minimize the effects of reservoir aging and associated loss of habitat structure, meanwhile many reservoirs across the United States approach 100 years post impoundment. Although it may not be possible to return these impoundments to the highly productive fisheries

they were once were, managers may hope to sustain populations in a trophic equilibrium (Hutchinson 1973). Placing supplemental logs and brush shelters in reservoirs was strongly tied to largemouth bass use during the spawning season (Vogele and Rainwater 1975; Hunt and Annett 2002). These woody structures also increased nesting success of largemouth bass, which increased embryo and fry production (Vogele and Rainwater 1975; Hunt and Annett 2002). Growth rates of adult largemouth bass were higher in ponds with supplemental brush piles compared to ponds lacking in brush (Wege and Anderson 1979). However, these augmentation structures can benefit other aquatic species as well. Supplemental gravel beds were used extensively by adult bluegill *Lepomis macrochirus* during the spawning season (Brown 1986) and may provide refuge for important prey species such as crayfish *Orconectes spp.* (Crowder and Cooper 1986). Therefore, a number of aquatic species can benefit from the addition of augmentation structure.

While augmentation structure may increase spawning success and growth; many of these projects are aimed at concentrating or redistributing sport fish to these structures to increase angler success. Angler catch rates increased in smaller impoundments following the addition of augmentation structure (Wilbur 1978; Prince and Maughan 1979; Rogers and Bergersen 1999). However, these results may not be applicable to all systems. In a large Florida impoundment, neither fish abundance nor angler catch rates increased following a large habitat enhancement project (Allen et al. 2003). While habitat enhancements have been utilized extensively over recent years,

more work needs to be done evaluating the effects of augmentation structures on fish habitat use and concentration, especially in larger reservoirs.

Largemouth bass are one of the most important economic and recreational sport fisheries in the United States (Quinn and Paukert 2009). Largemouth bass are currently thriving in 49 states throughout the U.S. (Noble 2002), in part because of reservoir stocking (Moyle and Cech 1982). Because of the wide distribution, popularity among anglers, and high abundance in reservoirs, largemouth bass were selected to evaluate the habitat improvement project in Table Rock Lake, Missouri.

Substantial research has been conducted on habitat selection of largemouth bass in systems lacking augmentation structure. In small impoundments (<250 ha) largemouth bass select for vegetated habitats and large woody debris (Schlagenhaft and Murphy 1985; Annett et al. 1996; Olson et al. 2003; Hasler et al. 2009). Largemouth bass in large reservoirs (>2000 ha) are often associated with aquatic vegetation (Durocher et al. 1984; Karchesky and Bennett 2004; Slipke and Maceina 2007). Our study site is unique in that it is a meso-eutrophic system and relatively devoid of aquatic macrophytes, which provided us with an opportunity to document largemouth bass habitat selection in a relatively unstudied environment. In addition, we could not find any studies on largemouth bass diel or seasonal habitat selection over a 12 month period in large reservoirs. Therefore, our objective was to determine which variables best predict diel and seasonal habitat selection of largemouth bass following a habitat improvement project in a large, aging reservoir.

Augmentation structure in Table Rock Lake was placed proactively to determine if fish would use these areas while natural structure was still present. Our hypothesis is that if largemouth bass select for these structures at a similar rate to naturally occurring structure, these augmentation structures may be used in the future to help restore decreasing natural habitat structure in many reservoirs across the country. We hypothesized largemouth bass will select near shore areas of intermediate depths with woody structure during both day and night. However, we hypothesize that largemouth bass will be located in areas closer to shore during night hours compared to day. Seasonally, we expect largemouth bass to utilize the littoral zone within intermediate depths throughout the year. During summer, fall, and winter we predict largemouth bass will use naturally occurring woody debris, and select complex augmentation structure at similar rates to naturally occurring woody structure. During spring we predict a shift to flat areas near complex structure for nesting opportunities and to provide recently hatched offspring adequate cover (Annett et al. 1996). The addition of augmentation structure in an aging reservoir may provide largemouth bass with a suitable alternative to natural habitat, which continues to deteriorate in many reservoirs.

Methods

Study site

Table Rock Lake is a large (17,443 ha) meso-eutrophic reservoir relatively devoid of rooted aquatic macrophytes, with much of the near-shore habitat complexity comprised of floating boat docks, woody structure, and rocky shorelines. Table Rock

Lake is located in the White River Hills region of the Ozark Plateau along the Missouri-Arkansas border (Figure 1) and was completed in 1959. The reservoir is steep-sided, with over 1,200 km of shoreline, mean depths of 19 m and annual water level fluctuations of 4.5-6.0 m (Novinger 1987). Our study focused on the Kings River Arm of Table Rock Lake, which has steep-sided shorelines (Figure 2), shallower mean depths (12 m; Figure 2), reduced water transparency (1-2 m) and decreased fishing and boating traffic compared to the main reservoir (Bush 2010).

Since 2007, approximately 2,000 habitat augmentation structures (trees, sumps, and rock piles) have been distributed and geo-referenced by the Missouri Department of Conservation (MDC). A proactive approach was taken to enhance reservoir habitat before a complete loss of natural structure occurred. Within approximately 13 km from the confluence of the Kings River Arm there are 88 augmentation structures including: 25 hardwoods, 28 evergreens, 6 evergreen/hardwood mixes, 7 rock piles, 8 stump fields, and 14 rock/stump mixes (Figure 1). However, eventually all structure types were grouped into two broad categories: complex and coarse augmentation structure (see Analysis section below). Main lake structures were placed at depths of 3-7.5 m (at conservation pool), while cove structures were placed at 1-4 m depths (at conservation pool). Size of individual structures varied based on materials available, however most wood structures were comprised of a single barge load which measured approximately 6 m x 4.5 m x 1.5 m and rock and stump piles were made of larger loads, up to 38 metric tons.

Largemouth bass collection and tagging

During April 2011, 60 adult largemouth bass between 380 and 590 mm total length (680-3383 g) were collected for transmitter implantation with pulsed direct current boat electrofishing within an 8 km shoreline reach of the Kings River Arm of Table Rock Lake. Fish were held in a recirculating livewell, weighed, measured, and anesthetized prior to surgical implantation of the radio telemetry transmitters and insertion of t-bar anchor tags (so anglers could identify tagged fish). A mixture of 1 L seltzer to 45 L lake water (1:45) was used for anesthesia, which was combined in a 68.1 L plastic container, and was a sufficient quantity to anesthetize 4-5 fish. Dissolved oxygen levels were maintained above 5 mg/L. An additional ten adult largemouth bass between 380 and 546 mm total length were collected in October 2011 to supplement the original tagged fish, for a total of 70 radio tagged bass within the reservoir.

Surgical procedures were similar to Hart and Summerfelt (1975). We implanted largemouth bass with ATS radio transmitters (model F1840B with a weight of 18g in air, battery life of about 486 days, and a pulse rate of 35 per minute). Radio transmitter weight ranged from 0.5 to 2.6% of fish body weight, which fell slightly outside of the “2% rule” (Winter 1996). However, transmitters up to 12% of fish body weight have been shown to have little effect on swimming performance when implanted intraperitoneally (Brown et al. 1999).

Surgery began by placing the fish ventral side up on a piece of open-cell foam, with a mixture of lake and seltzer water constantly recirculating over the gills. The first 1

cm incision was posterior to the pelvic fins and a 14 gauge needle was inserted to thread the transmitter antenna out of the body cavity posterior to the incision. After transmitter insertion, sutures (monofilament PDS 3-0 FS-1) occurred every 2-6 mm along the incision. After surgery, fish were held in the lake inside a floating holding pen until fully recovered, which was typically 15-30 minutes. If fish had difficulty recovering (>1 hour upside down, little to no gill movement), the tag was removed and inserted into another fish. The entire surgery was completed within 3-5 minutes. Once fully recovered, fish were released near their collection site.

Radio tracking and collection of habitat variables

Radio tracking began May 2011, which was >30 days post transmitter implantation to avoid issues related to erratic behavior known to occur the week following capture and surgery (Mesing and Wicker 1986). Monthly tracking was accomplished within 2-3 days each month from May 2011 through June 2012, when reduced battery life prohibited relocations.

We relocated fish by tracking paths 100-150 meters along the shore to cover the most area, following the river arm up and downstream alternating shorelines. We also randomized our sampling pattern (varied starting location, time, and direction) to minimize bias associated with relocating the same fish at approximately the same time of day each month. We used Lotek SRX 600 telemetry receivers coupled with a 3 or 5-element hand held yagi antenna. The scan cycle was set at 3 seconds so we could detect 1-2 pings before the cycle moved onto the next frequency. We used a combination of

triangulation and direct pinpointing with the antenna to locate tagged fish. When a signal was found we would reduce gain and float over the top of fish until the signal was lost, repeating this process until an exact location could be determined. Because of low secchi depths (<2 m) boats rarely influenced fish locations. However, if fish were close to the boat (<5 m), and a sudden change in location (scared fish) occurred, we recorded the initial location before the move, rather than continue chasing the fish. Based on test tag trials we estimated an average error of 5 m on fish locations.

Our goal was to relocate all 70 tagged fish once a month during the daytime (1 hour after sunrise to 1 hour before sunset). If all 70 fish were not found we expanded our search ≥ 10 km in each direction of the last fish location each month. Because we were also interested if habitat selection differed by diel period, we randomly selected about 20 fish each month to track during the night (1 hour after sunset to 1 hour before sunrise). A smaller sample size was used because of the small time window during night tracking.

Our final tracking event occurred June 2012 following largemouth bass spawning activities. During this time fish were likely nesting in shallow areas (<2.8 m) (Hunt et al. 2002) and guarding their nests several weeks following hatching (Cooke et al. 2002), which made tagged largemouth bass easier to detect in shallow water. Since not all fish were relocated during the last tracking event we performed expanded tracking the following day using 2 additional boats and telemetry receivers. After 60+ hours of additional tracking and over 80% of the reservoir searched, no other fish were located.

Both our first tracking event (May 2011), and final expanded search (June 2012) were not included into the final analysis because available locations were not recorded.

When a tagged fish was relocated we recorded GPS coordinates with a GPS unit with sub-meter accuracy. Water depth was recorded using a portable depth finder. Distance from shore was also recorded using a Bushnell sport 450 laser rangefinder. Any visible structure (floating woody debris, boat docks, standing timber, and rock ledges) within 15 m of a fish location were also recorded. In addition to visible structure, fish were recorded as “using” an augmentation structure (Figure 1) if they were located within a 30 m radius of the GPS-stored augmentation structure coordinates. After recording of the used location variables, three random “available” locations were recorded immediately following, which was used to determine habitat selection (see Analysis section below). A random distance based on the previous months mean largemouth bass day or night movement rate (Chapter 2) and a random bearing (1-360°) were used to determine the “available” locations. If an available point fell onto inaccessible areas (land), the distance was reflected back from the water’s edge until achieving the desired distance.

We were unable to measure aspect and bottom slope in the field, so we calculated these values using ArcMap 10.0 (ESRI 2011). All variables were derived from a depth profile map (Figure 2) using the geostatistical analyst kriging tool in ArcMap 10.0 (ESRI 2011), in which we used multiple 150 m transects ran parallel then perpendicular to the shoreline (unpublished data) collected in July 2011 and April 2012. Water levels

were standardized by adding or subtracting depth measurements to match conservation water levels (full pool). The outline of the shore at conservation pool was broken into 1 m points, each assigned a depth of 0.01 meters to create an edge for our kriging analysis. Using these points in addition to all transects and fish depths (standardized to conservation pool), a total of 206,000 depth point locations were used in the final kriging analysis. From the kriging map of depth we were able to determine bottom slope (degrees) and aspect (north, 337.5-22.5°; northeast, 22.5-67.5°; east, 67.5-112.5°; southeast, 112.5-157.5°; south, 157.5-202.5°; southwest, 202.5-247.5°; west, 247.5-292.5°; northwest, 292.5-337.5°).

Not all locations were included into our analysis. Because of the sedentary nature of largemouth bass (Mesing and Wicker 1986), two consecutive locations in the same coordinate were not sufficient evidence to assume the fish had died. Instead, we determined if fish were located in the same location over three consecutive months, and had been tracked during at least two 24-hour tracking events (Chapter 2) with no apparent movement they were presumed dead and removed from further analysis. However, we continued to record a used location on all fish presumed dead for the remainder of the study, in case the fish was alive and remained sedentary. No fish resumed movement after presumed dead.

