## AN ABSTRACT OF A THESIS

## SEASONAL DISTRIBUTION AND THERMAL ECOLOGY OF MUSKELLUNGE IN MELTON HILL LAKE, TENNESSEE

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Master of Science in Biology

Radio telemetry was used to determine the seasonal distribution and thermal preferences of muskellunge (*Esox masquinongy*) in Melton Hill Lake, a mainstem reservoir on the Clinch River in east Tennessee. Muskellunge have been stocked into Melton Hill Lake since 1998, creating a popular sport fishery on the southern edge of this species' native range. Unlike many reservoirs, Melton Hill Lake offers a thermally heterogeneous environment resulting from cold hypolimnetic discharges from an upstream dam and warmwater discharged from a coal-fired electric generation plant. Due to the wide range of water temperatures with suitable dissolved oxygen throughout much of the year, Melton Hill Lake differs from other systems in which muskellunge have been studied using biotelemetry. Adult muskellunge ($n = 30$) with internal temperature-sensing radio tags were tracked biweekly from March 2010 to March 2011. Maps of monthly and seasonal fish distributions were created using 50% and 95% kernel density estimates with ArcGIS software. Seasonal differences in temperature selection, depth, and distance to the nearest shore were tested using mixed-model ANOVA. Fish in summer and early fall were widely distributed between the steam plant and Melton Hill Dam. In the spring, late fall, and winter they tended to occupy a small reach downstream of the stream plant. Tagged fish occupied shallow, inshore water during spring, fall, and winter, and deeper, offshore water during summer. Mean tag temperatures varied among seasons and were highest in summer, intermediate in spring and fall, and lowest in winter. When the greatest range in water temperatures was available (summer 2010; 7.1 – 33.3 C), tagged fish selected water between 20 to 25°C. During winter, they aggregated in the warmest water available at the thermal plume discharged from the steam plant. The abundance and composition of forage fish was sampled seasonally to assess the possible role of forage availability on the distribution of tagged muskellunge. Although catch rates of potential forage fish species varied, suitable forage appeared to be available throughout the reservoir in all seasons and the abundance (or lack thereof) of forage did not appear to influence habitat or temperature selection.

# SEASONAL DISTRIBUTION AND THERMAL ECOLOGY OF MUSKELLUNGE IN MELTON HILL LAKE, TENNESSEE

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**CERTIFICATE OF APPROVAL OF THESIS**

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by

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# CHAPTER 1

# INTRODUCTION

The muskellunge *Esox masquinongy* is a piscivorous fish species whose native range is restricted to the upper Mississippi River, Ohio River, and St. Lawrence River drainages of North America (Crossman 1978). In Tennessee, it is native to both the Tennessee River and Cumberland River drainages (Etnier and Starnes 1993). However, dam construction and habitat loss resulted in the extirpation of muskellunge in most Tennessee watersheds. Since 1998, the Tennessee Wildlife Resources Agency (TWRA) has stocked muskellunge fingerlings into Melton Hill Lake in east Tennessee at an average annual rate of 1.3 fish/ha, creating a unique sport fishery on the southern edge of this species' natural range.

Muskellunge are considered a valuable sport fish in North America (Menz and Wilton 1983; Crossman 1986) and are avidly sought by anglers due to their ability to reach large sizes (Casselman et al. 1999). The minimum length limit for muskellunge in Melton Hill Lake was raised from 1,118 to 1,270 mm total length (TL) in March 2010. This new regulation could potentially cause an increase in fishing pressure because (1) the reputation or potential of a lake to produce large fish is one criterion used by muskellunge anglers in selecting where to fish (Margenau et al. 1994; Casselman 2007); and (2) the new 1,270 mm length limit is what most muskellunge anglers consider trophy size (Margeneau and Petchenik 2004).

Melton Hill Lake anglers are especially successful during winter and early spring when muskellunge and forage fishes congregate in the vicinity of the discharge plume from the Tennessee Valley Authority's (TVA) coal-fired Bull Run Steam Plant (hereafter referred to as “the steam plant”). The attraction of temperate fish to heated discharges in winter is well documented (e.g., Barkley and Perrin 1971; Benda and Proffitt 1973; Cooke et al. 2004). Aside from winter, the distribution of muskellunge in Melton Hill Lake is largely unknown to anglers and biologists alike. Many researchers in more northern latitudes have documented the influence of seasons on habitat selection and general movement patterns of muskellunge (Miller and Menzel 1986a; Younk et al. 1996; Gillis et al. 2010). Understanding temporal shifts in habitat use by fish is useful information when assessing and managing fish populations, their habitats, and human users (Nielsen 1999).

Seasonal distributions and habitat use by fish are influenced by available habitat and the type of water body (Miller and Menzel 1986a; Wagner and Wahl 2007; Gillis et al. 2010). Being poikilothermic animals, fish are not able to internally maintain their body temperature; instead, they actively seek favorable water temperatures in thermally heterogeneous systems (Snucins and Gunn 1994; Baird and Krueger 2003). Thus, temperature acts as a directive factor in habitat selection (Wootton 1999). Although several factors can affect movements and distribution of muskellunge, water temperature has been suggested as an important factor affecting their movements (Minor and Crossman 1978; Dombeck 1979) and distribution in thermally-altered systems (Younk 1982). Forage is another factor that has been shown to influence habitats (and temperatures) piscivorous fish occupy (e.g., Bevelhimer 1996; Thompson 2006). The temperature preferred by a fish in a stable environment with suitable forage should represent the temperature that optimizes growth, survival, reproduction, and general fitness (Jobling 1981; Coutant 1987; Kelsch 1996).

Many researchers have studied muskellunge in northern rivers and lakes using biotelemetry (e.g., Miller and Menzel 1986b; Strand 1986; Younk et al. 1996); however, much less is known about muskellunge in southern U.S. systems. Melton Hill Lake, with its thermally heterogeneous environment, provides an excellent opportunity to study the distribution and thermal ecology of muskellunge in a southern U.S. impoundment. Muskellunge implanted with telemetry tags in previous studies did not experience higher mortality (Miller and Menzel 1986a; Strand 1986; Younk et al. 1996; Eilers 2008) or slower growth (Minor and Crossman 1978; Miller and Menzel 1986a; Strand 1986; Eilers 2008) as a result of being tagged. Good growth rates by tagged fish suggested the tagging process had little effect on muskellunge feeding behavior or prey capture efficiency (Eilers 2008).

The objectives of this study were to: 1) describe the distribution of adult muskellunge in Melton Hill Lake over the course of one year; 2) determine seasonal thermal preferenda of muskellunge; 3) evaluate the influence of temperature on habitat use; and 4) examine the possible influence of forage fish availability on habitat and temperature selection by muskellunge.

# CHAPTER 2

# STUDY AREA

Melton Hill Lake is a 2,303-ha mainstem reservoir on the Clinch River in Anderson, Knox, Roane, and Loudon counties in east Tennessee (Figure 1). The dam was built in 1963 by the TVA for hydropower and navigation and is located at Clinch River kilometer 37 (CRkm, measured from its confluence with the Tennessee River). Melton Hill Lake has 310 km of shoreline and a maximum depth of 18.3 m. The reservoir is narrow, with much of the lake less than 0.5-km wide. It is considered mesotrophic and the water level fluctuates ~1.5 m annually. Melton Hill Lake extends 92 km upstream to Norris Dam at CRkm 129. Hypolimnetic water is discharged through two hydroelectric turbines at Norris Dam, creating a cold tailwater that extends approximately 23 km below the dam. Auto venting turbines and an aerating weir dam below Norris Dam maintain dissolved oxygen concentrations in the tailwater above 6 mg/L (Yeager et al. 1987). Melton Hill Lake becomes more lacustrine downstream of the Highway 61 Bridge in Clinton, TN (CRkm 106); upstream of this bridge the Clinch River is riverine and comprised of extensive riffles and shoals.

No major tributaries enter the Clinch River in Melton Hill Lake. The cold hypolimnetic release from Norris Dam coupled with the short average hydraulic retention time of 12-d maintains cool water temperatures and suitable (>4.0 mg/L) dissolved oxygen concentrations over a wide range of water temperatures in Melton Hill Lake each summer (Peterson and Negus 2000). A density underflow often occurs in the spring and summer near CRkm 80 when the cold inflowing water from Norris Dam reaches the main basin of Melton Hill Lake and plunges below the warm surface waters (Bettoli 2005).

With its narrow width and short hydraulic retention time, Melton Hill Lake also exhibits a distinct temperature gradient. However, this thermal gradient is not uniform due to the influence of the steam plant, located approximately half way down the reservoir at CRkm 77. Bettoli (2005) recorded winter surface water temperatures in January 2000 of 8°C at CRkm 106, 20°C at CRkm 77, 13°C at CRkm 71 and 8°C at CRkm 53. Generally speaking, the longitudinal temperature gradient in Melton Hill Lake is very dynamic and varies with the discharges at Norris and Melton Hill dams, steam plant operations, and ambient air temperature. Dissolved oxygen concentrations below 4 mg/L were rarely observed in Melton Hill Lake in a previous study (Bettoli 2005); therefore, fish are theoretically able to choose from a wide range of temperatures in well oxygenated water throughout the year.

# CHAPTER 3

# METHODS

## Fish Collection and Tag Implantation

Muskellunge were collected between January and March 2010 using boat-mounted DC electrofishing gear (Smith-Root, Type VI-A electrofisher). The sampling crew consisted of a driver and two dip-netters. Shorelines were electrofished and additional effort was directed at the steam plant thermal plume and fallen trees. Temperature-sensing radio tags from Advanced Telemetry Systems (ATS) were surgically implanted into 30 adult muskellunge ranging in length from 720 to 1,240 mm TL (Table 1). Each tag broadcasted a unique frequency within the bandwidth range of 30.000 and 31.999 MHz. Tags were 55 x 15 mm, weighed 21 g out of water, had a 30-cm whip antenna, and possessed a battery life of 1,037 d. The tags telemetered the temperature within ± 0.5°C by varying the pulse rate as a function of temperature. Each tag had an associated second-order regression equation relating the pulse rate to its temperature. The temperature of the tag was assumed to approximate the ambient water temperature the fish was experiencing when it was located. Each tag had a label specifying ‘‘$50 Reward’’ and a phone number to call for returning the tag.

Immediately following capture, fish were placed in a livewell containing a solution of lake water and 80-ppm of tricaine methanesulfonate (MS-222; Strand 1986). After 5-6 min, fish lost equilibrium and were adequately sedated for surgery. Standard surgical practices were followed to avoid compromising the health of the fish (Wagner and Cooke 2005). Anesthetized fish were positioned ventral side up on a V-shaped operating trough covered with a waterproof non-abrasive sterile drape. During surgery, a 40-ppm solution of MS-222 was pumped over the fish's gills to maintain sedation and provide continuous irrigation. Surgical tools were autoclaved in separate packages for individual fish. Prepackaged sterile suture needles, suture material, and scalpel blades were used and discarded after every surgery. Any surgical tools that were reused in the field and all radio tags were sanitized by being soaked in a bath of chlorhexadine gluconate for several minutes and rinsed with sterile saline prior to each surgery (Burger et al. 1994; Mulcahy 2003). Surgeons wore sterile latex gloves and all tools were placed on a sterile drape when not in use. All applicable aseptic techniques were closely followed to minimize risk of infection (Mulcahy 2003).

All fish were measured (mm, TL) and sexed prior to surgery. Fish were sexed using the methods described by Lebeau and Pageau (1989). Prior to incision, the fish's mucous coating was removed at the surgical site by gently wiping the area with an untreated sterile cotton swab (Wildgoose 2000). A small mid-ventral incision was made anterior to the pelvic girdle along the linea alba. Incision length was kept as short as possible to minimize trauma and limit the risk of tag expulsion through the incision (Lucas and Baras 2000). The antenna was positioned through the body wall posterior to the incision using the shielded needle technique as described by Ross and Kleiner (1982). The tag was gently inserted into the muskellunge's peritoneal cavity and positioned at the incision site. The incision was closed with three evenly-spaced interrupted size-0 Monocryl Plus (Ethicon®) sutures (Summerfelt and Smith 1990; Wagner et al. 2000). The total surgery time for all fish was recorded and averaged 5.8 min (SE = 0.12).

Immediately following surgery, fish were restrained alongside the boat by holding their caudal peduncle until equilibrium was regained. Fish regained equilibrium and exhibited swimming behavior after 1 to 5 minutes of recovery. Following release, a Global Positioning System (GPS) receiver was used to acquire Universal Transverse Mercator (UTM) coordinates of the release site.

## Tracking

Tracking operations were conducted from a motorboat using an ATS 4500S digital scanning receiver, a boat mounted hand-held directional loop antenna, and an omni-directional antenna (i.e., coaxial cable with an exposed wire end). The receiver displayed the temperature of the tag (°C) by using the regression equation associated with each tag to convert the pulse rate to temperature. Each tag had unique equation coefficients, which were programmed into the receiver prior to tracking.

An analog ATS R2000 scanning receiver was occasionally used to locate tagged fish; this receiver did not have temperature-sensing capabilities. Instead, tag temperature was determined from the pulse interval by measuring the amount of time (sec) elapsed during 11 pulses with a stopwatch. This process was repeated, and the average pulse interval was then calculated and subsequently used to determine the temperature of the tag.

Fish were located from long range using the loop antenna. After a fish was located by triangulation with the loop antenna, the boat was positioned in the immediate vicinity and the location was pinpointed with the omni-directional antenna. Neimela et al. (1992) found this method of location to have a mean error of ± 2.9 m in a regulated river. Once the fish location was pinpointed, water depth (m) and GPS coordinates (UTM) were determined with a Garmin® GPSmap 188 Sounder. A Bushnell® laser rangefinder was used to measure the distance (m) to the nearest shoreline. Water temperature (°C) and dissolved oxygen (D.O., mg/L) were measured at the surface, midwater, and bottom with a Manta® submersible multiprobe. The date and time of contact and any visible structure were also documented. A description of the location was also recorded to cross reference with the UTM locations.

Tracking began two weeks following the implantation of the last tag (March 2010) to allow fish to recover from surgery and avoid potential changes in behavior due to capture and surgery (Summerfelt 1972; Paukert et al. 2001). Fish were located approximately biweekly for 13 months (March 2010 to March 2011). Tracking spanned 2 to 3 d and was considered as a single tracking event. The entire 69-km reach of Melton Hill Lake between the Highway 61 Bridge in Clinton and Melton Hill Dam was traversed each tracking event. Fish locations were recorded only once during each tracking event. The Clinch River below Melton Hill Dam (i.e., headwaters of Watts Bar Lake) was tracked from Melton Hill Dam to the thermal plume of TVA's Kingston Steam Plant once during February 2011 to search for any missing individuals that may have passed through the Melton Hill Lock and Dam. The Clinch River from Norris Dam to the steam plant was also searched in March 2011 and May 2011 to locate unaccounted tagged fish. Data were partitioned monthly and seasonally, with seasons defined as spring (March, April, May), summer (June, July, August), fall (September, October, November), and winter (December, January, February).

## Thermal Ecology

To monitor spatial and temporal variation in the thermal environment, six HOBO U22 Water Temp Pro v2 automatic temperature loggers were deployed longitudinally throughout the reservoir at a depth of 3 m. The lower, main basin of Melton Hill Reservoir (CRkm 37 to 64) is capable of stratification during spring and summer and the depth of the thermocline was 3 m as reported by Peterson and Negus (2000). These devices recorded the water temperature at one-hour intervals and were affixed to navigational day markers. The uppermost temperature logger was anchored on the bottom in the headwaters of Melton Hill Lake (Highway 61 Bridge in Clinton, CRkm 106; Figure 1) because the water was less than 3 m deep.