Analysis

Discrete choice models (Cooper and Millspaugh 1999) were used to determine habitat selection of tagged largemouth bass. Discrete choice models assume that

individuals receive utility (e.g., increased foraging opportunities, increased growth, decreased probability of predation) from selecting specific habitats over less desirable areas (Cooper and Millspaugh 1999) and have seen increased application for terrestrial (Irwin et al. 2011) and aquatic systems (Bonnot et al. 2011). The utility U of resource i to the individual j takes the form:

$$U_{ij} = B'X_{ij} + e_{ij} = \beta_1x_{1j} + \beta_2x_{2j} \dots \beta_mx_{mj} + e_{ij}$$

where B' is a vector length of m estimable parameters and X is a vector of m measurable attributes of the resource, and e is the error term (Cooper and Millspaugh 1999). In its simplest form discrete choice is basically a mixed effects logistic model, where individual radio tag frequencies were used as random effects.

Discrete choice assumes that resource availability is not constant over time and that individuals do not have equal access to all resources considered available (Cooper and Millspaugh 2001). Many habitat selection studies record availability estimates once throughout the study period (Schlagenhaft and Murphy 1985) or not at all (Lyons 1993). This may be problematic when documenting habitat selection in variable environments such as reservoirs where available resources may change daily. Therefore, we created “choice sets” in which each used fish location was paired with three corresponding available locations, recorded at the same time as the used location.

Availability in our study was defined using the previous months mean largemouth bass movement rate (Chapter 2). Largemouth bass movement patterns can vary by water temperature and diel period (Warden and Lorio 1975; Sammons and

Maceina 2005; Hanson et al. 2007). Therefore, we defined a new area of availability each month for both day and night because of significant differences we observed between monthly and diel movement rates (Chapter 2). We assumed the entire reservoir arm is not available to the fish. Instead, availability was defined by the mean distance all fish traveled each month during the day or night, depending on when the fish was relocated. For example, when fish moved little in February during daylight hours (mean=11 meters/hour; Chapter 2), fish had 132 m of available day habitat to select from (11 m/h *12 hours of daylight).

We developed 12 *a-priori* models based on our knowledge of how largemouth bass select habitats. Multiple continuous and categorical variables (Table 1) comprised the models, which were grouped into 6 candidate model sets: 1)day, 2)night and 3)summer, 4)fall, 5)winter, and 6)spring to examine differences observed between diel and among seasonal periods. Based on the distribution of our used habitat data we assumed non-linear distributions. Multiple distributions (e.g. exponential, square root, squared, etc.) were tested, with the best fit for the model (based on AIC weight) being chosen for each variable. We fit a natural log (ln) form to the distance from shore variable and fit a quadratic form ($\beta_1x_1 + \beta_2(x_2^2)$) centered around its mean ($x_i + x_i^2$) to our depth and slope variables (Franklin et al. 2000). Categorical variables required a dummy variable be designated to compare to all other categorical variables. We designated open water as our dummy variable in habitat structure analysis. For our aspect analysis we combined southeast, south, and southwest aspects and used this as the dummy variable to compare with other aspects.

We used Akaike's information criteria (AIC) corrected for small sample sizes (AIC_c) to rank our candidate models and select the model(s) with the most support based on model weight (Burnham and Anderson 2002). If more than one model was supported ($\Delta \text{AICc} < 2.0$) the parameter estimates were averaged across models using:

$$\widehat{\beta} = \sum_{i=1}^R w_i \widehat{\beta}_i$$

Where $\widehat{\beta}$ is the model averaged estimate of the parameters, w_i is the Akaike weights from the most supported models, and $\widehat{\beta}_i$ is the parameter estimate from model i (Burnham and Anderson 2002). Averaging models may help to reduce bias and increase precision (Burnham and Anderson 2002). From our top model(s) we were able to calculate parameter estimates to determine the direction and magnitude of selection for individual variables. The relative probability of selection at different intervals of use can be calculated from the parameter estimates for each choice set using:

$$P_j(A|i) = \left(\frac{\exp(U_{Aj})}{\sum_{A \rightarrow i} \exp(U_{ij})} \right)$$

where j is the individual, A is the resource in question, and i is any other resources available to that individual (Cooper and Millspaugh 1999).

In order to validate our top model(s) we used a k-fold cross validation to assess model accuracy (Boyce et al. 2002). We randomly selected 80% of our data from each candidate set (e.g., day, night, summer, fall, winter, and spring) to be used as training data, while the remaining 20% were used as test data to validate our models. Training

data were used to re-run the top ranked models. If there was support for more than one model ($\Delta AICc < 2.0$), model averaging was performed. This was repeated five times for the top model in each candidate set. The training data parameter estimates were used with the test data set to calculate the utility of each value in the choice set (1 used and 3 available). Correctly classified sets were those in which the relative probability of use was higher than the sum of the relative probability of available. Averaging the results among the five replicates gave us the model accuracy, which shows the predictive ability of the top model from each candidate set.

Results

Mortality and tag detection

A total of 70 largemouth bass were tagged over the course of our study. Of those tagged, seven (10%) were never relocated after initial implantation. We could confirm an additional 23 (33%) of our fish died or expelled radio tags sometime throughout the 14 month tracking period. However, we were able to collect data on these fish until they were presumed dead, after which time they were removed from further analysis. Confirmed angler harvest occurred on an additional three (4%) fish; while catch and release was reported on ten (14%) tagged individuals.

The number of fish relocated each month ranged from 13 to 42. We relocated an average of 31 fish between June and August 2011 and 16 fish per month from September 2011 through May 2012. The maximum number of times an individual

largemouth bass was relocated was 12, with seven others being relocated at least 10 months out of the year.

Habitat selection

From June 2011 through May 2012, a total of 430 choice sets were used in our analysis. Diel habitat selection was determined using 256 choice sets for day (sunrise – sunset) and 174 choice sets for night (sunset – sunrise) over the 12-month study. We also collected 163 choice sets during summer (June – August 2011), 90 during fall (September – November 2011), 89 during winter (December 2011 – February 2012), and 88 during spring (March 2012 – May 2012).

Largemouth bass diel habitat selection was a combination of all choice sets (June 2011 – May 2012). The diel habitat selection of largemouth bass was best described by model 10 (Table 2), which included depth, distance from shore, and structure for both day and night (Table 3) with Akaike weights of 0.89 (day) and 0.96 (night). Diel models accurately predicted use in 76% of cases during the day and 85% of cases during night. Habitat selection was consistent for both day and night periods with the exception of depth selection. Largemouth bass selected for shallow depths (2-4 m) during night and deeper areas (4-7 m) during daylight (Figure 3), whereas selection of areas near shore (<25 m; Figure 3), and selection of structure was similar between both day and night periods (Figure 3). Largemouth bass selected boat docks at twice the rate of natural woody debris, and three to four times more than all other structure types during both diel periods (Figure 3). Natural woody debris was selected more than all other structures

types except boat docks during both diel periods. During day hours complex augmentation structures were selected 1.5 times as often as standing timber and three times more than rock ledges. However during night hours, selection of coarse augmentation structure was higher, with a selection 2.5 times higher than standing timber and 4.5 times more than rock ledges (Figure 3).

Seasonal habitat selection was determined from all diel choice sets pooled over the three month seasons. Habitat selection could not be determined by diel period for each season due to small sample sizes so all seasonal analysis combined diel periods. We combined three subsequent months into seasonal categories (summer: June, July, August, fall: September, October, November, winter: December, January, February, spring: March, April, May). Seasonal models accurately predicted 71% of cases during summer, 81% during fall, 90% during winter, and 81% during spring. Summer habitat selection was best described by model 10 (Table 4) with an Akaike weight of 0.96, where intermediate water depths (4-7 m) near shore (<25 m) with structure were positively selected (Figure 4). Fall selection was described by model 9 and 10 with Akaike weights of 0.53 and 0.39 respectively (Table 4). The model-averaged estimates found areas of high use in intermediate depths (3-4 m), locations near shore (<25), with structure (Figure 4). Winter selection was best defined by model 6 with an Akaike weight of 0.82 (Table 4), and indicated largemouth bass selected shallower depths (2-3 m) near shore (<15 m; Figure 4). Spring selection was best explained by model 6 with an Akaike weight of 0.82 (Table 4), where largemouth bass selected intermediate depths (3-4 m) and locations near shore (<20 m; Figure 4). The presence of structure was important only for

summer (model 10) and fall (model 9 and 10), during this time structure types selected were similar between seasons (Figure 4). Largemouth bass selected boat docks at about 1.5 to 4.0 times more than any other structure type (depending on season). During both summer and fall complex augmentation structure was selected at the same rate as natural woody debris and more than any other structure type, except boat docks (Figure 4). Coarse augmentation structure was also selected more than standing timber or rock ledges but at only half the rate of natural woody debris and complex augmentation structure during both summer and fall (Figure 4).

Discussion

Habitat selection

Largemouth bass habitat selection was generally consistent between day and night periods, with the only difference being largemouth bass preferred slightly shallower areas during the night. This is likely due to the visual cues required by many *centrarchids spp.* to feed and therefore, may have reduced foraging success at low levels of light intensity (Howick and O'Brien 1983). Despite differences in depth selection, largemouth bass were using similar habitat structures during both day and night periods. While we did not find differences in habitat selection between diel periods, our study was the first to our knowledge that determined both day and night habitat selection and therefore provides a broader view of largemouth bass habitat selection in reservoirs.

Habitat selection of largemouth bass did vary among seasons. Intermediate depths were selected across all seasons; however variability occurred in the range of depths selected. During fall, winter, and spring a narrow range of depths (2-4 m) were used almost exclusively; while during summer a wider range of depths (4-7 m) were selected. This selection of greater depth may have been attributed to high water levels during summer, in which water levels were up to 4.3 m above conservation pool, compared to ± 0.3 m the rest of the year. These high water levels in summer created greater depths throughout the reservoir, even though bass appeared to be using similar distances from shore among seasons. Areas close to shore were also selected at higher rates than those off shore, possibly relating to high concentrations of structure or forage species such as bluegill (Paukert and Willis 2002). These areas may be suitable for largemouth bass feeding in which they spend time ambushing or searching for prey dependent on the type of habitat structure available within the littoral zone (Wanjala et al. 1986; Savino and Stein 1989).

Largemouth bass selection of structure was important but only during summer and fall. As hypothesized, during summer and fall largemouth bass selected natural woody structure, which can provide cover for many invertebrate and fish species (Everett and Ruiz 1993), camouflage for predators (Angermeier and Karr 1984), and is consistent with other studies in Texas that found largemouth bass use of woody debris was high in small (Schlagenhaft and Murphy 1985) and large (Lyons 1993) impoundments. In addition, complex augmentation structures (supplemental evergreen or hardwood tree piles) were selected at similar rates to naturally occurring woody

debris and standing timber, suggesting that supplemental habitat may provide the same benefits to largemouth bass as naturally occurring woody structures.

Largemouth bass did not select for habitat structure in spring despite other studies demonstrating how largemouth bass may prefer nesting near complex structure (Hunt et al. 2002). During spring, water temperatures averaged 19.3°C which coincides with nesting, spawning, and guarding activities in largemouth bass (Annett et al. 1996; Ludsin and DeVries 1997). However, close vicinity to structure also leads to increased brood predation in these areas (Hunt et al. 2002). Radio-tagged largemouth bass in Table Rock Lake appear to prefer areas further from structure which may be related to an instinctive desire to better protect their young.

Largemouth bass did not select for habitat structure during winter. This may be related to colder winter water temperatures which may reduce largemouth bass metabolism (Suski and Ridgway 2009), when they may be feeding less and likely not occupying ambush sites they would normally use to forage, such as areas of high structural complexity (Savino and Stein 1982). Shallow water depths were also used during winter in our study, which contrasts other studies that found very little use of shallow water during winter (Karchesky and Bennett 2004), with the greatest depths being used during the coldest months (Hanson et al. 2007). However, these studies had an abundance of ice cover during portions of their tracking, which may cause varying levels of dissolved oxygen throughout the lake (Hasler et al. 2009). During our study, ice cover never occurred and dissolved oxygen levels likely remained constant throughout

the water column. Therefore largemouth bass were likely targeting shallow areas because of warmer surface temperatures (Gibbons et al. 1972).

Many studies have demonstrated the importance of woody structure for several life stages of largemouth bass (Vogele and Rainwater 1975; Schlagenhaft and Murphy 1985; Hunt and Annett 2002), but very few have documented such high selections of boat docks. Previous studies evaluating floating augmentation structures found higher numbers of bluegill on these structures possibly because these structures provide overhead cover and shade which can be used to avoid predation (Helfman 1979). Another explanation of the high dock use could be the presence of artificial lights, which were found on all boat docks and have been shown to attract different fish (Floyd et al. 1984). Therefore, largemouth bass may be selecting boat docks due to their attraction of forage species such as bluegill. Similar to our study, low abundances of largemouth bass in other reservoirs have been observed near steep natural rocky areas (Sammons and Bettoli 1999), which may demonstrate how other variables such as slope may play an important part in selecting overhead cover types. There was also little use of coarse augmentation structure by largemouth bass during fall and summer which was surprising given that largemouth bass in reservoirs have been found to utilize rocky shorelines and rip-rap areas throughout the year (Sammons and Bettoli 1999).

Largemouth bass strongly selected for boat docks although they rarely occurred on the landscape. Groups of boat docks in the King's River Arm of Table Rock Lake averaged 600 m to the next nearest dock (unpublished data), thus it was unlikely that a

fish would select a boat dock and have another dock available to them which likely inflated our selection indices. In contrast, the opposite occurred with standing timber, which was readily selected, but had very high availability due to wooded shorelines and fluctuating water levels. The high availability of standing timber reduced the overall selection by largemouth bass. Therefore, it is important to consider that while a specific structure may not be selected at a high rate it can still play an important role in the animal's habitat requirements.

Mortality and tag detection

Our estimates of tag loss, mortality, and catch-and-release are consistent with other studies. About 33% of tagged largemouth bass died or expelled their tag over the 14-month tracking period, which was similar to other largemouth bass tracking studies, (e.g., 32% mortality in an Alabama reservoir; Hunter and Maceina 2008) and was consistent with total annual mortality estimates in lakes and reservoirs (30-35% ; Beamesderfer and North 1995; Paukert and Willis 2004). We were unable to locate an additional 10% of our fish even with expanded tracking efforts. This loss of individuals may be attributed to tag failure, fish moving out of the system, or angler harvest. Exact numbers of fish harvested by anglers may be hard to determine because tag return rates vary between 55-65% (Green et al. 1983). However, previous studies found similar results with 11% of tagged individuals never being relocated after initial release (Hunter and Maceina 2008). Based on angler correspondence of our transmitter-tagged largemouth bass that were caught, 77% were released. An angler creel survey conducted between 2006-2007 on Table Rock Lake found an average of 77% of black

bass caught were also released (Bush 2009). Our results follow closely with others who used creel surveys to estimate catch and release rates on black bass.

Our results may have been influenced by detection probability of our radio transmitters. Although we located 90% of our fish at least once throughout the 12 month tracking period, few locations were in depths greater than 4 m. Radio telemetry signals often dissipate in deep water (Cooke et al. 2012), and a pilot study we conducted found the maximum detection range of the transmitter was over 1.5 km when the transmitter was at a depth of 2 m but was less than 100 m when the transmitter was at a depth of 12 m. Certain areas of Table Rock Lake had depths over 30 m. While these depths are likely unavailable to fish during certain times of the year due to thermal stratification, fish may be able to use depths over 12 m at times. However, all augmentation habitat structure was placed in depths less than 12 m so if a fish was in depths greater than 12 m (and we did not detect them) it was not using an augmentation structure. Because of these factors, our inferences on habitat selection should be for fish in 12 m depths or less.

Management implications

Largemouth bass in Table Rock Lake selected for areas of intermediate depth (2-7 m), near shore (<25 m), in the presence of structure. Boat docks and woody debris were the most selected structures, but complex augmentation structure were used at similar rates to naturally occurring woody structure, which suggests these augmentation structures may be able to supplement the loss of habitat occurring in many reservoirs

throughout the United States. While natural and augmentation woody structures were selected at similar rates, the high selection of boat docks warrants further research. In addition to sinking structure types, it may be important to diversify structure types and implement some form of floating augmentation structure for future habitat enhancements. With these data we can provide recommendations to managers on placement of future augmentation structure to best target sport fish, such as largemouth bass.

Results from this study will provide managers with information on largemouth bass habitat use in response to a large scale habitat improvement project. This study is one of the few studies that determined habitat selection of largemouth bass over a 12-month period during both day and night hours in a large reservoir, and may be applicable to other large reservoirs, especially where deteriorating fish habitat is problematic. Because large scale habitat improvement projects are costly and time consuming, managers need science based information to make informed decisions about the design and placement of these structures. Our results suggest the addition of augmentation structure may be able to supplement the habitat needs of adult largemouth bass, as well as other species that rely on woody or rocky habitat to meet their life history requirements.

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Table 1. Covariates used in resource selection models for largemouth bass habitat selection located in Table Rock Lake, Missouri 2011-2012.

Variable	Description	Range	Mean
D	Water depth (m)	0.5 - 30	9
DS	Distance from nearest shoreline (m)	2 - 285	50
S	Slope (degrees)	1 - 83.5	49
ASPECT _N	Northern aspect (degrees)	337.5 – 22.5	N/A
ASPECT _{NE}	Northeastern aspect (degrees)	22.5-67.5	N/A
ASPECT _E	Eastern aspect (degrees)	67.5 - 112.5	N/A
ASPECT _W	Western aspect (degrees)	247.5 - 292.5	N/A
ASPECT _{NW}	Northwestern aspect (degrees)	292.5-337.5	N/A
WD	Woody debris (Presence/absence)	0 - 1	N/A
TMB	Standing timber (Presence/absence)	0 - 1	N/A
DOCK	Floating boat docks (Presence/absence)	0 - 1	N/A
LEDGE	Rock ledge (Presence/absence)	0 - 1	N/A
AUG _{Complex}	Complex augmentation structure (Presence/absence)	0 - 1	N/A
AUG _{Coarse}	Coarse augmentation structure (Presence/absence)	0 - 1	N/A

Table 2. *A-priori* models representing hypothesis illustrating habitat selection of largemouth bass in Table Rock Lake, Missouri, 2011-2012. See Table 1 for variable names and definitions.

Hypothesis	Model structure
1). Increased selection of structure	$=\beta_1(\text{WD}) + \beta_2(\text{TMB}) + \beta_3(\text{DOCK}) + \beta_4(\text{LEDGE}) + \beta_5(\text{AUG}_{\text{Complex}}) + \beta_6(\text{AUG}_{\text{Coarse}})$
2). Increased selection of a mid-range of depths	$=\beta_1(\text{D}) + \beta_2(\text{D}^2)$
3). Decreased selection of increasing distance to shore	$=\beta_1(\text{DS})$
4). Increased selection of a mid-range of slopes	$=\beta_1(\text{S}) + \beta_2(\text{S}^2)$
5). Decreased selection of north facing slopes	$=\beta_1(\text{ASPECT}_N) + \beta_2(\text{ASPECT}_{NE}) + \beta_3(\text{ASPECT}_E) + \beta_3(\text{ASPECT}_W) + \beta_5(\text{ASPECT}_{NW})$
6). Increased selection of a mid-range of depths and decreased selection of increasing distance to shore	$=\beta_1(\text{D}) + \beta_2(\text{D}^2) + \beta_3(\text{DS})$
7). Decreased selection of north facing slopes and Increased selection of mid-range of slope	$=\beta_1(\text{ASPECT}_N) + \beta_2(\text{ASPECT}_{NE}) + \beta_3(\text{ASPECT}_E) + \beta_3(\text{ASPECT}_W) + \beta_5(\text{ASPECT}_{NW}) + \beta_6(\text{S}) + \beta_7(\text{S}^2)$
8). Increased selection of structure and decreased selection of north facing slopes	$=\beta_1(\text{WD}) + \beta_2(\text{TMB}) + \beta_3(\text{DOCK}) + \beta_4(\text{LEDGE}) + \beta_5(\text{AUG}_{\text{Complex}}) + \beta_6(\text{AUG}_{\text{Coarse}}) + \beta_7(\text{ASPECT}_N) + \beta_8(\text{ASPECT}_{NE}) + \beta_9(\text{ASPECT}_E) + \beta_{10}(\text{ASPECT}_W) + \beta_{11}(\text{ASPECT}_{NW})$
9). Increased selection of a mid-range of depths and Increased selection of structure	$=\beta_1(\text{D}) + \beta_2(\text{D}^2) + \beta_3(\text{WD}) + \beta_4(\text{TMB}) + \beta_5(\text{DOCK}) + \beta_6(\text{LEDGE}) + \beta_7(\text{AUG}_{\text{Complex}}) + \beta_8(\text{AUG}_{\text{Coarse}})$
10). Increased selection of a mid-range of depths and selection of structure with decreased selection of increasing distance to shore	$=\beta_1(\text{D}) + \beta_2(\text{D}^2) + \beta_3(\text{WD}) + \beta_4(\text{TMB}) + \beta_5(\text{DOCK}) + \beta_6(\text{LEDGE}) + \beta_7(\text{AUG}_{\text{Complex}}) + \beta_8(\text{AUG}_{\text{Coarse}}) + \beta_9(\text{DS})$
11). Increased selection of a mid-range of slope and selection of structure with decreased selection of increasing distance to shore	$=\beta_1(\text{S}) + \beta_2(\text{S}^2) + \beta_3(\text{DS}) + \beta_4(\text{WD}) + \beta_5(\text{TMB}) + \beta_6(\text{DOCK}) + \beta_7(\text{LEDGE}) + \beta_8(\text{AUG}_{\text{Complex}}) + \beta_9(\text{AUG}_{\text{Coarse}})$
12). Global model	All Parameters

Table 3. Akaike information criterion (AIC) output for top 5 diel models (see Table 2 for model number and variables) explaining habitat selection of largemouth bass in Table Rock Lake, Missouri from June 2011 to May 2012.

Diel period	Model #	Log likelihood	K	AICc	Δ AICc	Weight
Day	10	-164.97	10	350.85	0	0.89
	6	-173.65	4	355.45	4.61	0.09
	12	-161.22	17	359.02	8.17	0.01
	11	-169.59	10	360.08	9.23	0.01
	3	-182.76	2	369.57	18.72	0
Night	10	-95.48	10	212.31	0	0.96
	9	-100.21	9	219.52	7.21	0.03
	6	-107.01	4	222.26	9.95	0.01
	12	-92.79	17	223.51	11.2	0
	2	-110.66	3	227.47	15.16	0

Table 4. Akaike information criterion (AIC) output for top 5 seasonal models (summer: June, July, August, fall: September, October, November, winter: December, January, February, spring: March, April, May) explaining habitat selection of largemouth bass in Table Rock Lake, Missouri. See Table 2 for model number and variables.

Season	Model #	Log likelihood	K	AICc	Δ AICc	Weight
Summer	10	-146.01	10	313.48	0.00	0.96
	11	-149.87	10	321.18	7.71	0.02
	6	-156.64	4	321.54	8.06	0.02
	12	-144.43	17	327.09	13.61	0.00
	3	-162.24	2	328.56	15.08	0.00
Fall	9	-33.58	9	87.41	0.00	0.53
	10	-32.61	10	88.02	0.61	0.39
	12	-25.25	17	93.01	5.60	0.03
	2	-44.01	3	94.31	6.90	0.02
	11	-35.96	10	94.70	7.29	0.01
Winter	6	-19.42	4	47.32	0.00	0.82
	10	-14.24	10	51.31	3.99	0.11
	3	-24.95	2	54.04	6.72	0.03
	12	-5.78	17	54.19	6.87	0.03
	11	-17.51	10	57.85	10.53	0.00
Spring	6	-46.09	4	100.67	0.00	0.82
	10	-41.11	10	105.07	4.40	0.09
	3	-50.77	2	105.68	5.01	0.07
	2	-51.35	3	108.99	8.32	0.01
	9	-45.47	9	111.25	10.58	0.00