Temperature (°C) and D.O. (mg/L) profiles (1-m intervals) were measured each month at six main basin locations and in three embayments using the Manta® submersible multiprobe. The embayments were Bull Run Creek (CRkm 75; Figure 1), Scarboro Creek (CRkm 66), and Bearden Creek (CRkm 51). Profiles were taken mid-embayment in the main channel. Main basin profiles were taken in the navigational channel at the Highway 25 Bridge in Clinton (CRkm 94), above the steam plant (CRkm 80), opposite the mouths of Bull Run Creek, Scarboro Creek, and Bearden Creek, and in the reservoir forebay (CRkm 38). If a tagged fish was located in one of the aforementioned embayments during biweekly tracking events, D.O and temperature profiles were measured mid-embayment and in the main channel of the reservoir basin opposite the embayment.

## Forage Availability

Forage fish were sampled seasonally using a stratified random sampling design and boat-mounted DC electrofishing gear (Smith-Root, Type VI-A electrofisher) to determine the longitudinal composition and abundance of forage fish. The sampling crew consisted of a driver and one dip-netter. The reservoir between the Highway 61 Bridge (CRkm 106) and Melton Hill Dam (CRkm 37) was divided into five reaches of equal length (Figure 2). Within each reach, waypoints were created at 0.5 km intervals along the centerline of the navigational channel in ArcMap 9.3. Six waypoints in each reach were randomly selected prior to sampling each season. The bank to sample (i.e., left bank descending or right bank descending) was determined by a coin toss. Five-minute electrofishing transects were conducted by proceeding downstream on the chosen bank opposite the waypoint. The start and end of each transect were marked on a handheld Garmin® GPSMAP 60CSx to determine distance (m) of each transect. All fish collected were identified to species and measured to the nearest mm TL. Catch per unit effort (CPUE) was calculated for each family collected.

## Data Analysis

All radio telemetry locations were converted into shapefiles in ArcMap 9.3 using Minnesota DNR Garmin 5.4.1 (Minnesota DNR 2008).

To assess patterns of spatial distribution, maps of monthly and seasonal fish distributions were created with 50% and 95% kernel density estimates using Hawth's

Analysis Tools in ArcMap 9.3. Kernel density estimation is a nonparametric technique where utilization distributions (UDs) are created based on the observed data points that approximate the intensity of usage within the area. Fixed-kernel estimates were used because they are considered to give the least biased results (Seaman and Powell 1996). In a kernel analysis, a mound (i.e., kernel) is placed over each observation; the width of each kernel is defined by the smoothing parameter (h; Horne and Garton 2006). The density at any point in space is estimated by averaging the densities of all kernels overlapping that point (Seaman and Powell 1996). These density probabilities form UDs and are separated by contour lines. The 50% UDs are accurate for defining heavily used areas relative to 95% or 99% UDs (Vokoun 2003). The 50% UD encompasses the smallest area containing one half of the fish locations, and is considered to be the area of core activity (Hooge et al. 2001).

All tagged fish were treated as one collective individual and composite kernel distribution estimates were calculated by month and by season (Banish et al. 2009). The number of observations each month exceeded 30, which is the recommended minimum number of observations for accurate kernel estimates (Kernohan et al. 2001).

Choosing the appropriate level of h, the smoothing parameter, is considered the most important factor in kernel density analysis because it can have a dramatic effect on the resulting estimate (Worton 1995; Seaman and Powell 1996; Horne and Garton 2006). Likelihood cross validations (CVh) on pooled monthly and seasonal fish locations were performed using Animal Space Use 1.3 software (Horne and Garton 2009) to determine the proper value of h. The CVh technique is recommended over alternative bandwidth selection procedures to obtain good estimates of high use areas, especially with sample sizes less than 50 (Horne and Garton 2006). The premise of CVh is to minimize the Kullback-Leibler distance between the observed and the estimated distribution (Horne and Garton 2006). Any UDs that were disconnected (i.e., separated by river bend, or embayment) were clipped in ArcMap 9.3.

The longitudinal distribution of tagged fish during each tracking event was also plotted using box and whisker plots. Fish locations were spatially joined to the nearest CRkm in ArcMap 9.3, and fish located in embayments were assigned to the CRkm nearest the mouth of the embayment. Box plots represented individual tracking events, with boxes indicating the median, 25$^{th}$, and 75$^{th}$ percentiles, and whiskers indicating the 10$^{th}$ and 90$^{th}$ percentiles. All outliers were plotted as individual points.

Seasonal differences among means for tag temperature, depth, and distance to the nearest shore were tested with a repeated-measures analysis of variance (ANOVA; Penne and Pierce 2008) using the MIXED procedure in the Statistical Analysis System version 9.2 (SAS Institute, Cary, North Carolina). The spatial power covariance structure was used for all mixed-model ANOVAs. All data were $\log_e$-transformed to stabilize the variance. Season was a fixed effect and fish and the fish*season interaction were random effects. Bonferroni's multiple-comparisons procedure ($\alpha = 0.05$) was used to assess differences in depth, distance to nearest shore, and tag temperature among seasons when the global model was statistically significant ($P \leq 0.05$).

All temperatures observed in main channel profiles, embayment profiles, profiles where fish were located, and temperature loggers were compiled to determine the range of temperatures available to tagged fish during each tracking event. Box and whisker plots were created from tag temperatures observed during each tracking event

To determine if water temperature influenced the use of the three largest embayments (Bull Run Creek, Scarboro Creek, and Bearden Creek), water temperatures in embayments and their adjacent main channels were compared each month by plotting the mean temperatures (°C) in the top 5 m (measured at 1-m intervals) for each of the two habitat types. The pooled monthly mean temperatures (averaged over the top 5 m) for each of these habitat types was also calculated. The percent occupancy each month (number of locations in embayments / total number of locations) for the major embayments was determined and temperature differences (if any) between embayments and their adjoining main channel profiles were reported. Any trends in the longitudinal movements of tagged fish were reported and changes in the longitudinal thermal environment were also described.

Longitudinal and seasonal differences in the abundance and composition of potential forage fish were tested with two-way fixed-effects ANOVA models to assess the possible influence of forage availability on the distribution of tagged muskellunge. Reach and season were the main effects and the response variables were the catch rates of the most common families of fishes (with more than 50 observations) that are commonly preyed upon by muskellunge elsewhere: *Catostomidae*, *Centrarchidae*, and *Cluepidae* (Axon 1981; Bozek et al. 1999; Brenden et al. 2004). Variation in total catch, representing all fish collected, was also tested with a two-way ANOVA. In a previous study, large (≥60 cm TL) muskellunge consumed prey 36% of their own length (Deutsch 1986). Bozek et al. (1999) reported that large (≥60 cm TL) muskellunge selected prey that averaged 20% of their own length, but muskellunge consumed prey fish as long as 47% of their own length. In the present study, only fish less than or equal to 450 mm TL were considered to be potential forage for muskellunge; that length was approximately 36% of the largest muskellunge tagged in this study and 47% of the mean length of tagged muskellunge (Table 1). All CPUE data were $\log_{10}$-transformed to stabilize variances. Prior to transformation, 1 was added to all CPUE data due to some catches of 0.

# CHAPTER 4

# RESULTS

Radio-tagged muskellunge were located 604 times during 26 tracking events (Table 1). At the conclusion of this study in March 2011, 22 of the 30 tagged fish were still alive. Fish #642 was located once 11 d post tagging, but was never located again. Therefore, it was either illegally harvested or the tag failed. Three fish (#70, #201, and #160) likely died; two of those tags were recovered on shore and one was on the bottom. Those suspected mortalities occurred 132 to 337 d post tagging, indicating mortality was unlikely to have resulted from the tagging process, or that tag expulsion occurred. One fish (#90) was harvested below Melton Hill Dam in September 2010 and the tag was returned for its reward; that fish was last located in Melton Hill Lake opposite Scarboro Creek in mid-June 2010. Three tagged fish were lost for unknown reasons (i.e., illegal harvest, tag failure, downstream dam passage) after 225 to 305 days at large. Anglers reported catching and releasing 17 radio-tagged muskellunge during this study, 11 of which were verified with a photograph. No fish were found in the 36 km-reach of the Clinch River below Melton Hill Dam when that reach was searched in February 2011.

## Distribution

Tagged muskellunge were rarely observed above the steam plant in the headwaters of Melton Hill Lake, and the lower reaches that they occupied each month in the 92-km long reservoir varied substantially between March 2010 and March 2011

(Figure 3). Tagged fish were located primarily in the reach between the steam plant and Bull Run Creek in March 2010, when the TVA was operating the steam plant; however, 50% UDs were also located in Scarboro Creek and the reach upstream of Solway (Figure 4). Fish moved downstream in April 2010 with the cessation of operation at the steam plant (Table 2). The areas or reaches containing the highest concentrations of fish and associated 50% UDs in April 2010 were Bull Run Creek, immediately upstream and downstream of Solway, and Scarboro Creek; some tagged fish were also located further downstream at Williams Bend, Bearden Creek, and between Bearden Creek and the Melton Hill Dam (Figure 5).

Based on their 50% kernel UDs, the spatial distribution of tagged fish in May 2010 was similar to that in April 2010 (Figures 5 & 6). Tagged fish continued to disperse downstream in June 2010, with more contacts occurring in Williams Bend (as represented by the addition of a 50% UD in that area); multiple locations were also observed in Gallaher Bend and near the dam (Figure 7). Aside from the Williams Bend 50% UD, the 50% UDs in June 2010 appeared similar to those in April and May 2010 and encompassed Bull Run Creek, the reaches immediately upstream and downstream of Solway, and Scarboro Creek. Tagged fish in July 2010 moved out of the embayments and into the main channel (Figure 8). The 50% UDs for July were primarily centered on main channel reaches between Bull Run Creek and Scarboro Creek, and also Williams and Gallaher bends.

Abrupt changes in the distribution of tagged fish were evident in August 2010 when the TVA began drawing Norris Lake down to winter pool by discharging more water from Norris Dam (Figure 9). Greater releases from Norris Dam cooled Melton Hill

Lake (Figure 10) and tagged fish returned to embayments and other near-shore areas (Figure 11). The August 50% UDs included Bull Run Creek, the reach immediately below Solway, Scarboro Creek, and Gallaher Bend. Fish in and around Gallaher Bend during August 2010 were primarily in small embayments; in contrast, fish in the Gallaher Bend reach in July 2010 were mostly offshore (Figure 8). The 50% Kernel UDs in September and August 2010 were similar (Figures 11 & 12).

Beginning in October 2010, some tagged fish started to move upstream (Figure 3); thus, the size of the 50% UD in Gallaher Bend was reduced and the 50% UD in Williams Bend increased (Figure 13). The other 50% UDs in October 2010 were in Scarboro Creek and Bull Run Creek. Tagged fish continued to move upstream in November 2010, especially in late November when all fish were located between CRkm 66 and 78 (Figure 3). The November 50% UD was between the steam plant and Scarboro Creek, and included the lower portion of Bull Run Creek (Figure 14). Few fish were located downstream of Scarboro Creek in November 2010. The 50% UD moved further upstream in December 2010 and encompassed the area immediately above the steam plant and down to Solway (Figure 15). As in November, few fish were located downstream of Scarboro Creek in December 2010; however, more fish were located above the steam plant (Figure 14).

In January 2011, the 50% UD encompassed the area from the steam plant to the mouth of Bull Run Creek, and only one fish was located below Scarboro Creek (Figure 16). Tagged fish were dispersed widely in early January 2011 but were congregated in and around the discharge canal of the steam plant in late January 2011. The steam plant operated for only five consecutive days prior to the late-January 2011 tracking event

(Table 2), at which time, 19 of 22 fish were located inside or near the discharge canal. Operations at the steam plant ceased in late January 2011 (Table 2) and fish subsequently dispersed downstream in February 2011, although two fish were located above the steam plant (Figure 17). In February 2011, small aggregations of fish were observed between the steam plant and Scarboro Creek, but the greatest concentration of fish was in Bull Run Creek.

Tagged fish tended to aggregate in embayments in March 2011; 50% UDs were in Bull Run Creek, the cove upstream of Solway, and Scarboro Creek (Figure 18). Two fish also made substantial upstream movements in March 2011 and were located in Coal Creek (CRkm 121) in the Norris Lake tailwater (Figures 1 & 3). Both fish were located downstream in Melton Hill Lake at CRkm 80 in late February or early March 2011. Neither of these two fish were located in the Norris Dam tailwater when it was searched in May 2011, indicating they did not take up residency there.

When data were pooled, distinct patterns were also evident in the spatial distribution of radio-tagged fish each season. In spring 2010, fish were distributed between the steam plant and Scarboro Creek, including Bull Run Creek, and few fish were located below Scarboro Creek (Figure 19). Tagged fish were widely distributed between Bull Run Creek and Melton Hill Dam during summer 2010 (Figure 20). In fall 2010, fish remained widely distributed, but fewer fish were located in Williams and Gallaher Bends and most locations occurred in the Bull Run and Scarboro Creek embayments (Figure 21). During winter 2010-2011, tagged fish were highly concentrated near the steam plant, in Bull Run Creek, and the reaches above and below Solway (Figure 22).

## Water Depth

Tagged fish tended to use deep areas in summer and shallow areas in spring, fall, and winter. Geometric mean depths occupied by tagged fish were significantly less in spring (2.8 m), fall (2.9 m), and winter (2.5 m) than in summer (4.3 m) (Figure 23; df = 3, 74; $F = 30.21$; $P < 0.0001$). On a monthly basis, tagged fish occupied shallow waters in March 2010 (Figure 24; mean water depth = 2.4 m; SE = 0.18), moved progressively deeper during April (mean = 3.6 m; SE = 0.28) and May 2010 (mean = 4.5 m; SE = 0.38), and occupied the deepest water in June (mean = 5.4 m; SE = 0.32) and July 2010 (mean = 5.2 m; SE = 0.27). Tagged fish returned to shallow water in August 2010 (mean = 3.6 m; SE = 0.23) with cooling lake temperatures (Figure 10) and moved shallower in October (mean = 3.2 m; SE = 0.24). Tagged fish continued to be located in shallow water (range: 2.4 – 2.8 m) from November 2010 to March 2011.

## Distance to Nearest Shoreline

Tagged fish were farther offshore in summer and closer to shore in the spring, fall, and winter. The geometric mean distances to the nearest shoreline were similar in spring (27.9 m), fall (22.1 m), and winter (23.9 m), but were significantly greater in summer (38.1 m) (Figure 25; df = 3, 74; $F = 8.07$; $P < 0.0001$). On a monthly basis, tagged fish were close to shore in March 2010 (Figure 26; mean = 28.5 m; SE = 8.81) and moved further offshore from April to June 2010 when mean distances to the shoreline each month ranged from 60.7 to 63.9 m. Fish were furthest from shore during

July 2010 (mean = 90.5 m; SE = 12.70). Tagged fish returned to near-shore areas in August 2010 (mean = 36.7 m; SE = 6.89) with cooling lake temperatures, and stayed relatively close to shore (range: 29.6 – 42.4 m) from August to November 2010. Mean distance to nearest shoreline increased in December 2010 (mean = 60.3 m; SE = 12.64) when fish primarily used main channel habitats, but decreased in January 2011 (mean = 20.3 m; SE = 3.76) when many fish were located in the discharge canal of the steam plant. Mean distance to nearest shoreline then increased in February 2011 as fish dispersed from the steam plant (mean = 46.2 m; SE = 7.95), and decreased in March 2011 (mean = 21.9 m; SE = 3.53) when fish were primarily found in embayments.