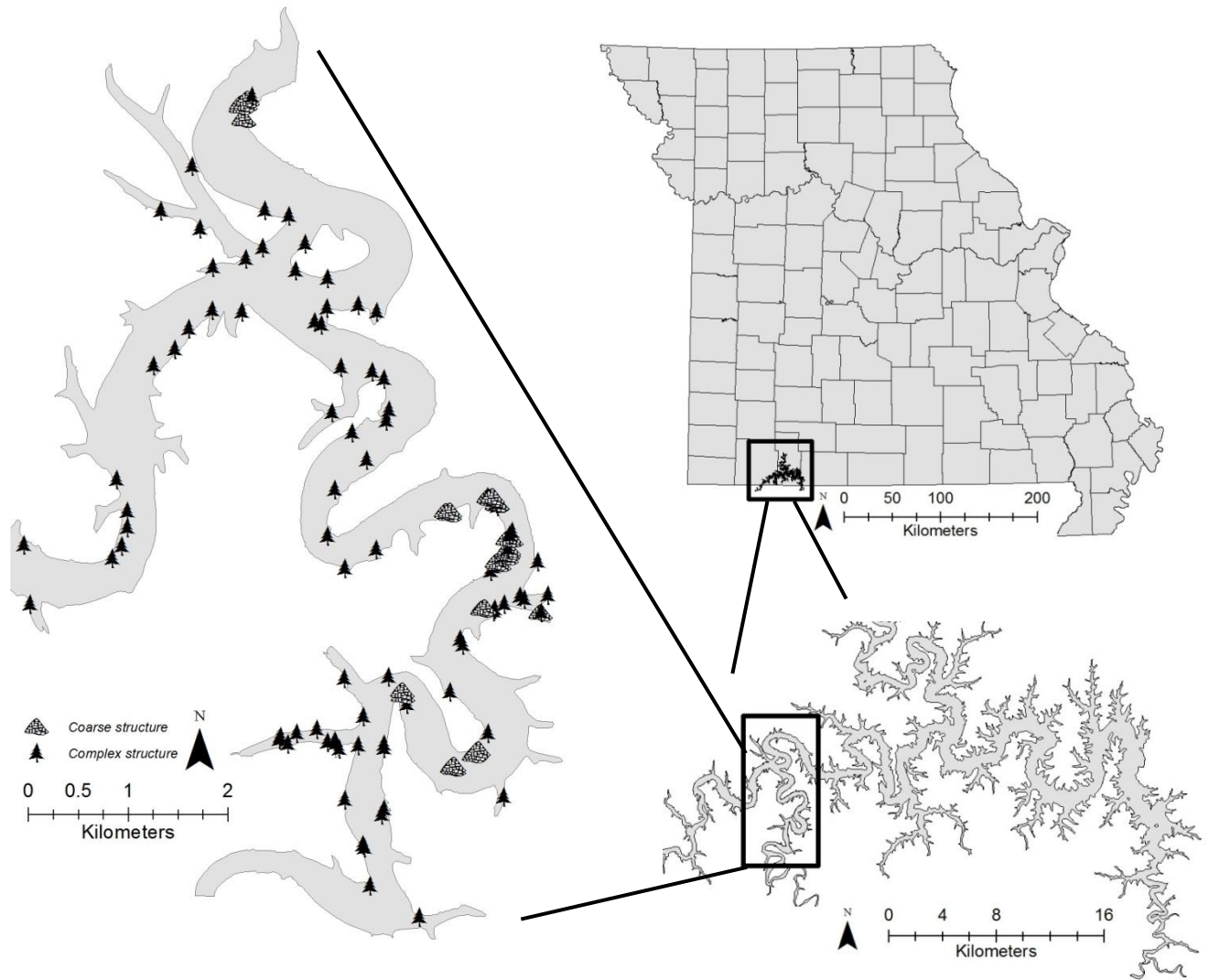


Figure 1. Study site location and distribution of coarse (stump and rock piles) and complex (evergreen and hardwood trees) augmentation structures within the Kings River arm of Table Rock Lake, Missouri.

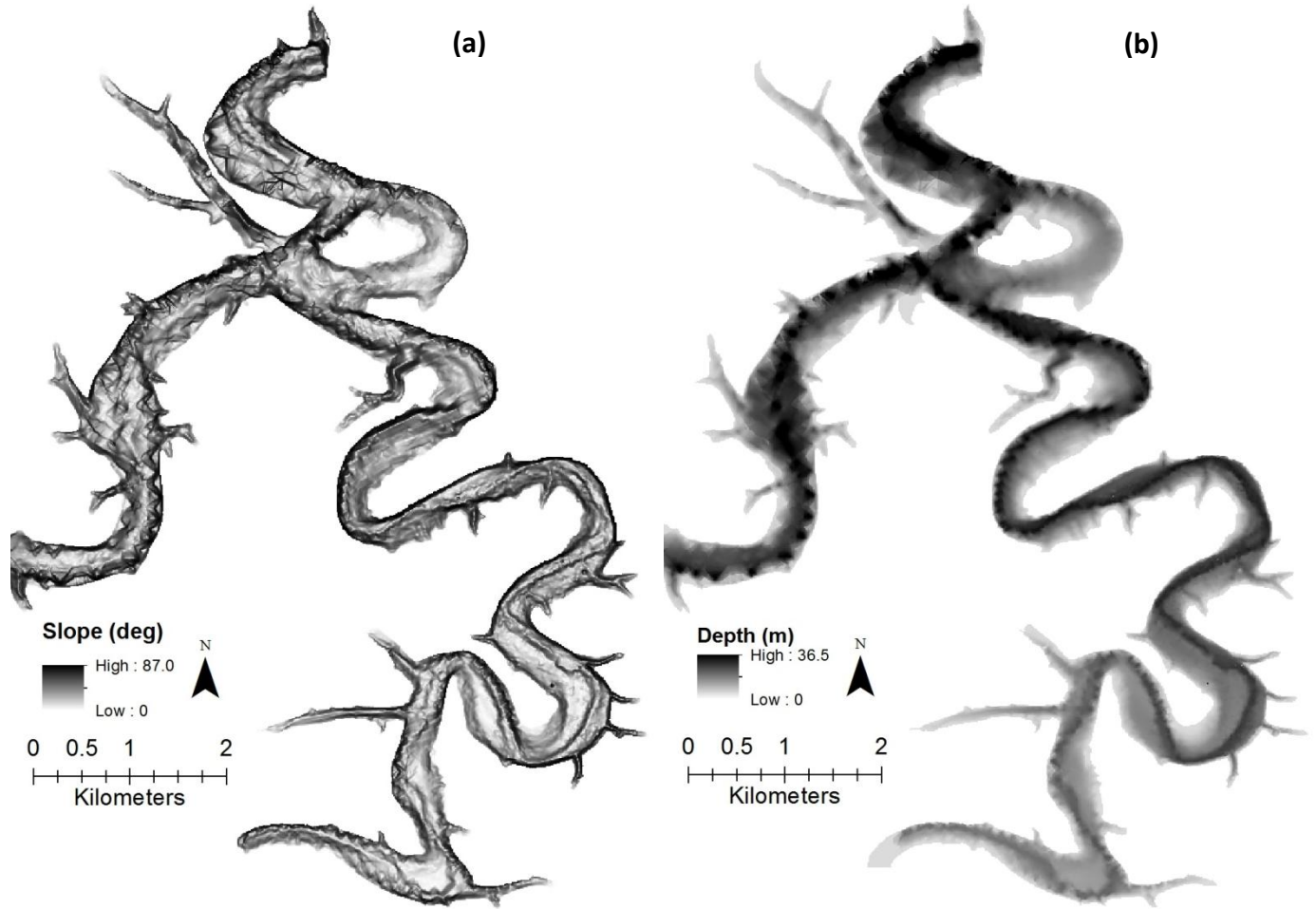


Figure 2. Kriging estimate of slope (degrees) (a) and depth at conservation pool (meters) (b) in the Kings River Arm of Table Rock Lake, Missouri.

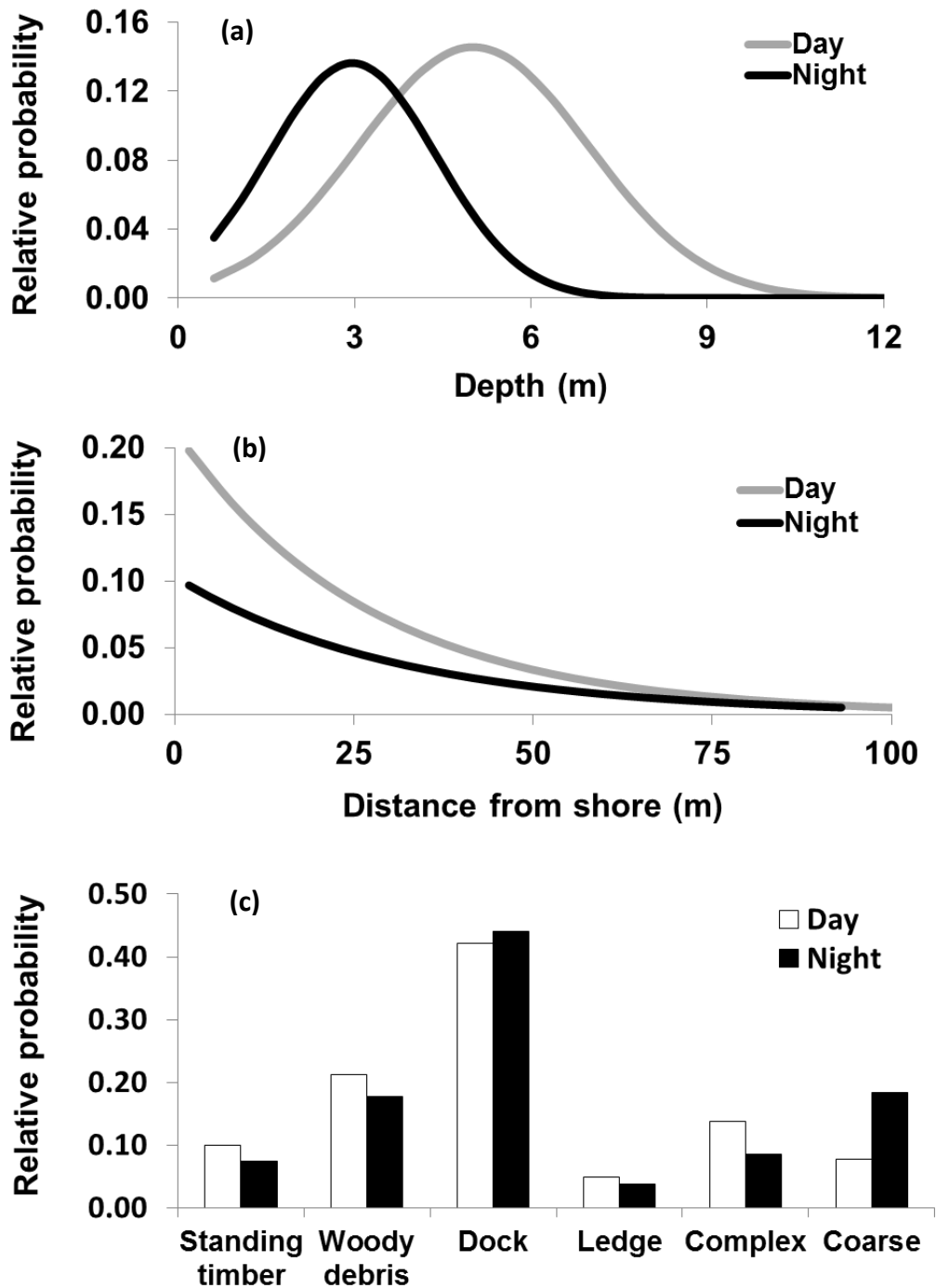


Figure 3. Results from our top model in the diel candidate set showing the relative probability (derived from parameter estimates and odds ratios) of largemouth bass selecting a specific depth (a), distance from shore (b), and structure (c), specifically standing timber, natural woody debris, boat docks, rock ledges, complex (evergreen and hardwood trees) and coarse (stump and rock piles) augmentation structure.

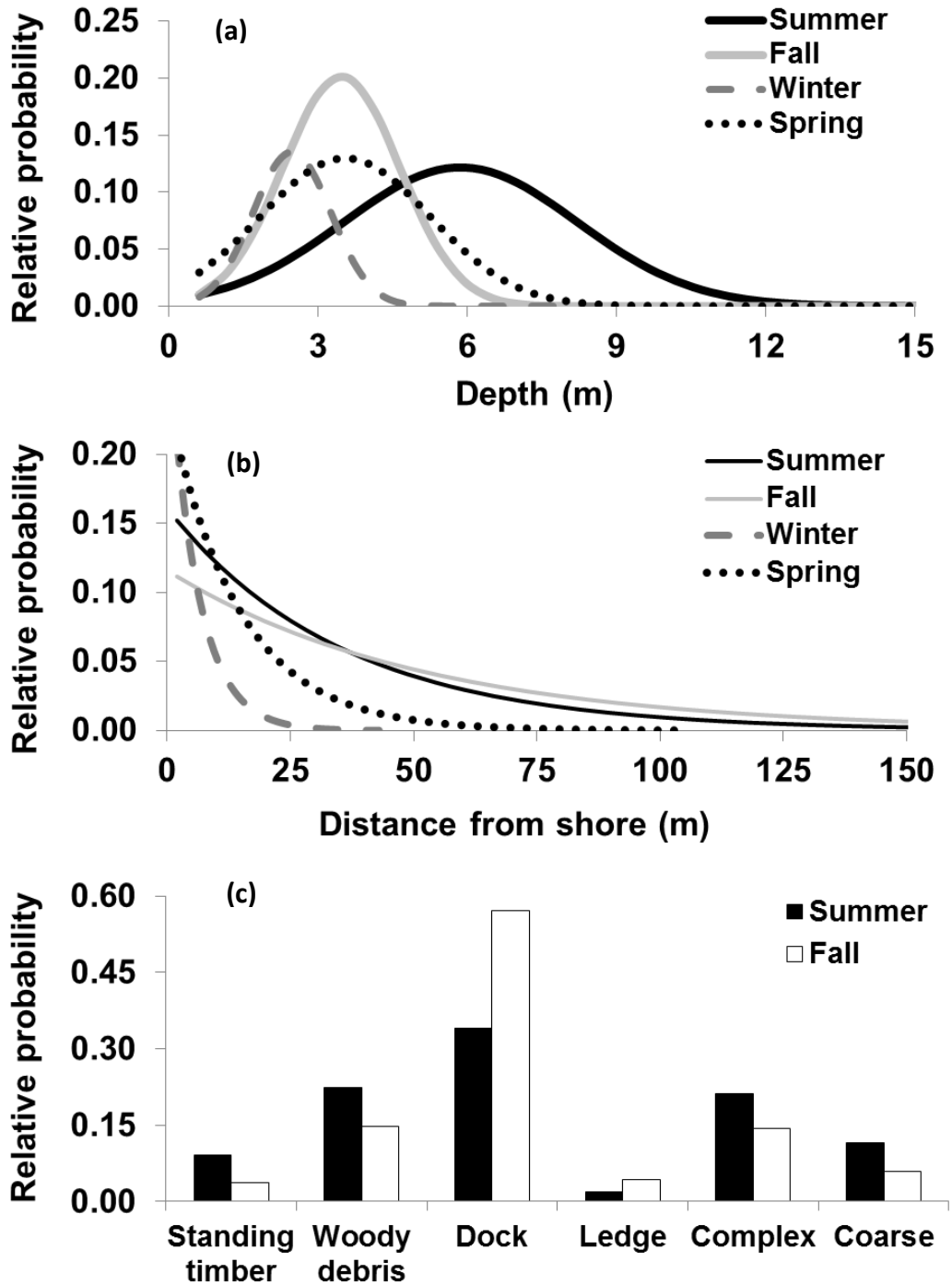


Figure 4. Results from our top models in the seasonal candidate set showing the relative probability (derived from parameter estimates and odds ratios) of largemouth bass selecting a specific depth (a), distance from shore (b), and structure (c), specifically standing timber, natural woody debris, boat docks, rock ledges, complex (evergreen and hardwood trees) and coarse (stump and rock piles) augmentation structure.

Chapter 2

Movement and home range of largemouth bass (*Micropterus salmoides*) in a large Missouri reservoir

Jason M. Harris, Craig P. Paukert, Shane C. Bush, Michael J. Allen, and Michael J. Siepker

Abstract

Largemouth bass movement and home range estimates are limited in large reservoirs. Previous research has been geographically isolated or limited temporally (e.g., weeks to months), and a broader scope is needed to fully understand largemouth bass behavior. We tracked largemouth bass in a large (17,443 ha) Midwestern reservoir that has recently been supplemental with augmentation structures. Seventy radio-tagged largemouth bass (380 - 590 mm total length) were tracked over a 24-hour period once a month for 13 months from May 2011 to May 2012 to determine movement rates, water depth used, distance observed offshore, and an annual 50% core home range. Largemouth bass movement rates ranged from 0 m/h to 652 m/h and were greatest during day hours in June and July (mean=83.5 m/h) and nighttime movement rates were generally 17% (July) to 73% (December) of daytime rates. Movement rates also increased with water level ($r = 0.49$, $P = 0.09$), water temperature ($r = 0.63$, $P = 0.02$), and day length ($r = 0.59$, $P = 0.03$). Largemouth bass water depths ranged from

0.3 m to 22 m and was greatest during day hours in July (mean= 7 m), and lowest during low light and night hours in February (mean=1.9 m). Distance from shore ranged from 0.1 m to 200 m with peaks during July during day hours (mean= 61 m), and lowest during low light hours during May (mean = 8 m). Core (50%) home range estimates averaged 7.9 ha and longer fish had smaller home ranges ($r = -0.64$, $P = 0.03$). However, home range size did not differ in the presence of augmentation structure compared to those without. Our results provide a broader view of largemouth bass that have not been documented in a large, Midwestern reservoir over a 12 month period.

Introduction

Largemouth bass *Micropterus salmoides* are a common sportfish throughout the United States which has substantial economic and recreational value (Quinn and Paukert 2009). Largemouth bass research has focused extensively on management objectives such as regulations (Paragamian 1982; Novinger 1987) and stockings (Boxrucker 1986; Copeland and Noble 1994); while most biological research has concentrated on recruitment, growth and survival (Stone and Modde 1982; Ludsin and DeVries 1997; Garvey et al. 1998), with little research devoted to home range and movements. However, there has been recent work on largemouth bass movements and home range in reservoirs (Sammons and Maceina 2005; Hunter and Maceina 2008), but this was concentrated in the south eastern United States. Movement and behavior seem to vary by system (Minns 1995), so further work is needed in reservoirs, particularly in other regions. We hope to build upon the foundation of these studies to further our ecological understanding of this species by determining factors that can influence movements, while expanding spatially to include data from a large Midwestern reservoir.

Early telemetry studies were constrained by technology of the time with most inferences being made on small (<250 ha) water bodies (Warden and Lorio 1975; Winter 1977; Fish and Savitz 1983). Advances in technology have developed smaller transmitters with longer battery life and thus the opportunity to conduct movement studies over longer time periods. Recent studies have begun to utilize this technology for long term (12 month) tracking studies. However, these studies of largemouth bass

movements have produced contradictory results. Hunter and Maceina (2008) found similar movement rates between spring, summer, and fall, with lower movement rates to occur during winter, while day movement was always greater than night movement across all seasons. Sammons and Maceina (2005) found the highest movements occurred during fall and the lowest 24-hour movement occurred during day hours. These studies comprise the bulk of largemouth bass movement research and were completed in the same region (Alabama and Georgia), and thus further work is needed to expand the geographic scope of these movement projects to gain a broader understanding of largemouth bass movements.

Fish movement is likely influenced by numerous biotic and abiotic factors. Diel movement is likely influenced by visual cues largemouth bass utilize to initiate foraging activity (Howick and O'Brien 1983), which leads to increased movement during day and low light hours with decreased movement during night. Differences in diel movement also exist in spotted bass *Micropterus punctulatus* (Horton and Guy 2002) and white crappie *Pomoxis annularis* (Guy et al. 1994), but no differences were observed in bluegill *Lepomis macrochirus* (Paukert et al. 2004). Monthly movement rates may be driven by abiotic variables such as water temperature (Mesing and Wicker 1986), leading to higher movement rates during warm summer months. Rogers and Bergersen (1995) found higher movement rates of largemouth bass during drawdown (low water periods) compared to full pool, however no differences in movement rates were observed in northern pike *Esox lucius* during drawdown compared to full pool. Our goal was to build

on the limited existing knowledge of largemouth bass movements in large reservoirs to identify the factors that influence these movements.

Home range estimates, like movement rates, vary substantially between systems which is likely due to size of the water body (Minns 1995), forage supply (Savitz et al. 1983), and fish size (Minns 1995). Multiple freshwater fish species home range size increases with fish length (Minns 1995). In similar sized reservoirs considerable differences in core home range (50%) estimates have been recorded for largemouth bass. Hunter and Maceina (2008) found largemouth bass home range estimates to range from 1.6 to 94.2 ha annually, while Sammons and Maceina (2005) found home range estimates were substantially smaller (0.31 to 10.45 ha) and did not vary by season. Similar results have been found in other centrachids such as bluegill where 50% estimates ranged from less than 0.01 to 27.2 ha (Paukert et al. 2004). Our objective is to determine home range estimates for largemouth bass in Table Rock Lake to build upon the existing research to determine factors that may influence home range size.

Table Rock Lake has recently supplemented reservoir habitat with additional augmentation structures (tree, rock, and stump) in select reservoir reaches, which may influence fish movement. Movement rates of yellow perch *Perca flavescens* compared between a simple and complex lake revealed movement rates were always higher in lakes devoid of complex structure (Radabaugh et al. 2010). Following a lake wide removal of aquatic macrophytes largemouth bass movement more than doubled during day hours (Sammons et al. 2003). Based on these studies we predict the addition of

augmentation structure in Table Rock Lake may decrease the movements and home ranges of largemouth bass.

Surprising little research has been conducted on largemouth bass movement and home range in large reservoirs, particularly outside of the south eastern U.S. We hypothesize largemouth bass movement rates will be highest during daylight hours and during dawn and dusk, with little movement during night. We predicted monthly movement rates will vary throughout the year following closely with water temperature. We also hypothesized that, largemouth bass will occupy a smaller home range when augmentation structures are present compared to those occupying areas devoid of augmentation structures.

Methods

Study site

Table Rock Lake, completed in 1959 is a large (17,443 ha) reservoir located along the southwest Missouri-Arkansas border and has a mean depths of 19 m, over 1,200 km of shoreline, secchi depths of 3.0 m, and annual water level fluctuations of 4.5-6.0 m (Novinger 1987). Our study focuses on the Kings River Arm (about 1,000 ha) of Table Rock Lake, which has a shallower mean depth (15 m; Chapter 1), and decreased fishing and boating traffic than the main reservoir (Bush 2010). The Kings River arm also has an average secchi of 1.7 m, mean chlorophyll a concentration of 8.4 $\mu\text{g/l}$ and mean total phosphorus concentration of 19 $\mu\text{g/l}$ (LMVP.org) and thus would be considered meso-eutrophic (Carlson 1977). Within approximately 13 km from the confluence of the Kings

River Arm there are 88 augmentation structures, composed of tree, stump, and rock piles. Main lake structures were placed at depths between 3-7.5 m (at conservation pool), while cove structures were placed at 1-4 m depths (at conservation pool). Size of individual structures varied based on materials available, however most wood structures were comprised of a single barge load measuring approximately 6 m x 4.5 m x 1.5 m. While rock and stump piles were made of larger loads, up to 38 metric tons.

Approach

During April 2011, 60 adult largemouth bass between 380 and 590 mm total length (680-3383 g) were collected for transmitter implantation with shoreline pulsed DC boat electrofishing within an 8 km reach of the Kings River arm of Table Rock Lake. Fish were held in a recirculating livewell until they were weighed, measured, and anesthetized prior to surgical implantation of the radio telemetry transmitters. Sex could not be determined for all fish and was removed from all analysis. An additional ten adult largemouth bass between 380 and 546 mm total length were collected in October 2011 to supplement the original tagged fish, bringing the total to 70 radio tagged bass within the reservoir.

We implanted largemouth bass with ATS radio transmitters (model F1840B with a weight of 18g in air, battery life of about 486 days, and a pulse rate of 35 per minute) using procedures similar to Hart and Summerfelt (1975). Radio transmitter weight ranged from 0.5 to 2.6% of fish body weight, and only 4 fish were above the “2%” transmitter to fish weight ratio proposed by Winter (1996). However, transmitters up to

12% of fish body weight have little effect on swimming ability (Brown et al. 1999). A mixture of 1 L seltzer to 45 L lake water was used for anesthesia, and was able to anesthetize 4-5 fish. Dissolved oxygen levels were maintained above 5 mg/L.

Once anesthetized, fish were placed ventral side up on a piece of open-cell foam, with lake and seltzer water recirculating over the gills. A 1 cm incision posterior to the pelvic fins, was cut and a 14 gauge needle was inserted posterior to the incision to thread the transmitter antenna out of the body cavity. After transmitter insertion, monofilament sutures (PDS 3-0 FS-1) occurred every 4 mm along the incision. After surgery, fish were held in the lake inside a floating holding pen until fully recovered, which was typically 15-30 minutes. If fish had significant difficulty recovering (>1 hour upside down, little to no gill movement), the tag was removed and inserted into another fish. The entire surgery was completed within 3-5 minutes excluding anesthetizing and recovery. Once fully recovered, fish were released in a central location from their collection site.

Radio tracking began May 2011, which was >30 days following transmitter implantation which was sufficient to allow fish time to resume normal activities after surgery (Mesing and Wicker 1986). Every 30 days from May 2011 through May 2012, our goal was to track 20 fish per month over a 24-hour period using a Lotek SRX 600 telemetry receiver and 3 or 5-element hand held yagi antenna. We relocated fish every 3-4 hours, providing 6-8 relocations per fish, per 24-hour tracking event. We used a combination of triangulation and direct pinpointing with the antenna to locate tagged

fish. When a signal was found we would reduce gain and float over the top of fish until the signal was lost, repeating this process until an exact location could be determined; when fish were near shore, direct sightings were often used. We estimated an average error of 5 m based on visual sightings and test tag trials. When a tagged fish was relocated we recorded water depth and a GPS coordinate using a GPS unit with sub-meter accuracy.