## Thermal Ecology

Mean tag temperatures varied significantly among seasons (Figure 27; df = 3, 74; $F = 410.49$; $P < 0.0001$); geometric mean tag temperatures were warmest in the summer (22.0°C), coolest in the winter (9.2°C) , and intermediate during the spring (18.3°C) and fall (16.1°C). On a monthly basis, mean tag temperatures increased from March (Figure 28; mean = 19.5°C; SE = 0.29) to June 2010 (mean = 22.9°C; SE = 0.28) then decreased slightly during July (mean = 22.6°C; SE = 0.24), August (mean = 20.9°C; SE = 0.35), and September 2010 (mean = 20.7°C; SE = 0.26). Tag temperatures steadily decreased in October (mean = 15.9°C; SE = 0.23), November (mean = 12.3°C; SE = 0.12), and December 2010 (mean = 10.0°C; SE = 0.26) as did ambient water temperatures (Figure 29). Mean tag temperatures increased in late January 2011 (mean = 12.1°C; SE = 0.81) due to the release of heated effluent from the steam plant where fish were congregated.

Tag temperatures decreased in February 2011 (mean = 7.0°C; SE = 0.20) following the cessation of steam plant operations, but increased in March 2011 (mean = 11.6°C; SE = 0.54) as the reservoir warmed.

The thermal environment in Melton Hill Lake was extremely dynamic and tagged fish in this study were able to select from a wide range of temperatures throughout much of the year (Figure 29). The greatest range of temperatures (7.1 – 33.3°C) was available to tagged fish from May to early August 2010. Over that same interval the mean tag temperature was 22.4°C (SE = 0.13), with a range of 17.4 to 27.5°C (Figure 30). Most (89%) fish during that interval selected water between 20 to 25°C and nearly half (48%) of all observations were between 22 to 24°C.

The decrease in tag temperatures in late August 2010 coincided with the influx of cool water when TVA began lowering Norris Lake to winter pool. Subsequently, a narrower range of temperatures was available to tagged fish between October 2010 and early January 2011. Tagged fish were usually found in the warmest water available during the winter, especially when the steam plant was operating in late January 2011 (Figure 29) when available temperatures ranged from 5.9 to 19.4°C. The mean tag temperature in late January 2011 was 16.4°C (SE = 0.61) and tag temperatures ranged from 8.3 to 19.0°C, indicating tagged fish selected some of the warmest water available.

On only a few occasions were hypoxic conditions observed in Melton Hill Lake. In late May, June, July, and September 2010, D.O. concentrations in the hypolimnion in Bearden Creek were less than 3 mg/L; the lowest concentration observed in that embayment was 0.4 mg/L. Over those same months in 2010, D.O. concentrations elsewhere in the reservoir at all depths were always above 3.0 mg/L. The hypoxia observed in Bearden Creek may explain why tagged fish were only rarely observed in Bearden Creek during the summer of 2011.

## Influence of Temperature on Habitat Use

Bull Run Creek and Scarboro Creek were the two embayments used most frequently by tagged muskellunge (Figures 19, 20, 21, & 22) and water temperature appeared to influence the use of these two embayments. Due to lack of use, the Bearden Creek embayment was excluded from the embayment occupancy analysis. Percent occupancy by tagged muskellunge in the Bull Run Creek and Scarboro Creek embayments was greatest (i.e., March 2011) when the embayments were warmer than their adjacent main channel habitats, but the average water temperature in the top 5 m of the water column was less than 22°C (Figures 31 & 32). Embayment occupancy was low when the average temperature in embayments exceeded 22°C (June & July 2010) and when adjacent main channel habitats were warmer than embayments (November 2010 to January 2011).

Water temperature clearly influenced the uplake-downlake movements of muskellunge. Tagged fish made distinct upstream movements in November 2010 and tended to occupy the reach between CRkm 66 and 80 until March 2011 (Figure 3). Use of that reach by tagged fish coincided with a change in the longitudinal thermal environment. From early November 2010 to mid-January 2011, the water released from Norris Dam was warmer than the water in the basin of Melton Hill Lake (Figure 33); thus, the reach between CRkm 66 and 80 contained the warmest water available in the main basin of Melton Hill Lake at that time. Although slightly warmer water was available in the riverine reach of the reservoir (CRkm 106; Figure 10) during that same period (November 2010 – January 2011), tagged fish did not use that reach, perhaps due to its riverine nature and increased water velocity.

## Forage Availability

Catch rates of potential forage fish 450 mm TL or less (all species combined) varied by reach (Table 3; Figure 34; $df = 4, 19$; $F = 12.11$; $P < 0.0001$) but not by season ($df = 3, 19$; $f = 0.85$; $P = 0.4703$). Catch rates were usually lowest in the uppermost reach (reach 1) and were highest in reaches 2, 3, and 4; however, some forage was available throughout the year in all reaches. Catch rates of catostomids did not vary among reaches ($df = 4, 19$; $F = 0.50$; $P = 0.7335$) or seasons ($df = 3, 19$; $F = 0.59$; $P = 0.6214$). Catch rates of centrarchids were highest in reaches 3, 4, and 5 ($df = 4, 19$; $F = 16.14$; $P < 0.0001$), but did not vary seasonally ($df = 3, 19$; $F = 0.18$; $P = 0.9064$). Catch rates of clupeids varied by season ($df = 3, 19$; $f = 6.65$; $P = 0.0004$), and reach ($df = 4, 19$; $f = 2.90$; $P = 0.0258$); highest catches were in reaches 2 and 3 during spring, summer, and fall 2010, and in reach 5 during winter 2010-2011.

# CHAPTER 5

# DISCUSSION

Movements and distribution patterns of fish are influenced by biotic and abiotic factors as well as behavioral or life history characteristics. Lakes and reservoirs commonly exhibit vertical and horizontal gradients of temperature, dissolved oxygen, pH, and other physiochemical variables. Such vertically and horizontally structured environments fluctuate seasonally and influence the spatial distribution, depth, and habitat use of fish (Baldwin et al. 2002; Barwick et al. 2004; Penne and Pierce 2008; Banish et al. 2009). Changes in the distribution of fish should reflect their attraction to favorable environmental conditions. Because Melton Hill Lake is thermally heterogeneous and often exhibits a distinct longitudinal temperature gradient, the seasonal distribution of muskellunge in this system appears to be largely influenced by their thermoregulatory behavior in this free-choice environment.

Melton Hill Lake is unlike any other system in which muskellunge have been studied with biotelemetry because of its thermal diversity, which allowed tagged muskellunge to select a wide range of temperatures throughout much of the year. Previous muskellunge biotelemetry studies have been conducted largely in more northerly lakes (Crossman 1977; Miller and Menzel 1986a; Strand 1986; Eilers 2008), reservoirs (Wagner and Wahl 2007), and rivers (Younk et al. 1996; Gillis et al. 2010). Muskellunge have been studied with biotelemetry infrequently in the southern U.S. (Brenden et al. 2006) or in altered thermal environments such as cooling reservoirs (Henley and Applegate 1982; Younk 1982)

Melton Hill Lake muskellunge that were tracked in the present study demonstrated distinct seasonal patterns in their distributions. In general, fish occupied a small reach downstream of the steam plant in spring, late fall, and winter, and were widely dispersed in the lower-reservoir between the steam plant and Melton Hill Dam during the summer and early fall. Mean distance to the nearest shoreline varied by season, paralleling the mean depths of waters occupied and trends in tag temperatures. During summer, fish moved further offshore and were typically located in deeper water, presumably to avoid the higher water temperatures in near-shore waters.

Previous studies have also shown variation in the seasonal distribution and movements of muskellunge. In a study by Eilers (2008), tagged muskellunge moved offshore during the summer in Thornapple Lake, Michigan. Muskellunge in West Okoboji Lake, Iowa tended to inhabit deeper (4.0 – 8.8 m) offshore areas in early and mid- summer and returned to shallow (4.8 – 6.0 m) vegetated areas in late summer and fall (Miller and Menzel 1986a). In contrast, muskellunge in lotic systems have been documented to select deeper areas in winter and shallow areas in summer (Younk et al. 1996; Gillis et al. 2010). Many studies have also noted that muskellunge in northern lakes inhabit shallow water (2.0 m deep or less) during the summer (Crossman 1977; Minor and Crossman 1978; Dombeck 1979).

Although a wide range of temperatures were available year-round in Melton Hill Lake, tagged muskellunge in the present study tended to select temperatures between 20 to 25°C when available. When these temperatures were not available, tagged muskellunge sought out temperatures closest to this range as was the case in late January 2011 when the TVA operated the steam plant. The preference for warmer water in winter by muskellunge in the present study contrasts the findings of Bettoli (2005), who observed that striped bass *Morone saxatilis* in Melton Hill Lake did not select warm water in winter although it was available. Many researchers concluded that muskellunge were inactive and made only localized movements in winter (Minor and Crossman 1978; Dombeck 1979; Younk et al. 1996); however, in all of those studies water temperatures in winter were ~4°C or less. It is evident in the present study that when available, adult muskellunge will select water as warm as 19.0°C in winter. Henley (1981) also documented the preference of a single tagged muskellunge for the heated thermal plume during winter in a South Dakota power plant cooling reservoir. Other researchers have documented the attraction of muskellunge in natural lakes to shallow, near-shore areas that warm more rapidly than deeper waters in the spring (Dombeck 1979; Miller and Menzel 1986b).

Few fish in the present study inhabited water warmer than 25°C, which is consistent with the 25.6°C upper tolerance limit noted by Scott and Crossman (1973). Similarly, Dombeck (1979) did not observe decreases in muskellunge activity with rising temperatures until waters warmed past 25°C. Adult muskellunge in West Okoboji Lake, Iowa selected 23 to 25°C water in vegetated, shallow bays during late summer, although cooler water was available (Miller and Menzel 1986a). Those fish displayed reduced activity during late summer and their greatest activity occurred at temperatures of 11 to 17°C. Their selection of warmer temperatures may be due to the affinity of muskellunge for aquatic macrophytes (Scott and Crossman 1973), which Melton Hill Lake lacked.

The temperatures selected by muskellunge in Melton Hill Lake from May 2010 to early August 2010, when the widest range of temperature was available to tagged fish and the thermal environment was relatively stable (Figure 29), resembled a normal distribution (Figure 30). Typically, the distribution of temperatures selected by freshwater fish is negatively skewed because fish are thought to more actively thermoregulate when they are closer to their upper thermal limit than their lower thermal limit (Reynolds and Casterlin 1979a; Bettoli 2005). In contrast, Melton Hill Lake muskellunge appeared to select a well-defined range of temperatures by carefully avoiding not only an upper thermal limit but also a lower limit.

Nearly all previous studies on the thermal ecology of muskellunge have focused on juvenile fish. The mean temperatures selected by age-2 muskellunge in an Illinois reservoir were 21.7°C in spring, 28.4°C in summer, and 14.8°C in fall (Wagner and Wahl 2007). The warm temperatures occupied during summer in their study were potentially influenced by the absence of cooler, oxygenated water. Preferred temperatures and temperatures that optimized growth of juvenile muskellunge in laboratory settings ranged from 24.0 to 26.7°C (Coutant 1977; Reynolds and Casterlin 1979b; Jobling 1981; Bevelheimer et al. 1985; Clapp and Wahl 1996). Jobling (1981) and Wagner and Wahl (2007) proposed that the upper avoidance temperature for juvenile muskellunge was 32 to 34 °C; whereas the highest water temperature inhabited by an adult muskellunge in the present study was only 27.5°C. The higher preferred and upper avoidance temperatures of juvenile muskellunge in previous studies compared to adult fish in this study may be due to an ontogentic niche shift, which has been noted for other fish species (McCauley and Huggins 1979; Lafrance et al. 2005).

Aside from the two fish located in Coal Creek (8 km below Norris Dam) in late March 2011, no fish were located above CRkm 81 over the duration of the present study.

Although catch rates of forage fish varied among reaches, suitable forage was present throughout all reaches each season; therefore, forage availability did not appear to prevent muskellunge from inhabiting the uppermost reaches of Melton Hill Lake. Muskellunge prey heavily on catomstomids in other systems (Bozek et al. 1999; Brenden et al. 2004) and catch rates of catostomids in Melton Hill Lake did not vary by reach or season. In other reservoirs of the southern United States, clupeids (e.g., gizzard shad *Dorosoma cepedianum*) are thought to be important prey for muskellunge (Axon 1981; Wahl and Stein 1993). Catch rates of clupeids varied by both season and reach and it is not known whether their abundance influenced the distribution of muskellunge in Melton Hill Lake. Catch rates of centrarchids varied among reaches and were lowest in the upstream reaches and increased downstream. However, centrarchids are considered to be of minimal dietary importance to muskellunge (Wahl and Stein 1988; Bozek et al. 1999) and spatial differences in their abundance probably played no role in the distribution of muskellunge in Melton Hill Lake.

Possible explanations for tagged muskellunge not using the upper, riverine reaches of Melton Hill Lake include the cooler water temperatures present uplake throughout most of the year, greater daily fluctuations in water temperature in summer and fall, and differences in habitat. The Clinch River above the steam plant is more riverine, lacks any embayments, and water velocity is undoubtedly faster than downlake. Melton Hill Lake also experiences a distinct density underflow during the spring and summer, when cold inflows plunge below warm surface waters downlake, usually around CRkm 80 (Bettoli 2005), just upstream of the steam plant. The abrupt change in water temperature associated with the plunge point may block upstream movements of most muskellunge when it is present.

Muskellunge have been observed moving from lentic to lotic habitats (Crossman 1977; Eilers 2008) and the two fish located in the Norris Dam tailwater appeared to have exhibited a rheotactic response to the influx of water released from Norris Dam in March 2011. The upstream migrations of these two fish may have represented a spawning attempt which has been documented in other studies (Minor and Crossman 1978, Miller and Menzel 1986b). Although actual spawning could not be verified by these two fish, their long (at least 41 km) upstream movements coincided with both the timing and temperature (8 to 11°C) of muskellunge spawning migrations (Minor and Crossman 1978; Dombeck 1979; Strand 1986; Younk et al. 1996). Muskellunge in other systems have been known to make substantial (up to 27 km) upstream migrations (Younk et al. 1996) and use tributary streams for spawning (Eddy and Underhill 1976).

# CHAPTER 6

# MANAGEMENT IMPLICATIONS

Melton Hill Lake muskellunge are vulnerable to exploitation in winter if the Bull Run Steam Plant is operating because nearly all tagged muskellunge were located in the heated plume discharged by the steam plant. During this study, anglers reported catching and releasing nine radio-tagged muskellunge in the thermal plume during winter, six of which were verified with photograph. Eight of those fish were caught from January to March 2010, and one was caught in January 2011. Although most tagged muskellunge were located in the thermal plume during winter, only one tagged fish was found dead in the discharge canal. This individual is presumed to have died from catch-and-release mortality. The extent of exploitation in this unique fishery will be greatly influenced by the timing and duration of winter steam plant operations. Exploitation throughout the rest of the year is unlikely to be an issue because muskellunge become widely dispersed. Temporal trends in the distribution of muskellunge displayed in the present study may vary in subsequent years due to annual variation in weather patterns, releases from Norris and Melton Hill dams, and steam plant operations, all of which will affect the thermal regime in Melton Hill Lake.

Future surveys of Melton Hill muskellunge should occur when they congregate and are most susceptible to sampling. Therefore, managers should 1) continue to sample in and around the discharge canal of the steam plant when it is operating during winter; and 2) consider setting trap nets or using boat-mounted electrofishing gear in shallow embayments in March and April, especially when embayments are warmer than the main channel.

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Table 1. Summary of radio-tagged muskellunge in Melton Hill Lake, Tennessee, 2010–2011, indicating identification number (ID), total length (TL) sex, number of times each fish was located, and the fate of individual fish at the end of the study. The minimum number of days that fish were alive is listed in parentheses for those fish that died, went missing, or were harvested.

| ID | TL (mm) | Sex | Locations (N) | Fate |
|---|---|---|---|---|
| 10 | 1173 | F | 25 | Alive |
| 20 | 866 | F | 25 | Alive |
| 30 | 801 | F | 12 | Missing (225) |
| 40 | 1049 | M | 23 | Alive |
| 51 | 975 | F | 21 | Alive |
| 60 | 1190 | F | 24 | Alive |
| 70 | 720 | M | 9 | Dead (153) |
| 80 | 881 | F | 21 | Alive |
| 90 | 883 | F | 6 | Harvested (149) |
| 100 | 915 | M | 24 | Alive |
| 110 | 943 | F | 24 | Alive |
| 120 | 1240 | F | 21 | Alive |
| 130 | 899 | M | 24 | Alive |
| 140 | 802 | M | 19 | Missing (305) |
| 150 | 1003 | F | 25 | Alive |
| 160 | 720 | F | 19 | Dead (337) |
| 180 | 1000 | M | 25 | Alive |
| 190 | 940 | F | 25 | Alive |
| 201 | 1167 | F | 6 | Dead (132) |
| 250 | 905 | M | 23 | Alive |
| 260 | 819 | F | 17 | Missing (292) |
| 280 | 980 | M | 23 | Alive |
| 741 | 1010 | M | 24 | Alive |
| 922 | 1225 | F | 23 | Alive |
| 941 | 840 | F | 23 | Alive |
| 990 | 1224 | F | 23 | Alive |
| 1022 | 952 | M | 22 | Alive |
| 1611 | 888 | F | 24 | Alive |
| 1621 | 1100 | F | 24 | Alive |
| 1642 | 923 | M | 0 | Never Located (11) |

Table 2. Hours per day of generation at the Bull Run Steam Plant from March 1, 2010 to March 31, 2011.

| Date | Hours |
|---|---|
| 3/1/10 to 4/8/10 | 24 |
| 4/9/2010 | 9.18 |
| 4/10/10 to 5/31/10 | 0 |
| 6/1/2010 | 8.87 |
| 6/2/10 to 6/17/10 | 24 |
| 6/18/2010 | 10.53 |
| 6/19/10 to 6/25/10 | 0 |
| 6/26/2010 | 19.53 |
| 6/27/10 to 9/22/10 | 24 |
| 9/23/2010 | 17.95 |
| 9/24/10 to 12/17/10 | 0 |
| 12/18/2010 | 0.32 |
| 12/19/2010 to 12/24/2010 | 0 |
| 12/25/2010 | 23 |
| 12/26/2010 to 12/28/10 | 0 |
| 12/29/2010 | 24 |
| 12/30/2010 to 1/6/2010 | 0 |
| 1/7/2011 | 6.50 |
| 1/8/2011 | 14 |
| 1/9/11 to 1/12/11 | 24 |
| 1/13/2011 | 3 |
| 1/14/2011 | 21 |
| 1/15/11 to 1/30/11 | 24 |
| 1/31/2011 | 13 |
| 2/1/11 to 3/31/11 | 0 |

Table 3. Summary of two-way analysis of variance models testing the effects of season and reach on catch per unit effort of forage fish in 5-minute electrofishing transects.

| Family | Source of Variation | df | F | P |
|---|---|---|---|---|
| All Fish | Season | 3 | 0.85 | 0.4703 |
| | Reach | 4 | 12.11 | <0.0001* |
| | Season*Reach Interaction | 12 | 4.18 | <0.0001* |
| | Overall Model | 19 | 5.33 | <0.0001* |
| Catostomidae | Season | 3 | 0.59 | 0.6214 |
| | Reach | 4 | 0.50 | 0.7335 |
| | Season*Reach Interaction | 12 | 1.33 | 0.2113 |
| | Overall Model | 19 | 1.04 | 0.4217 |
| Centrarchidae | Season | 3 | 0.18 | 0.9064 |
| | Reach | 4 | 16.14 | <0.0001* |
| | Season*Reach Interaction | 12 | 3.05 | <0.0001* |
| | Overall Model | 19 | 5.35 | <0.0001* |
| Clupeidae | Season | 3 | 6.65 | 0.0004* |
| | Reach | 4 | 2.90 | 0.0258* |
| | Season*Reach Interaction | 12 | 2.58 | 0.0050* |
| | Overall Model | 19 | 3.29 | <0.0001* |

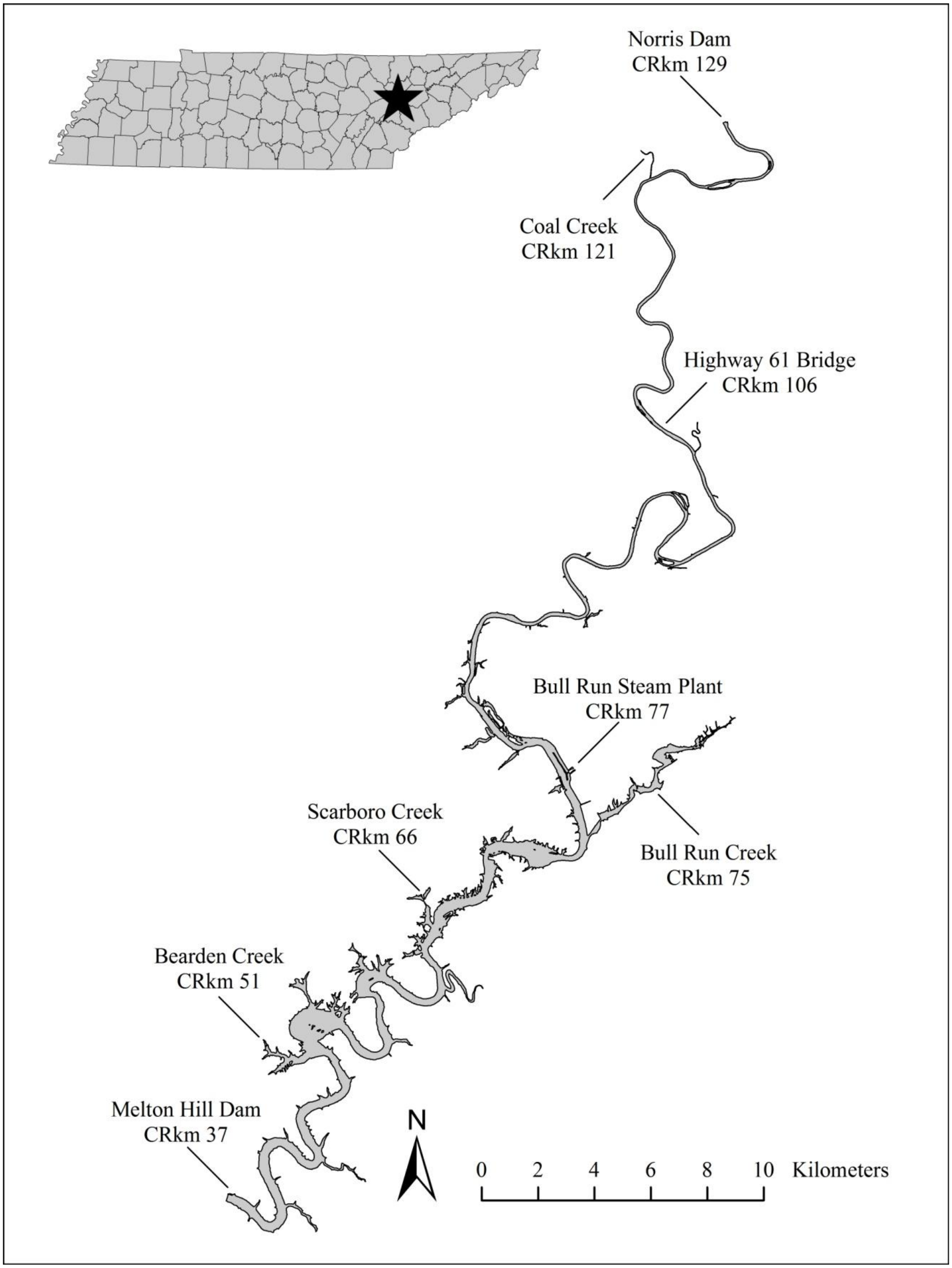


Figure 1. Map of Melton Hill Reservoir on the Clinch River, Tennessee

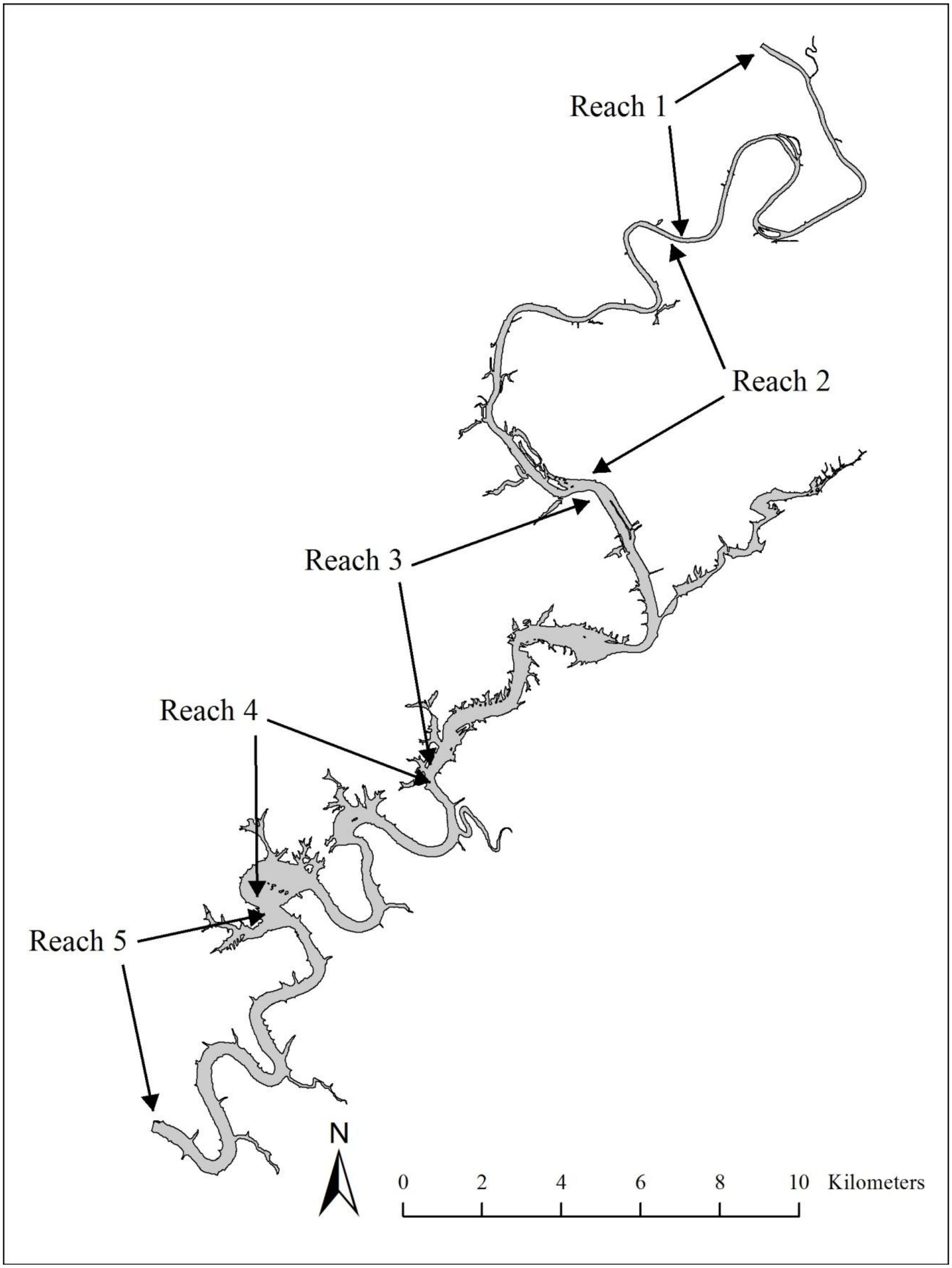


Figure 2. Map of forage sampling reaches in Melton Hill Lake, Tennessee.

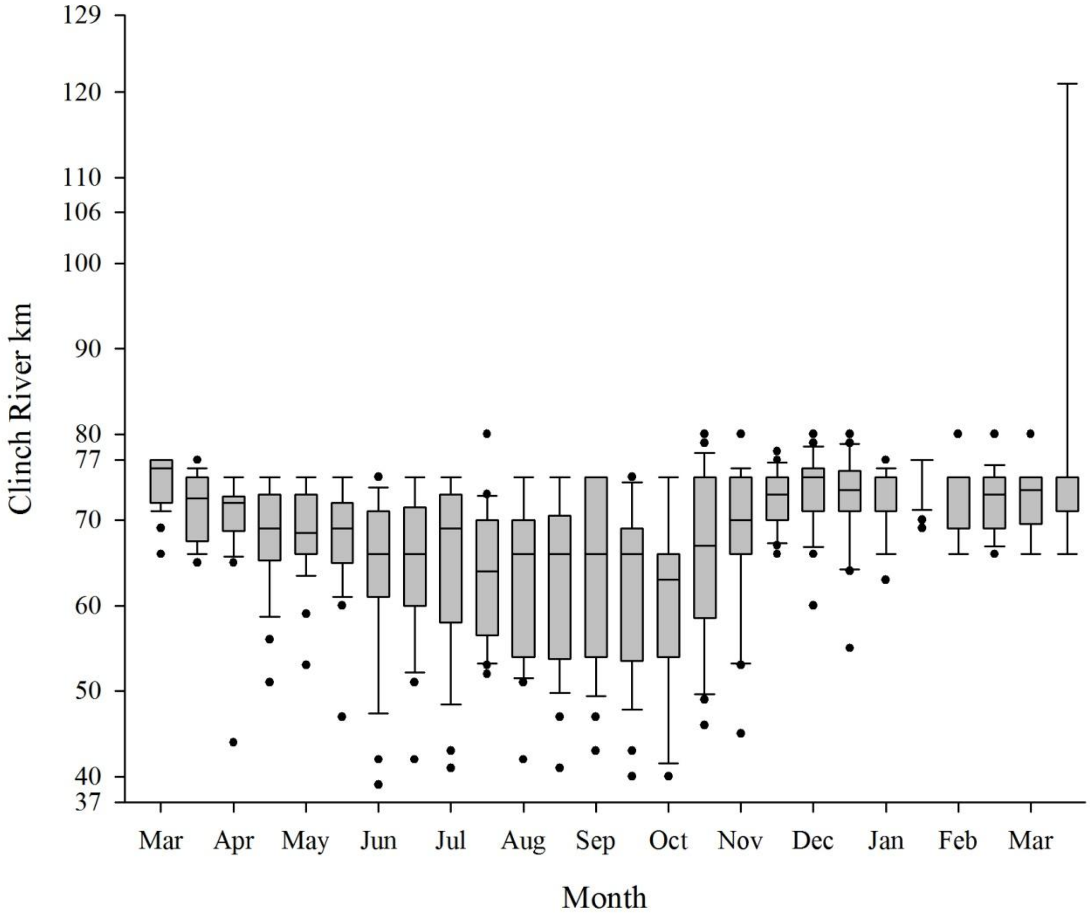


Figure 3. Box and whisker plots of the longitudinal distribution of radio-tagged muskellunge in Melton Hill Lake, Tennessee by Clinch River km, March 2010–March 2011. Each plot represents an individual tracking event. The lower and upper boundaries of each box indicate the 25th and 75th percentiles, respectively, and the median value is shown as a line within the box. The whiskers below and above each box represent the 10th and 90th percentiles. All outliers are presented as points. Key landmarks are: Melton Hill Dam (CRkm 37), Bull Run Steam Plant (CRkm 77), Highway 61 bridge (CRkm 106), and Norris Dam (CRkm 129).