In addition to fish location and depth we measured a number of additional abiotic variables during tracking. Water temperature was measured to the nearest tenth of a degree Celsius using an YSI meter (model 30) at 3 m below the surface every 8 hours during 24 hour tracking. Water level was retrieved from the Army Corp of Engineers website following 24 hour tracking. Day length was determined based on time of sunrise and sunset from Branson, Missouri, about 30 km from the Kings River Arm of Table Rock Lake.

Analysis

Fish movements between subsequent relocations were determined using ArcMap 10.0 (ESRI 2011) automated measuring tools to determine the shortest over water distance between two locations. Movement rates were expressed in meters per hour (m/h) a fish traveled between subsequent relocations. We determined distance from shore using our fish locations and an outline of Table Rock Lake at conservation flood pool. The outline of Table Rock Lake was broken into points every 1 m using the Geospatial Modeling Environment “point distances,” which determine the nearest

neighbor and estimates a distance between fish locations and shoreline points (Beyer 2012).

We grouped fish by month and diel periods, which were divided into day (two hours after sunrise to two hours prior to sunset), night (two hours after sunset to two hours before sunrise), and low light (two hours before and after sunrise and two hours before and after sunset). Dawn and dusk were combined into a low light category because small sample sizes for dawn and dusk individually made analysis difficult. We used a repeated-measures analysis of variance (ANOVA) (Proc MIXED; SAS Institute Inc. 2008) to determine if mean movement rate differed by month and diel periods using individual largemouth bass as the repeated measure. We also used a repeated measures ANOVA to determine if water depth (m), and distance from shore (m) at the fish location differed by months and diel periods including interactions of these variables. Because all data was positively skewed a \log_{10} transformation was used prior to analysis to meet the assumption of normality and equal variances (Brown and Guy 2007). We identified the covariance structure as first-order autoregressive (AR(1)) because we assumed fish relocations recorded closer together were more correlated than those recorded farther apart in time (Rogers and White 2007). If significant differences were observed a least-squares means procedure was used to identify where these differences occurred. Spearman's rank correlation (Kwak and Peterson 2007) was used to relate movement rates to abiotic factors (water temperature, day length, and water level). We used the mean movement rate of all fish each month (n=13) compared to the mean value for each abiotic variable for the days we tracked fish during that month (n=13).

Home range estimates were determined by daily locations (Chapter 1) and a subset of 24-hour tracking locations, which consisted of the first, middle, and last location (12 hours between relocations) in an effort to improve independence between relocations. We estimated the annual home range so fish that had been tracked over an entire year were required (located in May 2011 and May 2012). Home ranges were created using a fixed kernel estimate with a least square cross validated smoothing parameter because they have been shown to provide the least-biased estimates (Seaman et al. 1999). A 50% and 95% estimate were created to compare to other studies (Sammons and Maceina 2005; Hunter and Maceina 2008), however our results could only be compared to studies that also used fixed kernel home ranges (Cooper and Millspaugh 2001). Only the 50% home range estimates were used in the final results because 95% estimates drew a substantial (over half in some cases) amount of home range over land, and did not provide an accurate estimate of the home range. The 50% home range represents the core home range or high use areas fish utilize throughout the year (Hooge et al. 2001). Small portions of the home range that fell onto dry land were removed from analysis (Rogers and White 2007). Fish length was compared to 50% home range estimates using a Spearman's rank correlation (Kwak and Peterson 2007), to determine if fish size influenced home range size. Because we hypothesized fish length may influence home range size we designated this variable as our covariate in the analysis of covariance (ANCOVA; Hansen et al. 2007), in which we determined if the mean 50% home range differed between fish that had augmentation structure present in their home range and those that did not.

Results

We relocated from 11 to 19 fish (mean=15) each month from May 2011 to May 2012. Of the fish relocated each month we recorded 6-8 relocations per fish per 24 hour tracking event. Four of our fish were located at least 10 months, while an additional 10 fish were located at least 6 months over the 13 month tracking period. A total of 46 different fish were relocated and used in the final movement analysis.

Largemouth bass movement was variable throughout the 13 month study and averaged 28.6 m/h (range = 0 m/h to 652 m/h). Mean movement rates were not consistent among diel periods across months (month and diel period interaction; $F = 1.82$, $df = 24,973$, $P = 0.009$). However, removing the low light diel period from the analysis subsequently revealed consistent movement patterns for day and night periods (no month and diel period interaction; $F = 1.46$, $df = 12, 968$, $P = 0.135$). Movement rates were greatest during the daytime across all months ($F = 38.17$, $df = 1, 78.5$, $P < 0.001$), with night movement rates ranging from 17% (July) to 73% (December) of day movement rates (Figure 1). Movement rates varied by month with the highest movement rates during June and July, and the lowest movement rates during February and April ($F = 4.55$, $df = 12, 223$, $P < 0.001$; Figure 1). When we analyzed the lowlight period separately, July had the highest movement rates and February had the lowest ($F = 3.48$, $df = 12, 247$, $P < 0.001$; Figure 1).

Environmental variables may have also influenced largemouth bass movement rates. Water levels ranged from 278.62 m in May 2012 to 283.49 m in May 2011 (normal

flood pool = 278.89 m; Figure 2). We found some support that largemouth bass movement rate increased with water level ($r = 0.49$, $P = 0.09$; Figure 3). However, when we removed the high water event (May–July 2011) from the analysis we found little support that water level influenced movement rates ($r = 0.20$, $P = 0.58$). Mean water temperature which ranged from 7.5°C in February to 30.7°C in July (Figure 1) was positively correlated to mean monthly movement rates ($r = 0.63$, $P = 0.02$; Figure 3). While very similar results were found between mean monthly movement rates and day length ($r = 0.59$, $P = 0.03$; Figure 3). However, day length and water temperature were highly correlated ($r = 0.84$, $P < 0.001$).

Mean water depth at largemouth bass locations was also variable throughout the 13 month study and averaged 3.5 m but ranged from 0.3 m to 22 m. Mean water depths at fish locations were not consistent among diel periods across months (month and diel period interaction; $F = 3.67$, $df = 24,956$, $P < 0.001$). However, removing the day diel period from the analysis revealed consistent depth patterns for low light and night periods across months (no month and diel interaction; $F = 0.96$, $df = 12,462$, $P = 0.491$) and that water depths at fish locations did not differ between low light and night depths ($F = 0.3$, $df = 1,109$, $P = 0.582$). Mean night and low light water depths varied less than 1.2 m between any months (Figure 4). Depth at fish locations varied by month with the greatest depths used during June and July, and the shallowest depths used during February ($F = 3.25$, $df = 12,203$, $P < 0.001$). When we analyzed depth at fish locations only for the daytime period, the greatest water depth used was in July, with the shallowest depths used in February ($F = 9.77$, $df = 12, 160$, $P < 0.001$; Figure 4).

The average distance offshore averaged 22.8 m but ranged from 0.1 m to 200 m. Largemouth bass mean distance offshore was not consistent across diel periods and months (month and diel period interaction; $F = 2.09$, $df = 24,927$, $P < 0.001$). However, removing the day diel period from the analysis revealed consistent distances offshore for low light and night periods across months (no month and diel interaction; $F = 0.96$, $df = 12,448$, $P = 0.487$) and that distance offshore did not differ between low light and night distances offshore ($F = 0.07$, $df = 1, 101$, $P = 0.794$). Mean night and low light distances offshore varied less than 5 m between any months, with the exception of July in which night and lowlight differed by 16 m (Figure 4). Distance offshore also varied by month with the greatest distance offshore during July, and the closest distances to shore during May 2011 ($F = 3.82$, $df = 12,182$, $P < 0.001$). When we analyzed day distances offshore separately the greatest distance offshore was in July, with the closest distance to shore in May 2011 ($F = 5.08$, $df = 12, 159$, $P = <0.001$; Figure 4).

A total of 12 fish were used to estimate 50% annual home ranges. The number of times an individual fish was relocated averaged 38 and ranged from 29-49. Largemouth bass 50% annual home range estimates varied from 0.72 ha – 29.5 ha (mean = 7.9 ha) and decreased with increased fish length ($r = -0.64$, $P = 0.03$). All three fish over 430 mm total length had home ranges less than 3 ha, whereas fish under that size had home ranges from 0.7 to 29.5 ha (Figure 5). Home range size did not differ between fish that had structure in their home range estimates compared to fish that did not ($F = 0.03$, $df = 1$, $P = 0.869$), even after accounting for fish length in the ANCOVA (structure and length interaction $F = 0.04$, $df = 1$, $P = 0.838$).

Discussion

Our study builds on the limited information on largemouth bass movement and home range in larger reservoirs. Largemouth bass movement rates in Table Rock Lake peaked during summer months, which was similar to a study by Hunter and Maceina (2008) in an Alabama reservoir, but was over two times greater than mean summer movement rates Sammons and Maceina (2005) found in an Georgia reservoir. A steep drop in summer movement of largemouth bass was observed in a central Florida lake by Mesing and Wicker (1986) when temperatures neared 30°C, which may suggest a maximum thermal tolerance. However, the highest monthly water temperature in Table Rock Lake (30.7°C) coincided with the highest movement rates in our study, suggesting water temperatures up to 30°C may not impede movements in this Midwestern reservoir. The low winter movement of largemouth bass observed in our study was similar to others (Hanson et al. 2007; Hunter and Maceina 2008), likely due to a reduced metabolism (Suski and Ridgway 2009), which in turn reduces the need to forage and the associated burst movement largemouth bass may utilize to capture prey (Savino and Stein 1989). However, similar to other studies (Mesing and Wicker 1986; Hunter and Maceina 2008) we also found low movement occurred during early spring (April), when water temperatures averaged 19.7°C. Water temperatures that range from 14.6° to 21.0°C have been related to largemouth bass spawning and nest guarding (Ludsin and DeVries 1997), which may reduce movement rates. Largemouth bass in Table Rock Lake also experienced an increase in movement rates during March and May, which could

have been related to pre and post spawn feeding (Adams et al. 1982). Low movement during spawning and increased movement pre and post spawning were shown in other centrarchids such as white crappie (Guy et al. 1994). Therefore, using the 13 months of largemouth bass movement data we can build upon the limited (short term) movement studies available.

Greater largemouth bass movement rates were associated with increased water levels in Table Rock Lake. However, our study experienced a high water event (2.2-4.6 m above full pool) from May through July 2011 while the remaining 10 months were within 0.5 m of full pool. The high water event also coincided with the highest observed water temperatures and day length, which can also influence movement rates (Demers et al. 1996). When high water months were removed from the analysis, we found little evidence water level influenced movement rates. In contrast, Rogers and Bergersen (1995) found higher movement rates of largemouth bass during drawdown compared to full pool. From the limited variation in water level throughout much of the year, it is hard to determine whether this variable was actually driving largemouth bass movement rates in Table Rock Lake.

Largemouth bass movement was highest during day and lowlight (dawn and dusk) hours and lowest during night. Similar patterns of high day and low night movement were found for largemouth bass in other systems (Demers et al. 1996; Hanson et al. 2007; Hunter and Maceina 2008) and for other centrarchids. Populations of smallmouth bass (Bevelhimer 1995) and spotted bass (Horton and Guy 2002) also

exhibited higher movement rates during periods of daylight and decreased movement during night hours, which is consistent with the hypothesis that visual cues may dictate largemouth bass movements. High movement rates may be related to light penetration into the water column, which largemouth bass may use to forage efficiently (Howick and O'Brien 1983), which would be limited during nighttime.

Largemouth bass in Table Rock Lake occupied locations with deeper water during daylight hours throughout the summer months. However, this period also coincided with high water levels and it is likely the greater water depth locations were an artifact of water level and not necessarily preference for greater depths. Instead, the use of deeper areas may be attributed to locations observed further from shore during July. Largemouth bass venturing farther from the shore may indicate a shift in prey preference from littoral species (e.g., sunfish *Lepomis spp.*) in spring and early summer to pelagic prey (e.g., gizzard shad *Dorosoma cepedianum*) during mid-summer (Storck 1986).