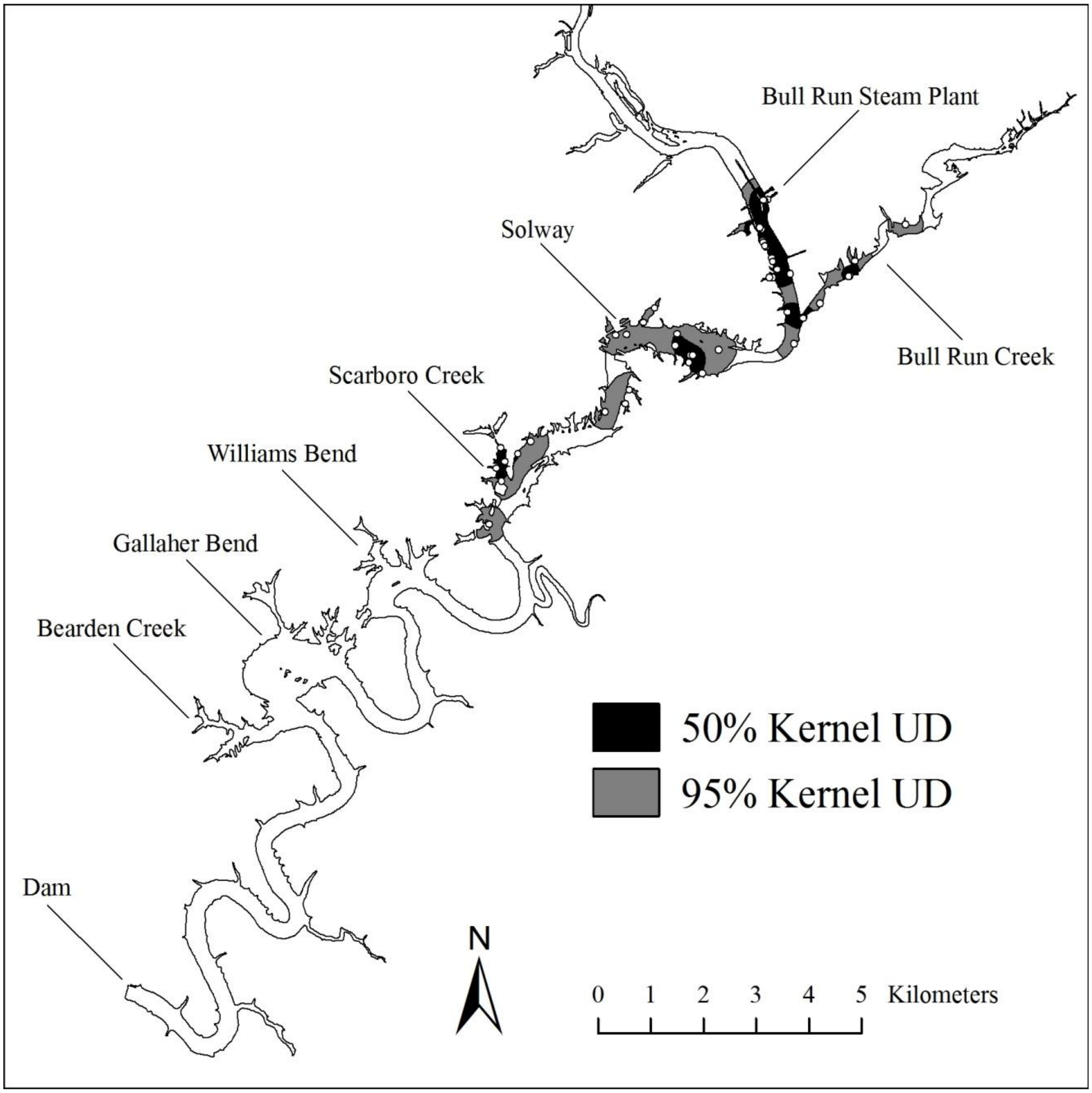


Figure 4. Map of 50% and 95% Kernel Utilization Distributions (UD) in March 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

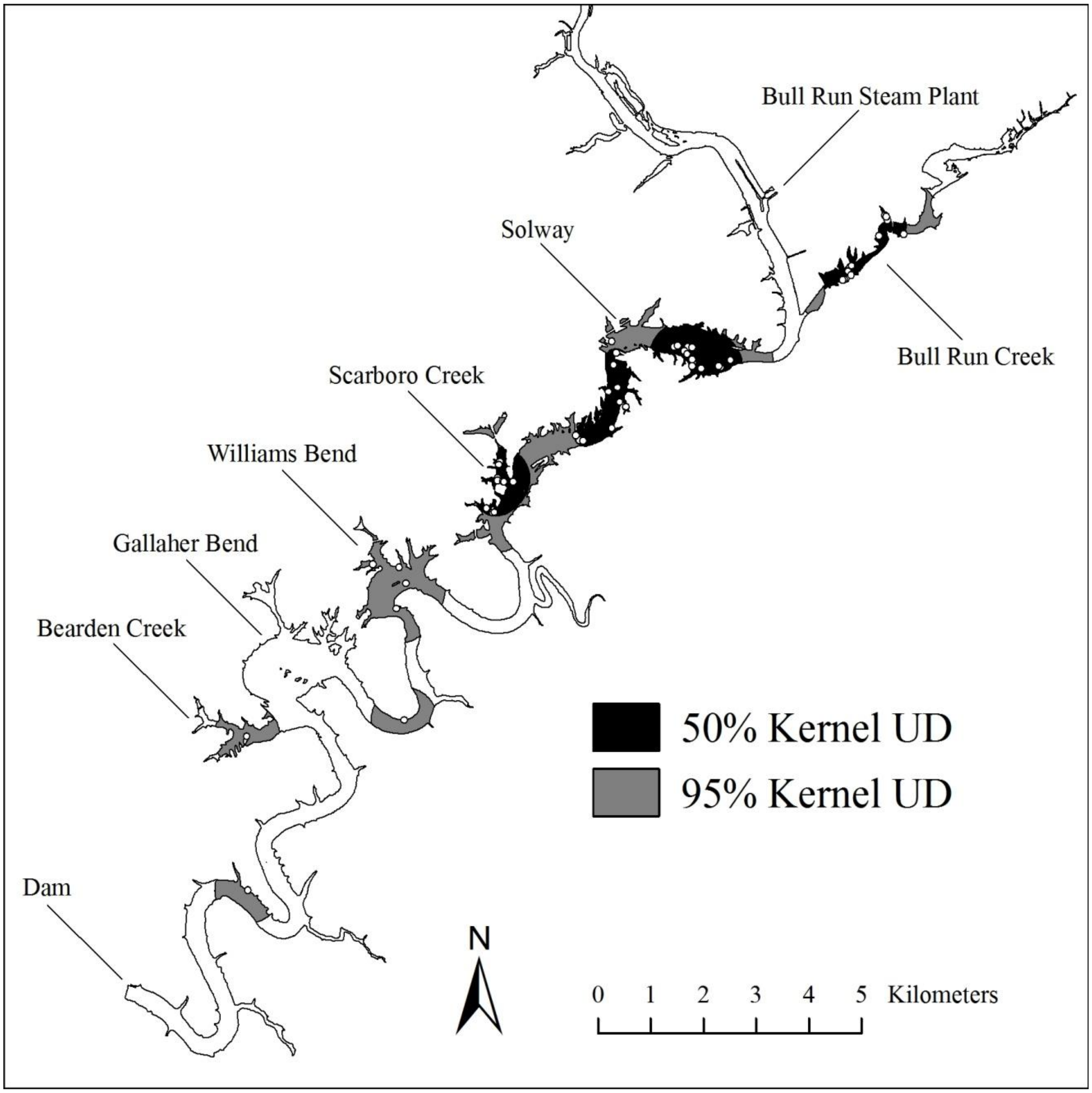


Figure 5. Map of 50% and 95% Kernel Utilization Distributions (UD) in April 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

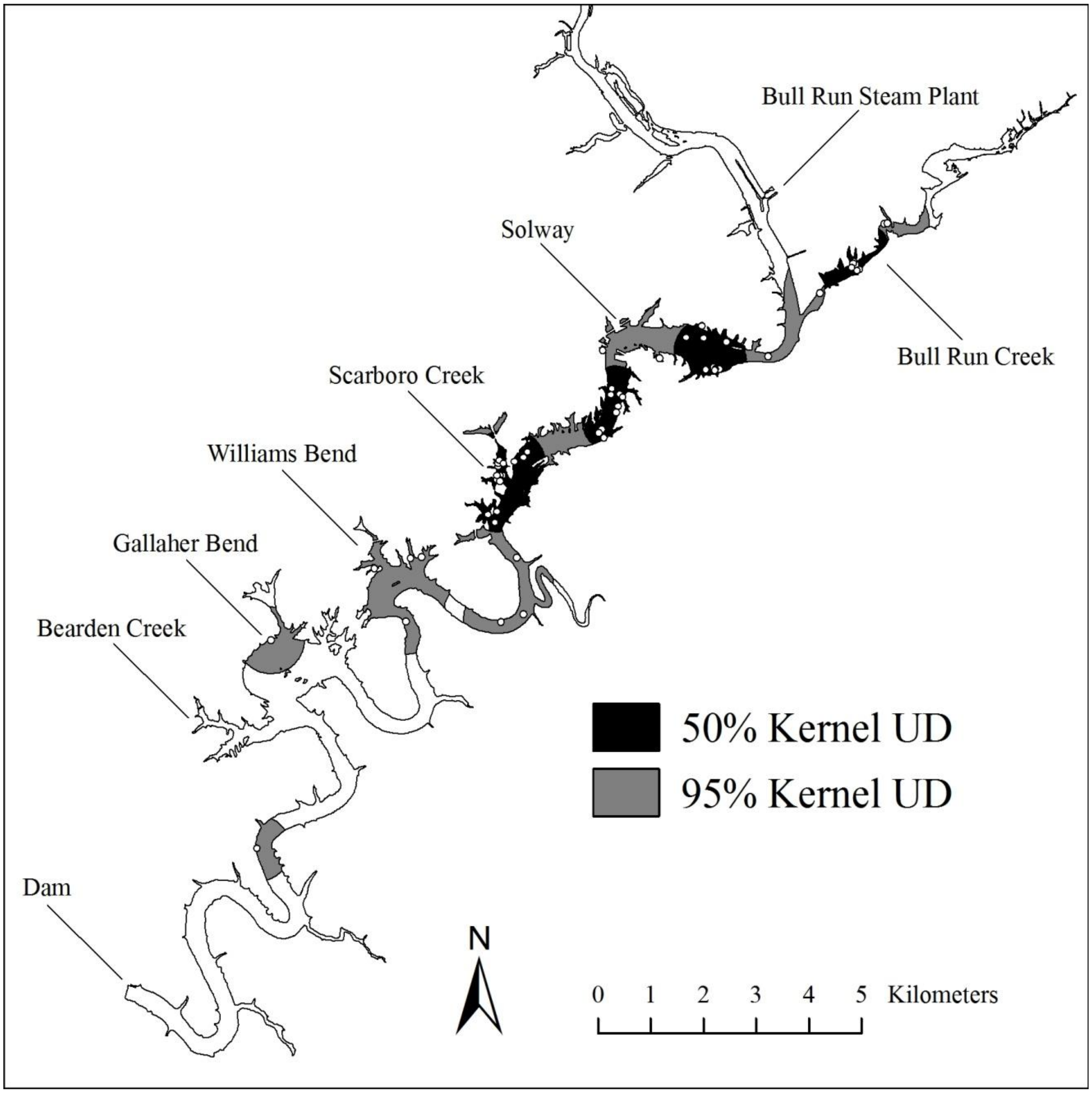


Figure 6. Map of 50% and 95% Kernel Utilization Distributions (UD) in May 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

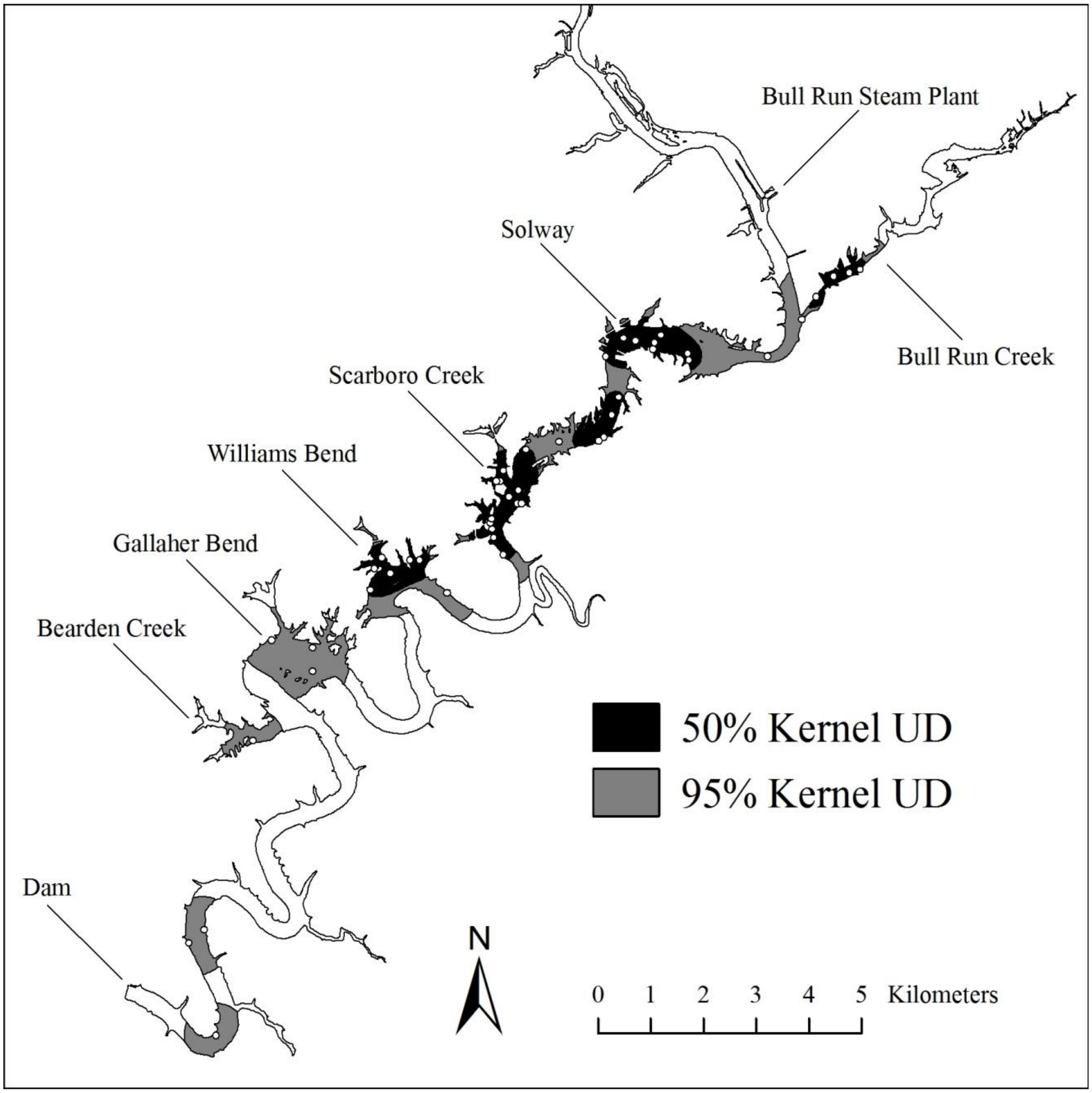


Figure 7. Map of 50% and 95% Kernel Utilization Distributions (UD) in June 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