Our study found variable core home range estimates between fish but average estimates (7.9 ha) were similar to largemouth bass in a Georgia reservoir with seasonal mean estimates of <6 ha (Sammons and Maceina 2005), but lower than an Alabama reservoir where largemouth bass core home ranges averaged 26 ha (Hunter and Maceina 2008). Other studies on largemouth bass home range estimates were limited by very small sample sizes (1-17 fixes per fish; Lyons 1993) and differing methods of home range calculation (e.g., grid cell method; Ridgway 2002), convex polygons; Fiah

and Savitz 1983; Savitz et al. 1983), and mark-recapture; Lewis and Flickinger 1967). Variability in home range estimates could also be attributed to some largemouth bass seeming to display transient behavior, while other remain sedentary (Moody 1960). Besides methods and behavior, largemouth bass home range can be influenced by a number of biological factors including: fish length (Minns 1995), forage supply (Savitz et al. 1983), or lake productivity (Hunter and Maceina 2008).

Our study contrasted the work by Minns (1995) who found a positive relationship between fish length and home range size. In Table Rock Lake, the larger fish had smaller core home ranges, suggesting these larger fish may have sufficient foraging opportunities (Savitz et al. 1983) from a much smaller area. Hunter and Maceina (2008) suggested productivity may explain why largemouth bass home range in an Alabama reservoir were larger and had lower productivity than home ranges in a similar sized reservoir in Georgia (Sammons and Maceina 2005). Productivity may explain why home range of largemouth bass in the Kings River, a meso-eutrophic arm of Table Rock Lake were smaller than home ranges observed in a less productive, oligo-mesotrophic impoundment in Alabama (Hunter and Maceina 2008). Productivity and foraging opportunity may also explain why largemouth bass home ranges were not smaller near augmentation structure; these fish may have adequate foraging opportunities in many areas of the lake that also include natural habitat structure.

Our results may have been influenced by the detection probability of our radio transmitters. Radio telemetry is less effective in deep water (Cooke et al. 2012), and a

pilot study determined that radio signals could be detected within 100 m when the transmitter was at a depth of 12 m and over 1.5 km when transmitters were <2 m (unpublished data). In a similar sized reservoir, largemouth bass were never found inhabiting water depths greater than 13 m (Hunter and Maceina 2008), even though they had the ability to detect fish in depths up to 25 m. Table Rock Lake does have depths in excess of 30 m, and it is possible largemouth bass could utilize these areas but inferences from our study may be limited to fish using water less than about 10-15 m.

The results from our study provide movement and home range data for a popular sportfish in a Midwestern reservoir. Existing literature on largemouth bass movements and home range is limited geographically and in scope. Our results build on the limited existing literature to show spatial differences in largemouth bass behavior exist. Our results broaden the ecological understanding of largemouth bass in reservoirs and point out the need for future research to continue expanding the ecological concepts that drive largemouth bass movements and behavior across their current range.

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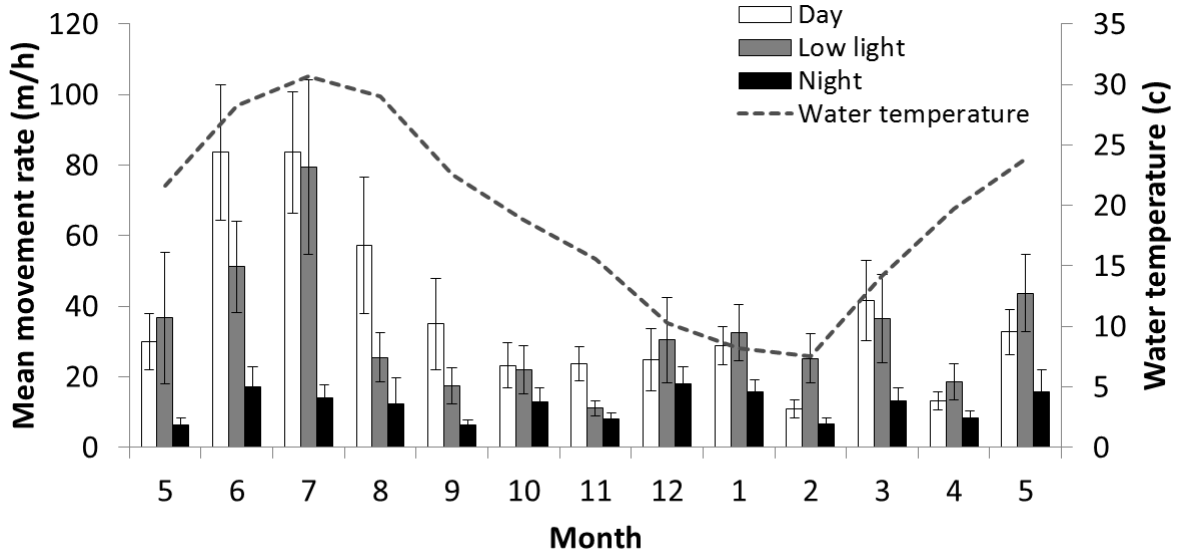


Figure 1. Largemouth bass mean movement rates (m/h) in Table Rock Lake, Missouri from May 2011 through May 2012 by diel period. Low light (gray bars) represent dawn and dusk (2 hours before and after sunrise/sunset) movement rates. Error bars represent one standard error.

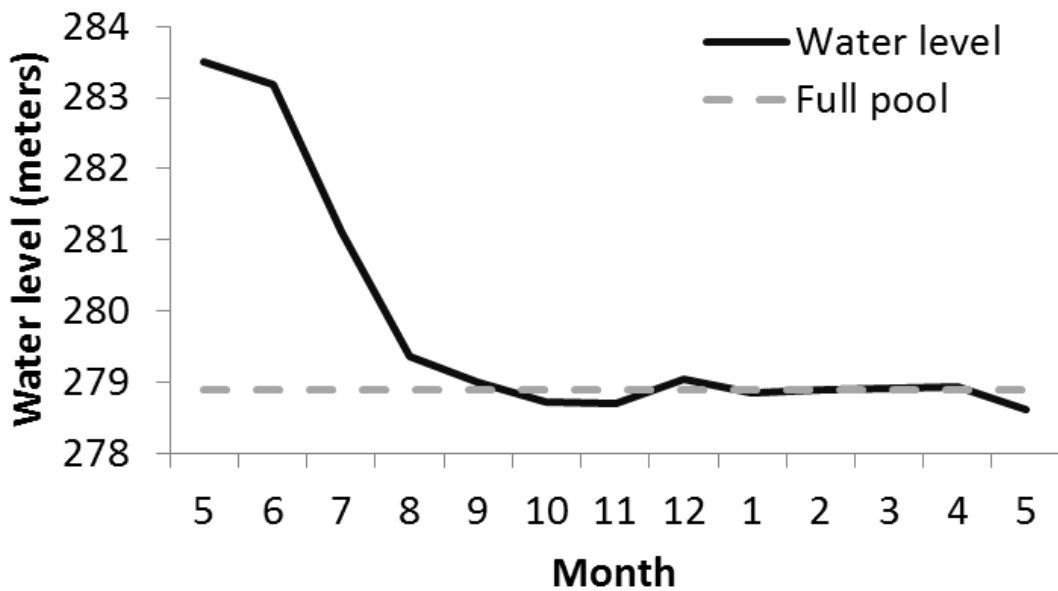


Figure 2. Observed water level (solid black line) compared to conservation pool (dashed gray line) from May 2011 through May 2012 in Table Rock Lake, Missouri.

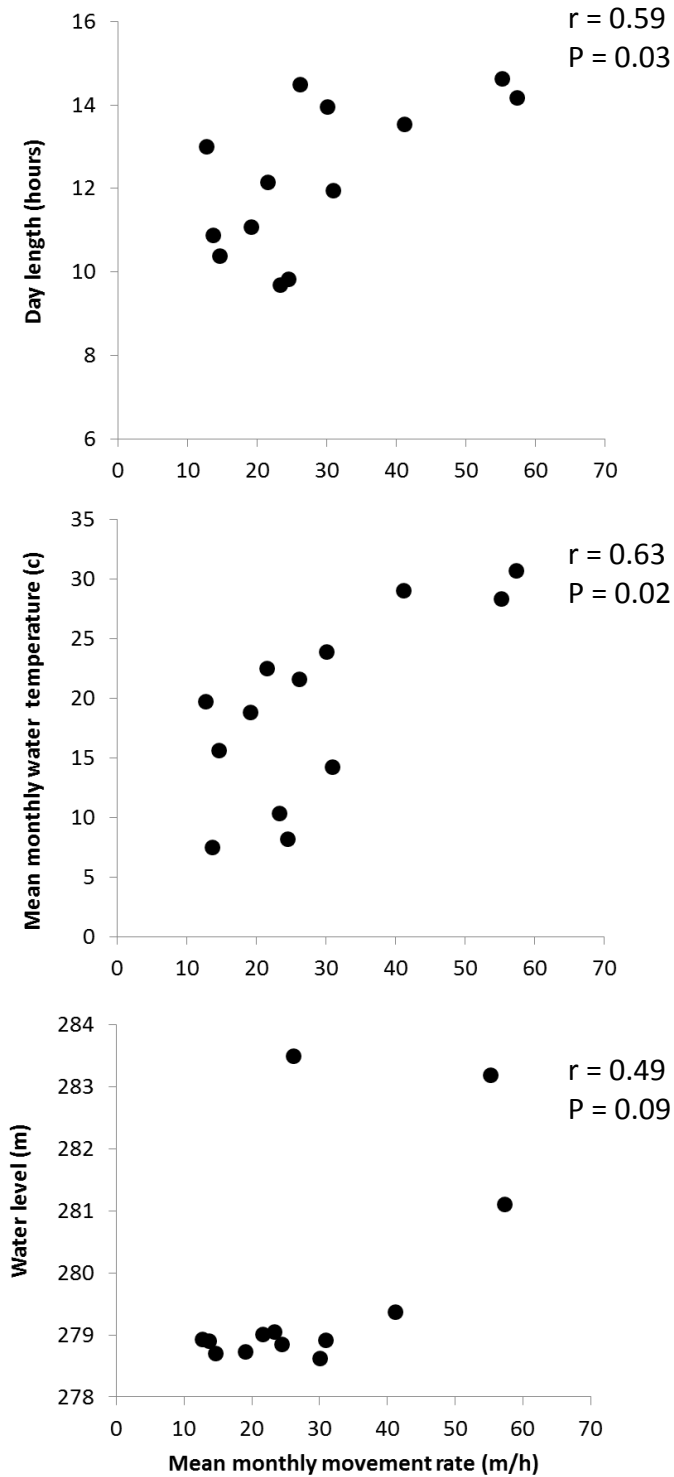


Figure 3. Mean monthly movement rate (meters per hour) compared to day length (hours) (top panel), mean monthly water temperature (Celsius) (middle panel), and water level (meters) for largemouth bass in Table Rock Lake, Missouri from May 2011 to May 2012.