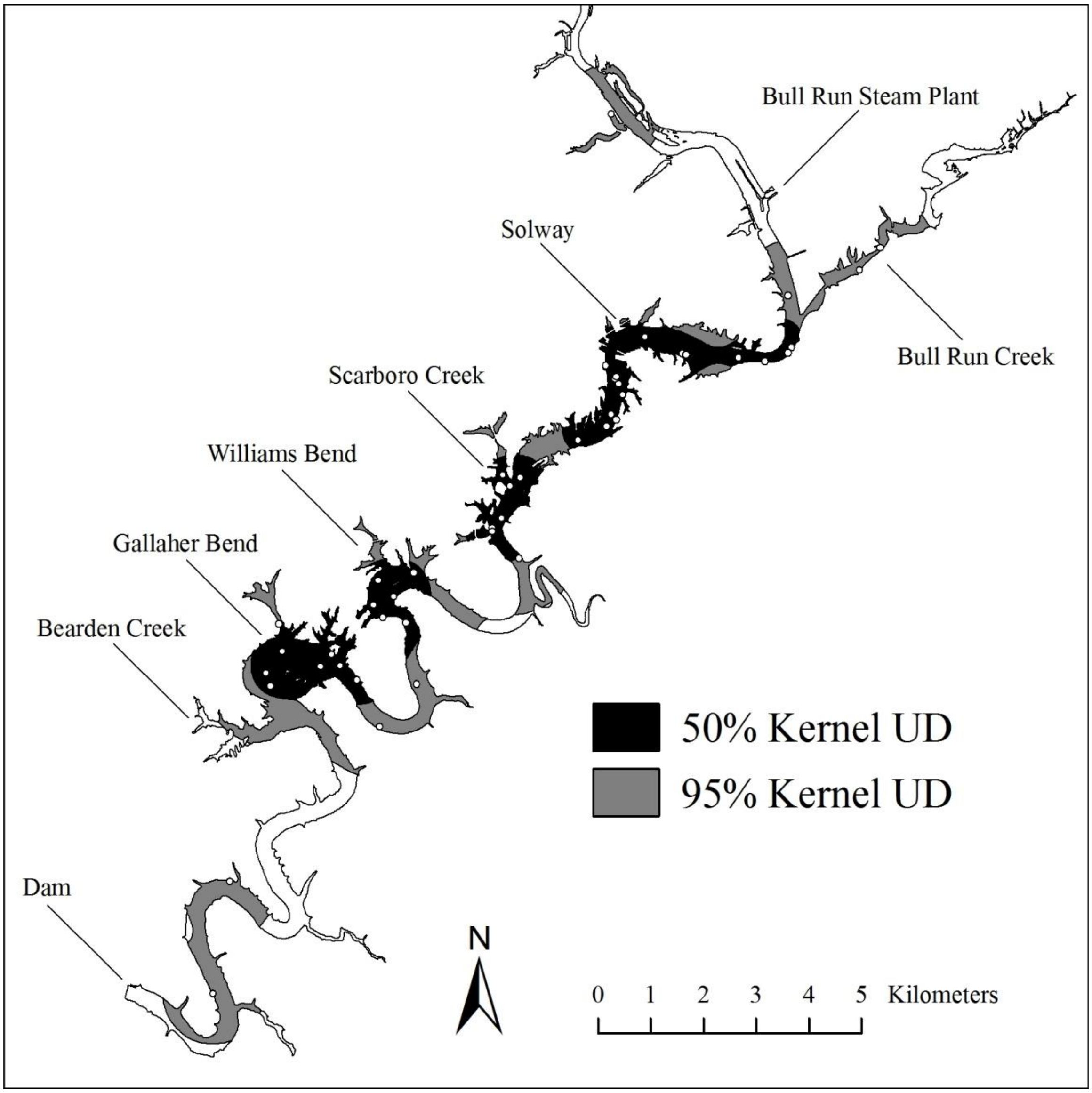


Figure 8. Map of 50% and 95% Kernel Utilization Distributions (UD) in July 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

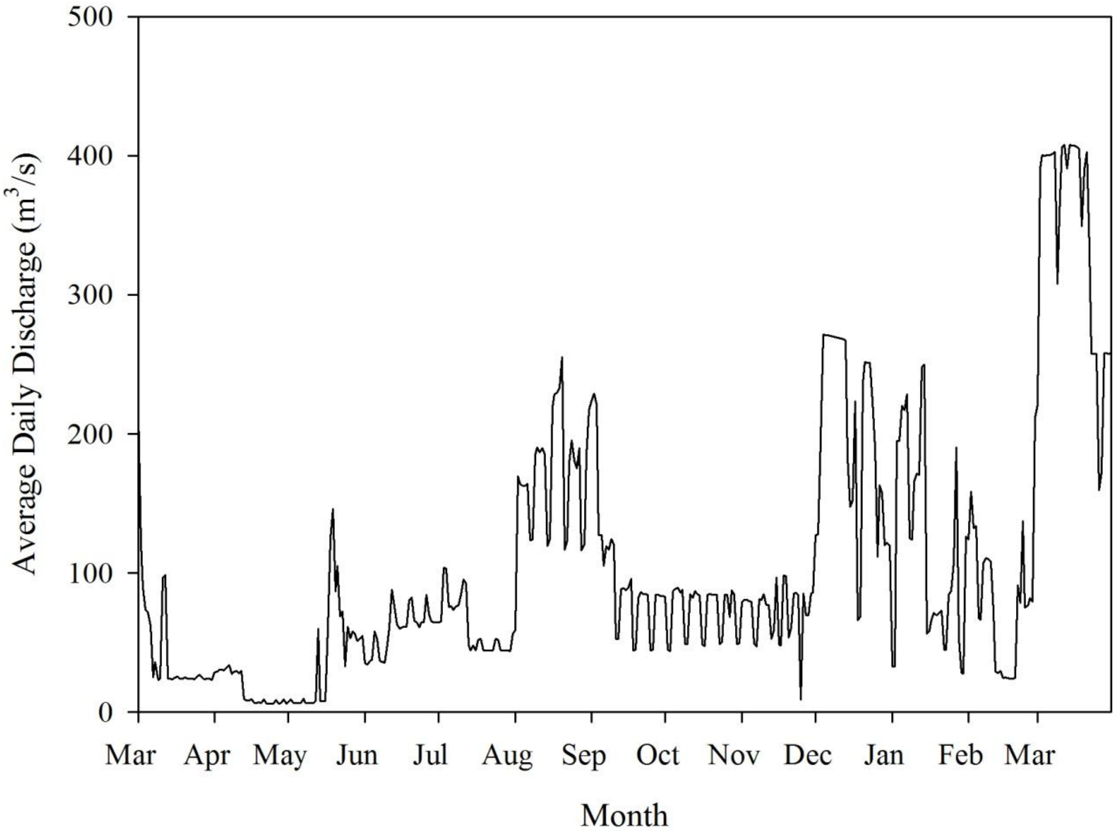


Figure 9. Daily average discharge ($m^3$/sec) from Norris Lake, Tennessee from March 2010 to March 2011.

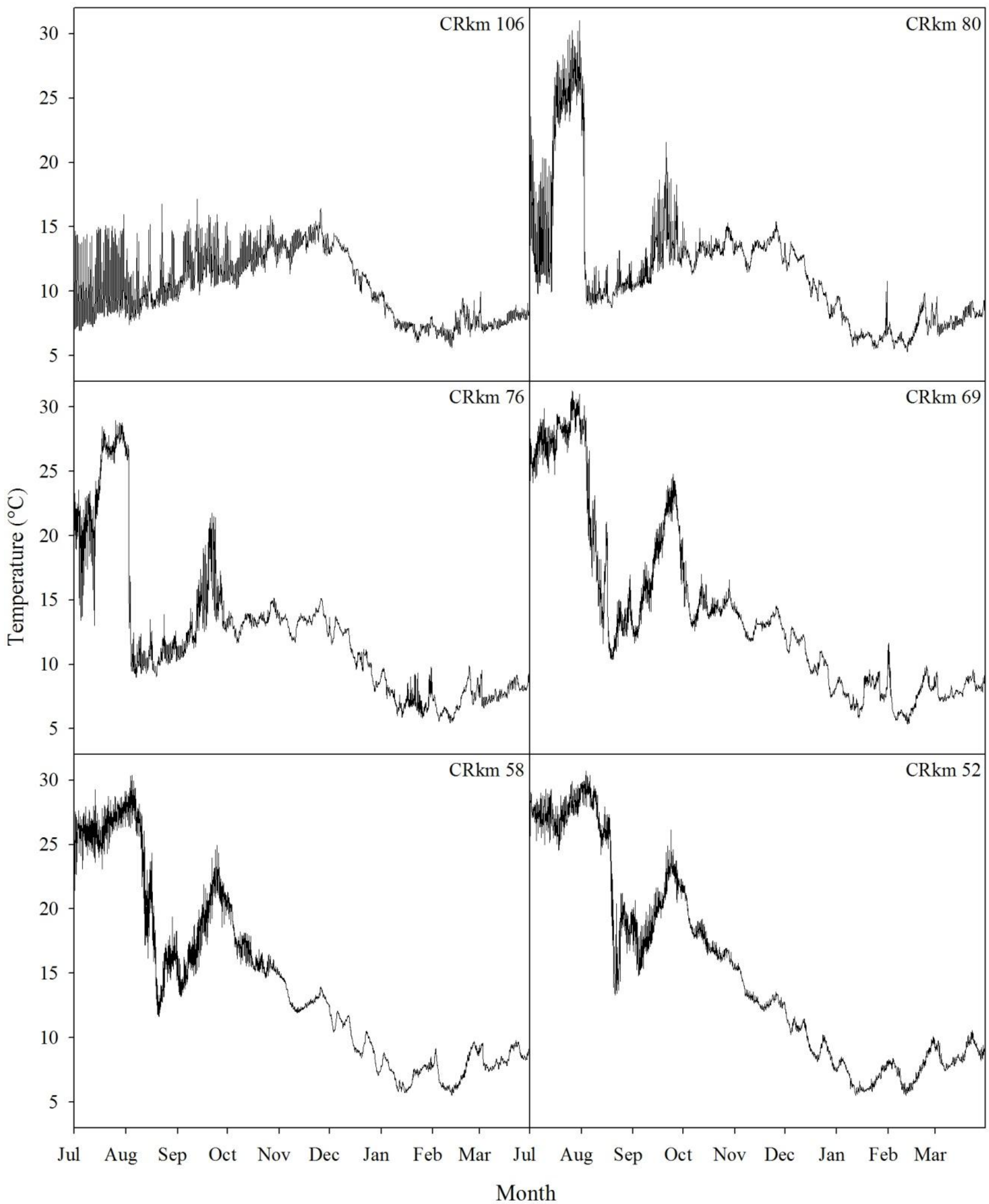


Figure 10. Hourly temperature (°C) recordings from six temperature loggers from July 2010 through March 2011 on Melton Hill Lake, Tennessee. The temperature loggers were located at Clinch River km (CRkm) 106, 80, 76, 69, 58, and 52.

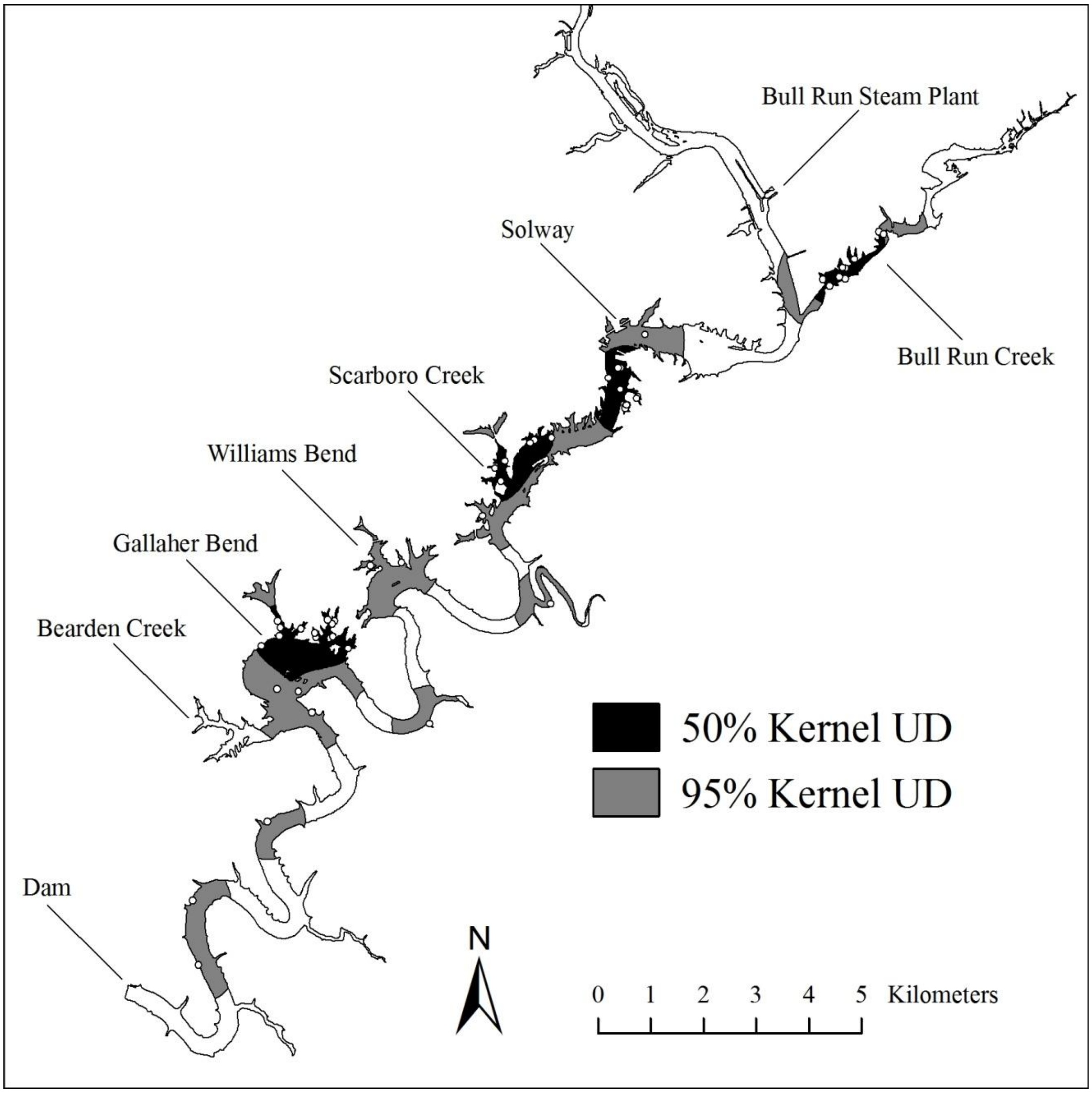


Figure 11. Map of 50% and 95% Kernel Utilization Distributions (UD) in August 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