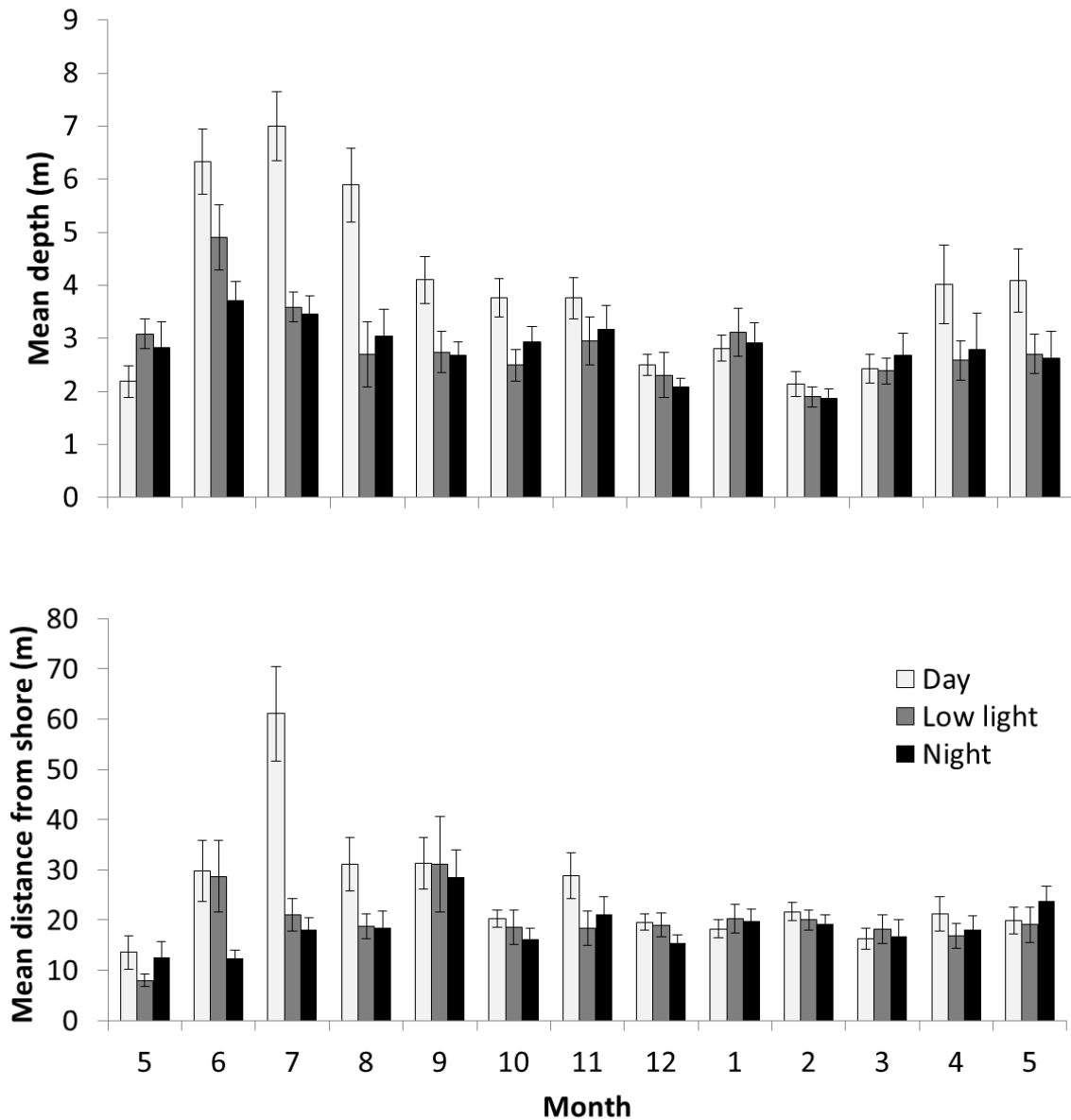


Figure 4. Mean water depth occupied (top panel) and mean distance from shore occupied by largemouth bass (bottom panel) in Table Rock Lake, Missouri from May 2011 through May 2012 by diel period. Low light (gray bars) represent dawn and dusk (2 hours before and after sunrise/sunset) locations. Error bars represent one standard error.

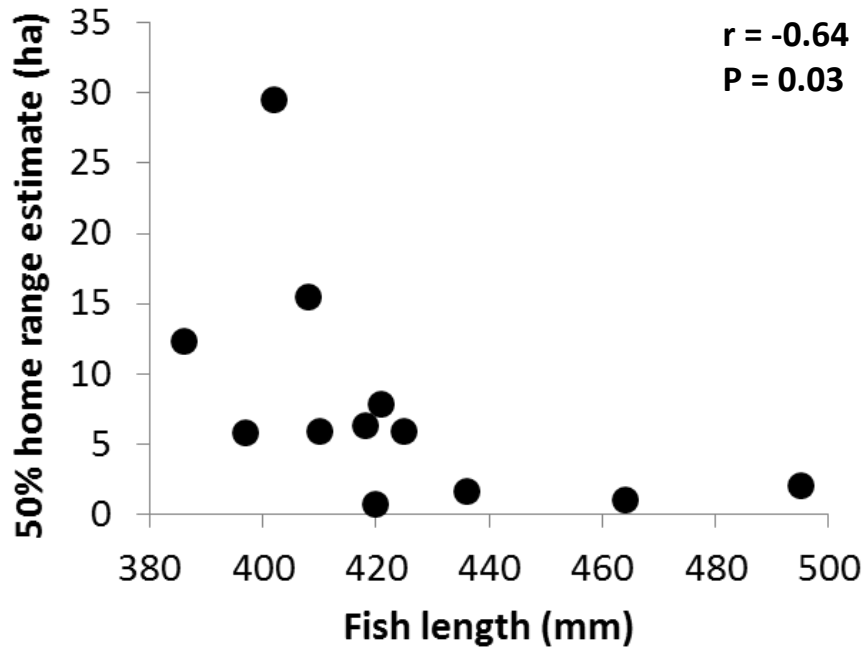


Figure 5. Annual core home range (50% least square cross validated fixed kernel estimate) compared to fish length for 12 largemouth bass in Table Rock Lake, Missouri from May 2011 to May 2012.

Conclusions

Our results can be used to prioritize future habitat structure placement within Table Rock Lake and other large reservoirs. Our research suggested that largemouth bass use depths between 2-7 m, in areas less than 25 m from shore (Chapter 1). Using a range of depths and distances from shore, opposed to a single value will allow managers to account for water level fluctuations by placing structures at a range of depths in the event of a low or high water. Largemouth bass were also selecting for complex (woody) augmentation structure at a similar rate to naturally occurring woody structure. Therefore, these augmentation structures may be able to supplement natural woody structure that is deteriorating in many reservoirs. The mean 50% home range estimate (7.9 ha) can provide managers with an area in which to distribute new structures (Chapter 2). Placement of future habitat augmentation structure can be described by three key points:

- Depths between 2-7 m
- 1-25 m from shore
- Distributed every 7.9 ha

These recommendations may be used to prioritize future habitat augmentation structure placement by identifying depths and areas near shore that are likely used by largemouth bass, while using the home range estimates to account for the spatial distribution of future augmentation structures. However, more work could be done assessing the effects of floating structure on fish habitat use and if this type of structure

would be useful in future habitat enhancement projects. This information provides managers with a guide to better manage their efforts, especially when targeting largemouth bass.

Managers and cooperators at Table Rock Lake took a pro-active approach to enhance and sustain one of the country's most popular fishing destinations. This was one of the first projects which took a lake-wide approach to habitat enhancement. Decreasing reservoir habitat continues to be problematic in many reservoirs across the United States. We hope this information coupled with the efforts of the Missouri Department of Conservation may be used not only to enhance fish production and slow the effects of reservoir aging in Table Rock Lake, but help to improve reservoir conditions and fish production across the U.S.

The results from this study have focused on furthering the ecological understanding of largemouth bass movement, home range, and habitat selection. However, this information can be used to meet additional objectives as well. Using our study in combination with efforts of the Missouri Department of Conservation, we can provide an example of a large-scale habitat enhancement project and how fish respond to these changes. The National Fish Habitat Action Plan is working to protect, restore, and enhance aquatic communities. We hope through the efforts of our research and the collaboration of the Missouri Department of Conservation we have met these goals in an important Midwestern reservoir.

Appendices

Appendix 1. Top discrete choice diel model parameter estimates for variable (β), with standard error (SE) and odds ratios (e^x).

Diel period	β	Estimate	SE	e^x
Day	D	-0.1308	0.0437	0.8774
	D2	0.0025	0.0046	1.0025
	DS	-1.3067	0.2560	0.2707
	TMB	-0.1457	0.4268	0.8644
	WD	0.6094	0.4266	1.8393
	DOCK	1.2938	0.4177	3.6466
	LEDGE	-0.8488	0.5026	0.4279
	COMPLEX	0.1682	0.5599	1.1832
	COARSE	-0.3918	2.1741	0.6758
Night	D	-0.2454	0.0759	0.7824
	D2	0.0122	0.0108	1.0123
	DS	-0.7771	0.2587	0.4597
	TMB	0.2058	0.5140	1.2285
	WD	1.0834	0.5435	2.9547
	DOCK	1.9943	0.6070	7.3471
	LEDGE	-0.4527	0.5841	0.6359
	COMPLEX	0.3482	1.8387	1.4165
	COARSE	1.1218	1.5813	3.0704

Appendix 2. Top discrete choice seasonal model parameter estimates for variable (β), with standard error (SE) and odds ratios (e^x). Fall values were model averaged, reporting the unconditional standard errors for this model. See Table 1 for variable definitions.

Season	β	Estimate	SE	e^x
Summer	D	-0.0911	0.0475	0.9129
	D2	-0.0020	0.0051	0.9980
	DS	-1.0982	0.2523	0.3335
	TMB	-0.2646	0.4516	0.7675
	WD	0.6389	0.5130	1.8944
	DOCK	1.0566	0.4962	2.8766
	LEDGE	-1.8217	0.6215	0.1618
	COMPLEX	0.5828	1.0345	1.7910
	COARSE	-0.0232	1.7046	0.9771
Fall	D	-0.3648	0.2680	0.6943
	D2	0.0193	0.0288	1.0195
	DS	-0.7649	0.6919	0.4653
	TMB	0.5379	1.3612	1.7125
	WD	1.8897	1.0699	6.6178
	DOCK	3.2456	1.3744	25.6785
	LEDGE	0.6628	1.4356	1.9402
	COMPLEX	1.8639	2.0360	6.4488
	COARSE	0.5058	3.4237	2.6494
Winter	D	-0.8160	1.4744	0.4422
	D2	-0.0145	0.1403	0.9856
	DS	-1.8572	1.1121	0.1561
Spring	D	-0.1719	0.0899	0.8421
	D2	0.0153	0.0127	1.0154
	DS	-1.2425	0.6086	0.2887

Appendix 3. Table of largemouth bass implanted with radio transmitters, showing the radio frequency, length (millimeters), weight (grams), floy tag number, date implanted, and the number of relocations per fish per month over the 14 month habitat selection study (Chapter 1) in Table Rock Lake, Missouri.

Radio frequency	Length (mm)	Weight (g)	Floy tag	Date implanted	Monthly relocations
164016	510	2164	6200	4/15/2011	4
164037	500	1937	6201	4/15/2011	2
164056	420	1080	6202	4/15/2011	14
164074	386	735	6203	4/15/2011	13
164097	421	1052	6204	4/15/2011	11
164115	436	1270	6205	4/15/2011	0
164136	397	857	6206	4/15/2011	1
164157	400	844	6207	4/15/2011	1
164176	488	1828	6208	4/15/2011	1
164193	397	894	6209	4/15/2011	9
164216	484	1451	6210	4/15/2011	1
164236	479	1769	6211	4/15/2011	4
164257	590	3384	6212	4/15/2011	5
164276	400	844	6213	4/15/2011	4
164296	390	762	6214	4/15/2011	1
164314	510	2259	6215	4/15/2011	4
164336	401	889	6216	4/15/2011	0
164355	436	1080	6217	4/15/2011	13
164376	383	726	6218	4/15/2011	7
164396	385	739	6219	4/15/2011	5
164417	413	998	6220	4/15/2011	3
164435	475	1429	6221	4/15/2011	3
164464	410	839	6222	4/15/2011	11
164486	409	903	6223	4/15/2011	1
164507	390	694	6224	4/15/2011	0
164525	393	794	6243	4/15/2011	3
164546	515	1982	6226	4/15/2011	1
164566	383	694	6227	4/15/2011	0
164587	380	680	6228	4/15/2011	5
164608	459	1551	6229	4/15/2011	7
164627	382	757	6230	4/15/2011	7
164646	405	948	6232	4/15/2011	0
164665	408	916	6233	4/15/2011	3
164684	384	689	6234	4/15/2011	4
164706	393	785	6236	4/15/2011	4
164726	405	880	6238	4/15/2011	3

164746	400	871	6239	4/15/2011	6
164765	418	1016	6240	4/15/2011	12
164785	402	848	6241	4/15/2011	8
164803	421	993	6242	4/15/2011	3
164829	411	943	6244	4/15/2011	4
164845	420	943	6245	4/15/2011	2
164873	429	1080	6246	4/15/2011	1
164894	494	1882	6248	4/15/2011	5
164916	397	853	6249	4/15/2011	2
164936	406	803	6250	4/15/2011	2
165024	425	1052	6251	4/15/2011	10
165044	400	1039	6252	4/15/2011	3
165064	422	898	6253	4/15/2011	2
165085	408	807	6254	4/15/2011	11
165108	429	1166	6255	4/15/2011	0
165125	495	1932	6256	4/15/2011	10
165143	403	812	6257	4/15/2011	3
165164	444	1306	6258	4/15/2011	2
165185	405	894	6259	4/15/2011	5
165213	484	1678	6260	4/15/2011	3
165235	392	776	6262	4/15/2011	3
165253	405	798	6263	4/15/2011	2
165273	466	1474	6264	4/15/2011	5
165304	464	1520	6266	4/15/2011	12
165360	397	N/A	6870	10/13/2011	5
165473	401	N/A	6869	10/13/2011	0
165423	403	N/A	6865	10/13/2011	0
165493	546	N/A	6866	10/13/2011	5
165448	453	N/A	6867	10/13/2011	9
165527	434	N/A	6868	10/13/2011	9
165384	380	N/A	6863	10/13/2011	0
165402	458	N/A	6864	10/13/2011	0
165314	384	N/A	6861	10/13/2011	0
165337	495	N/A	6862	10/13/2011	0