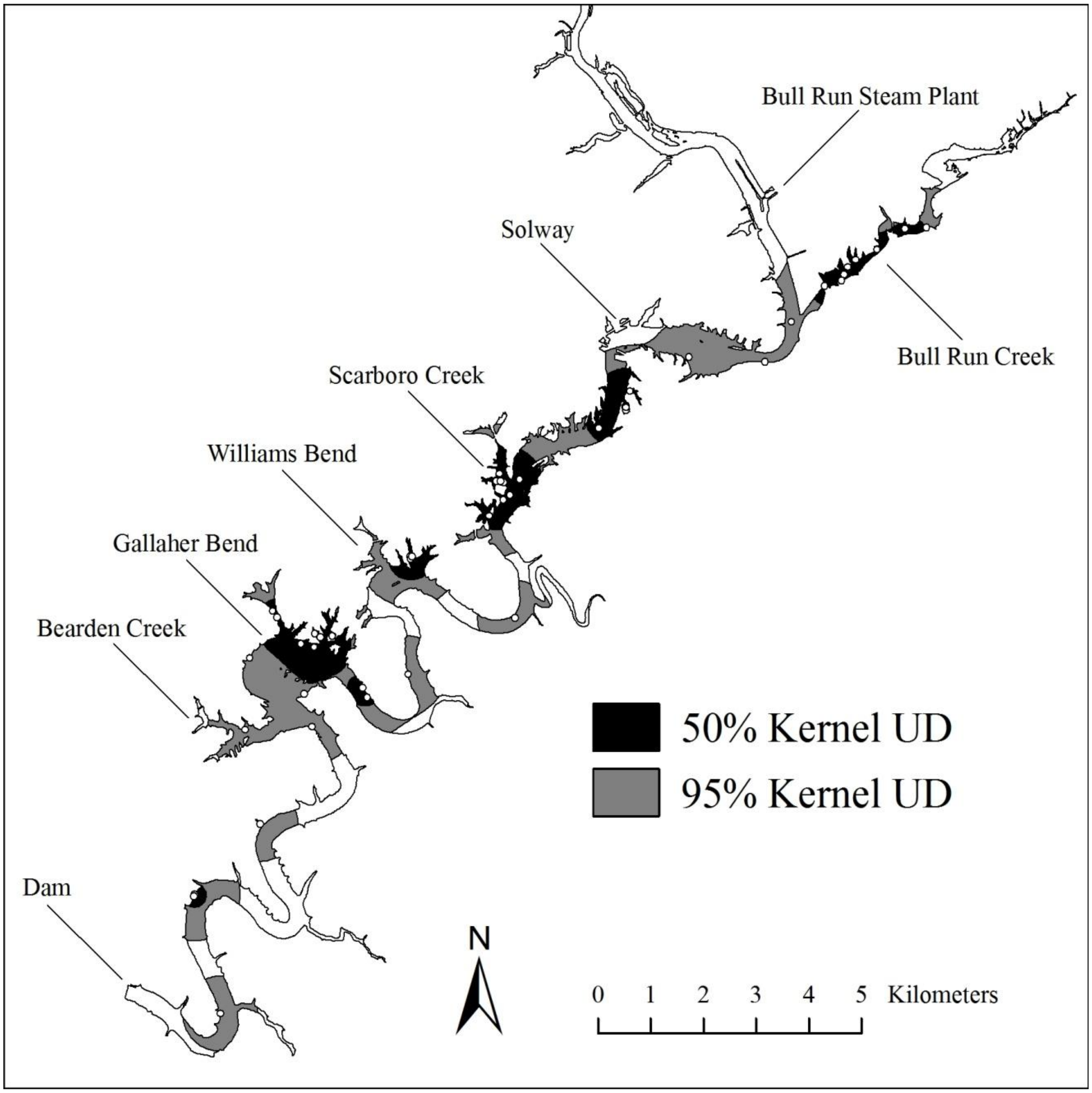


Figure 12. Map of 50% and 95% Kernel Utilization Distributions (UD) in September 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

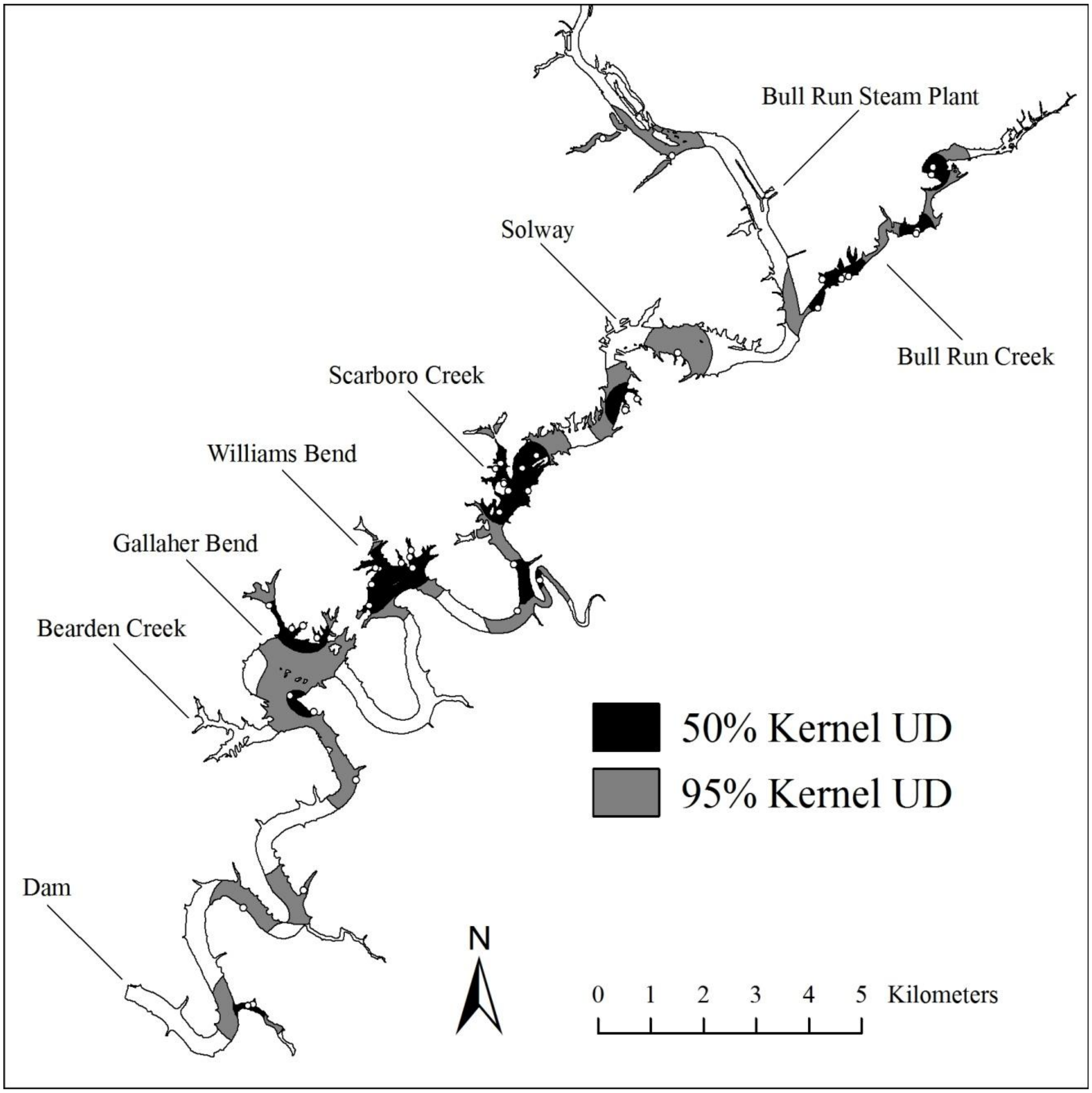


Figure 13. Map of 50% and 95% Kernel Utilization Distributions (UD) in October 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

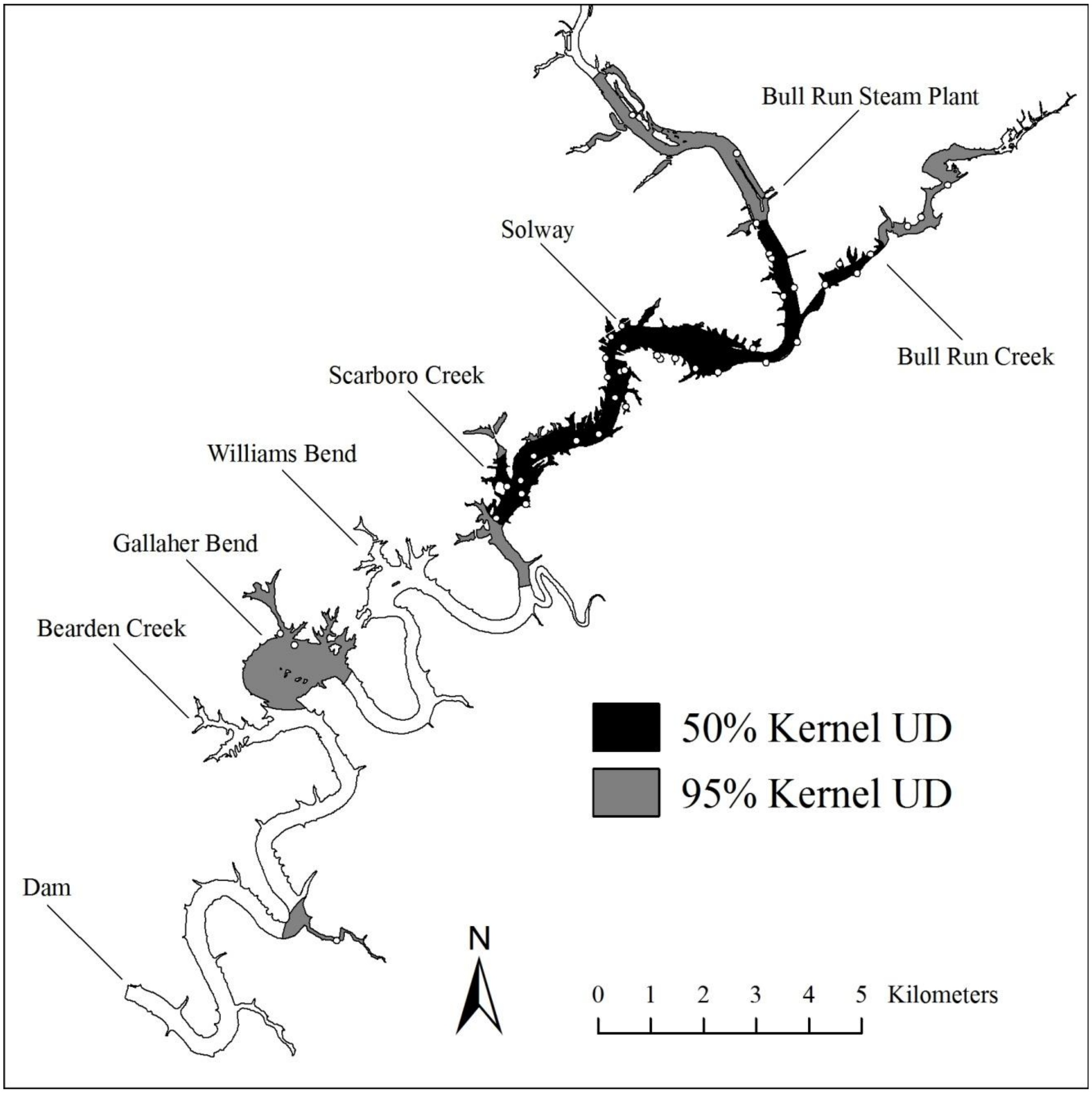


Figure 14. Map of 50% and 95% Kernel Utilization Distributions (UD) in November 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

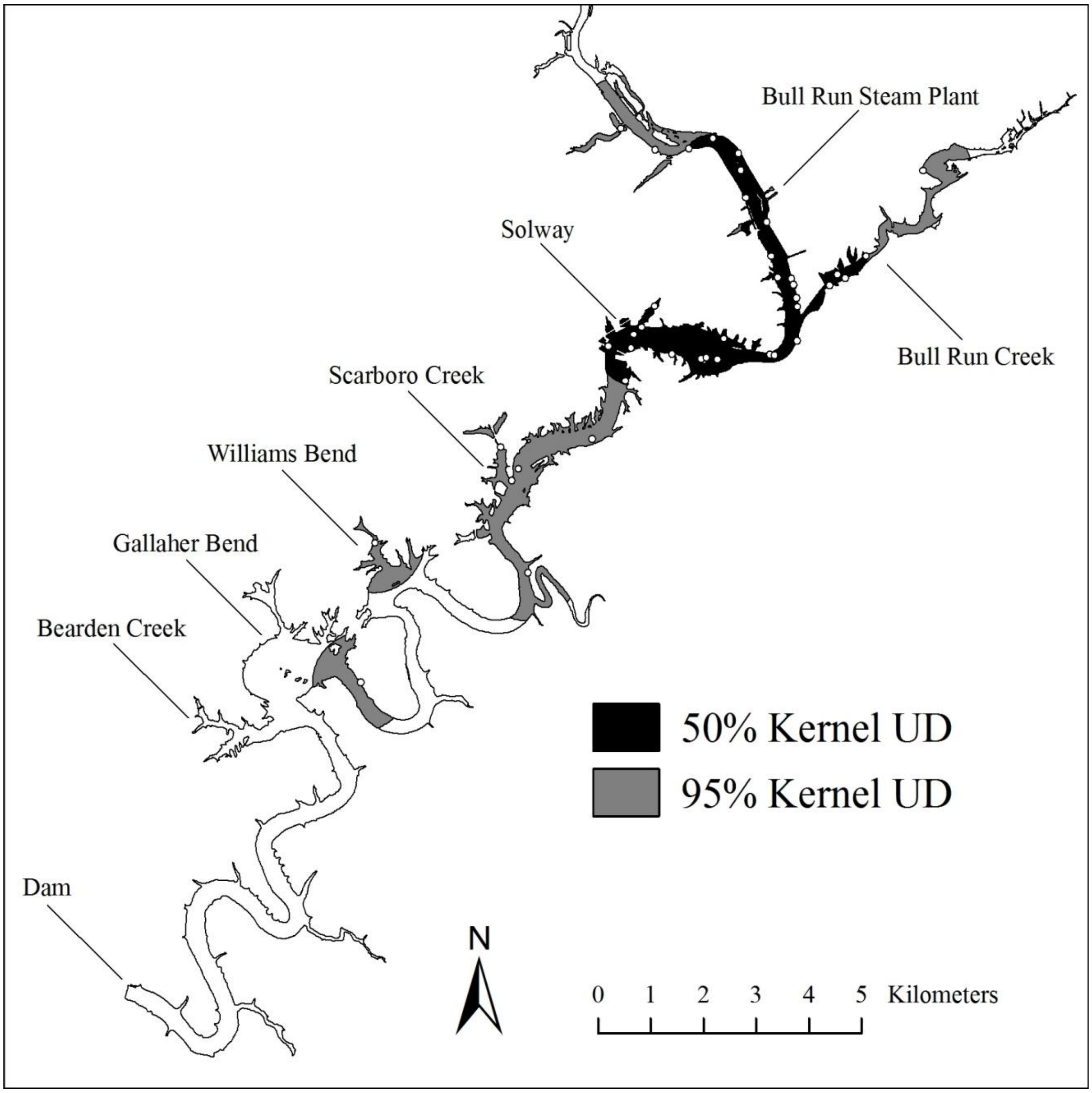


Figure 15. Map of 50% and 95% Kernel Utilization Distributions (UD) in December 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

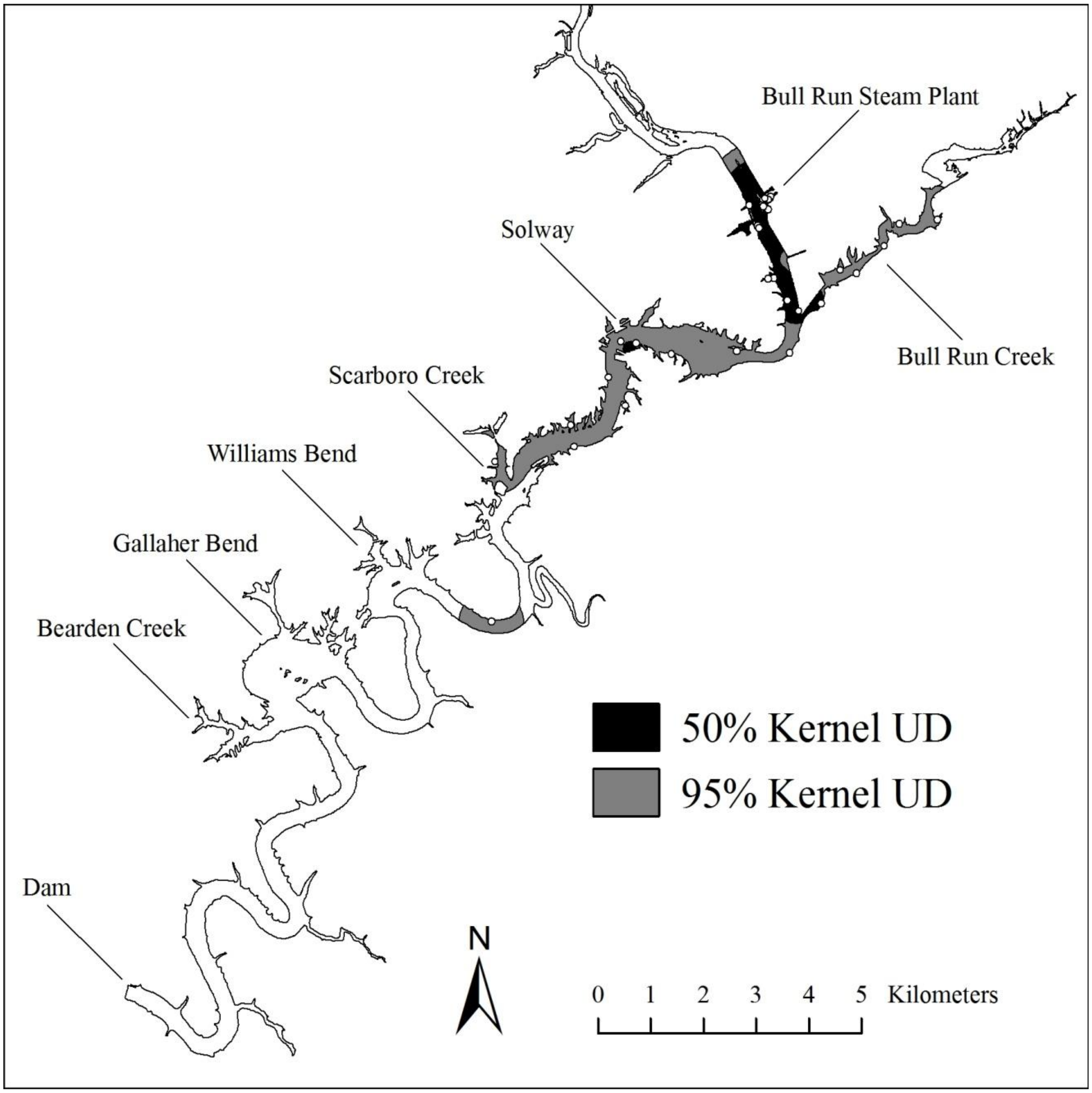


Figure 16. Map of 50% and 95% Kernel Utilization Distributions (UD) in January 2011 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

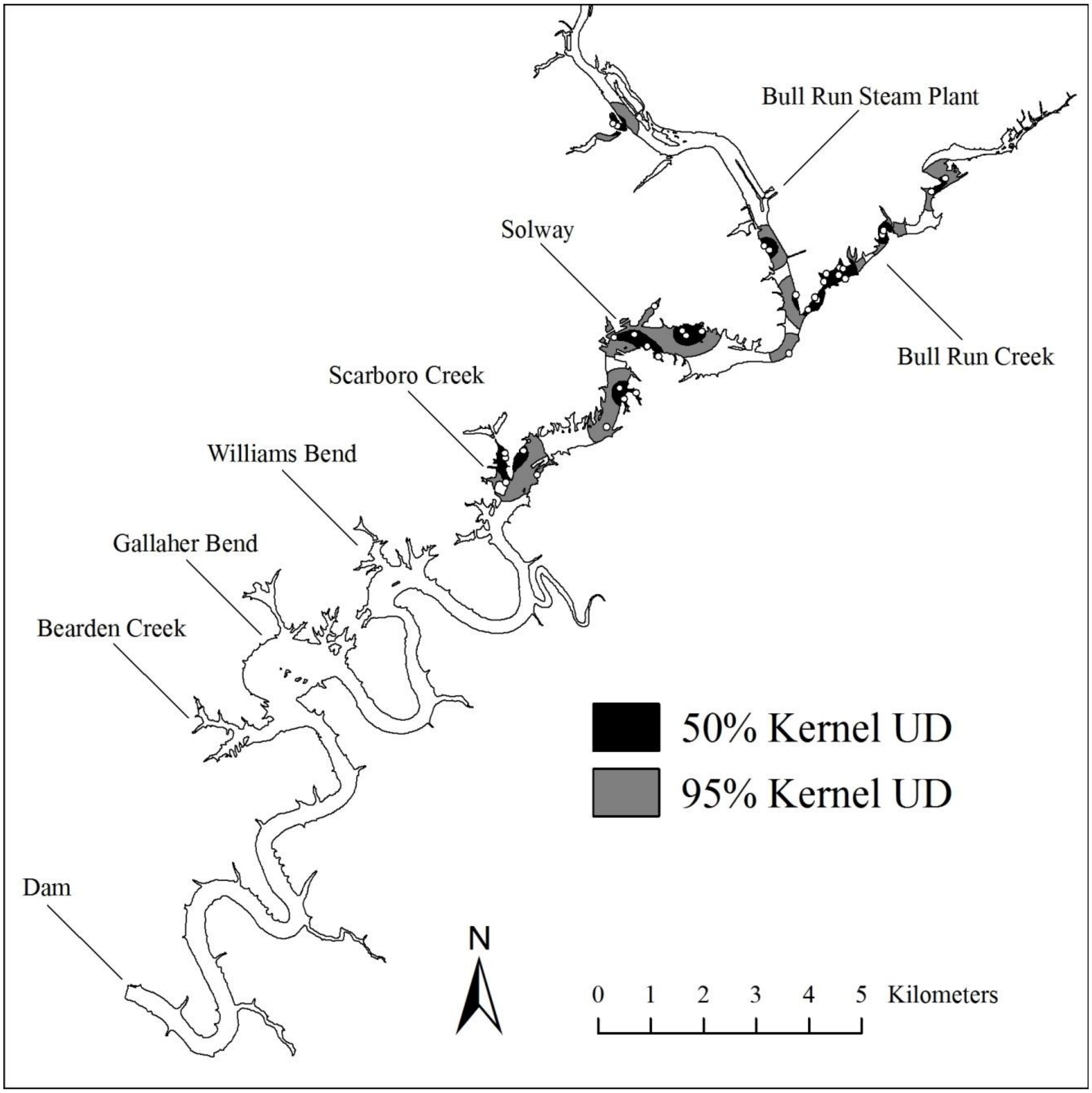


Figure 17. Map of 50% and 95% Kernel Utilization Distributions (UD) in February 2011 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

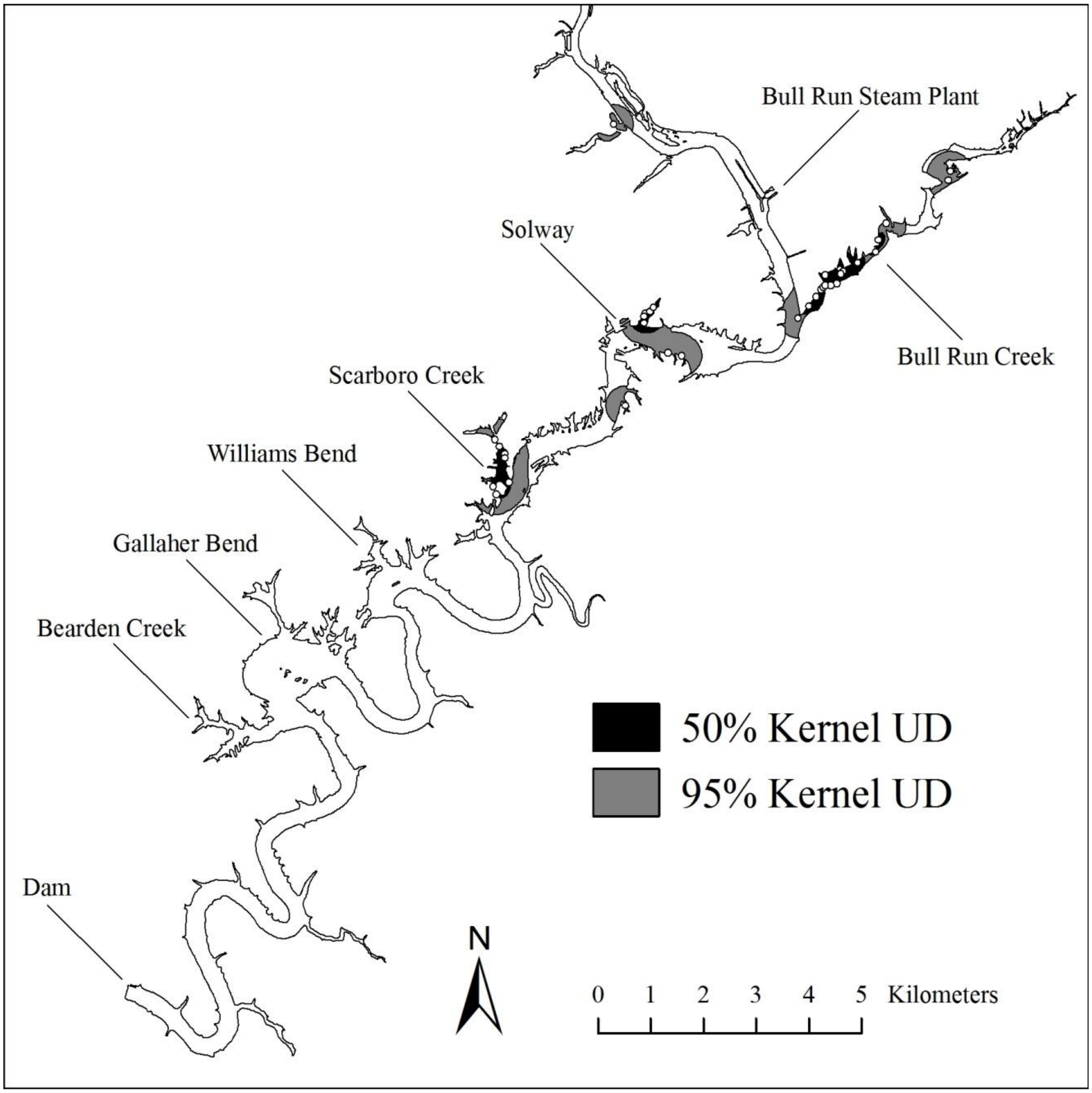


Figure 18. Map of 50% and 95% Kernel Utilization Distributions (UD) in March 2011 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

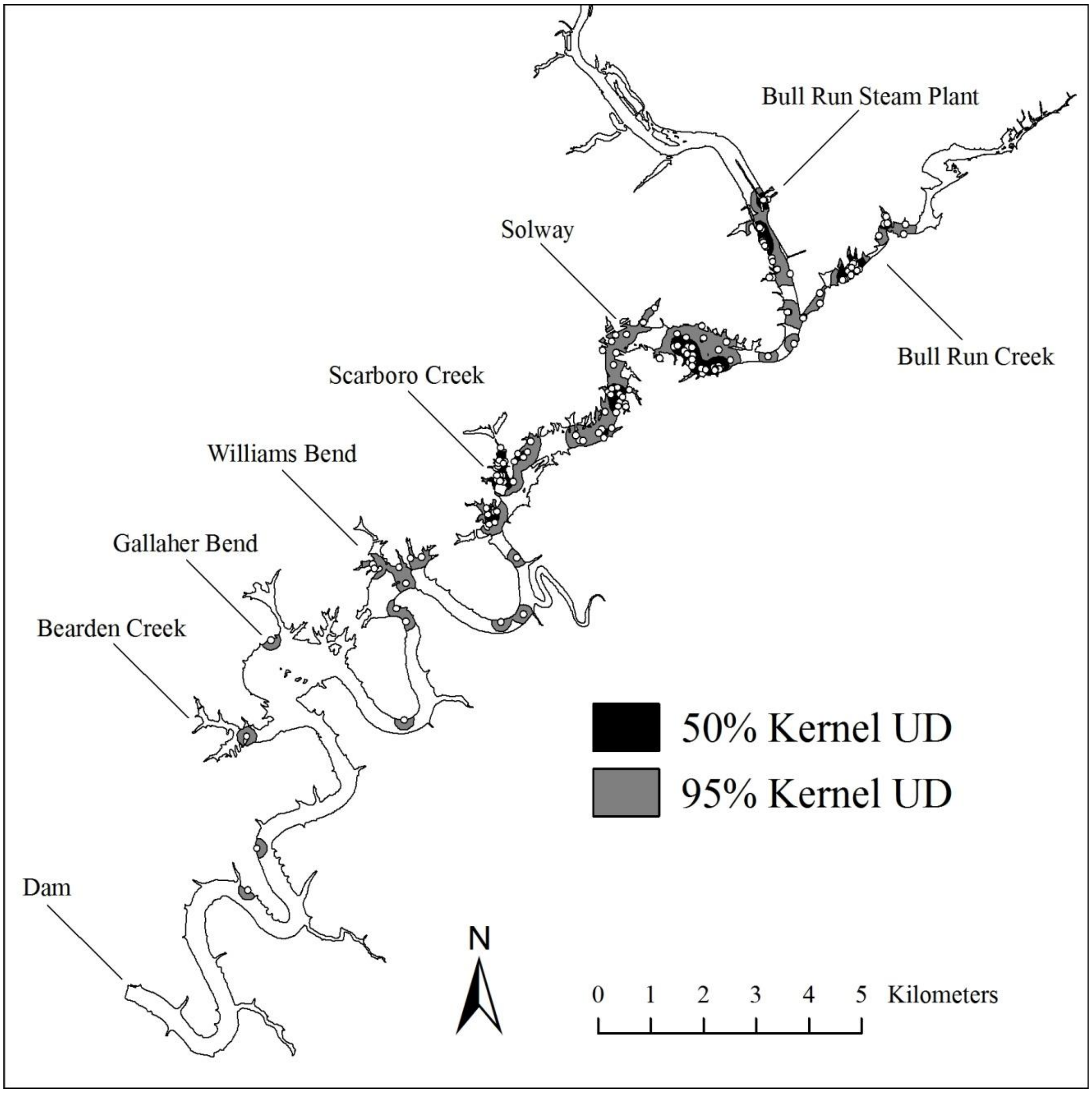


Figure 19. Map of 50% and 95% Kernel Utilization Distributions (UD) in spring 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

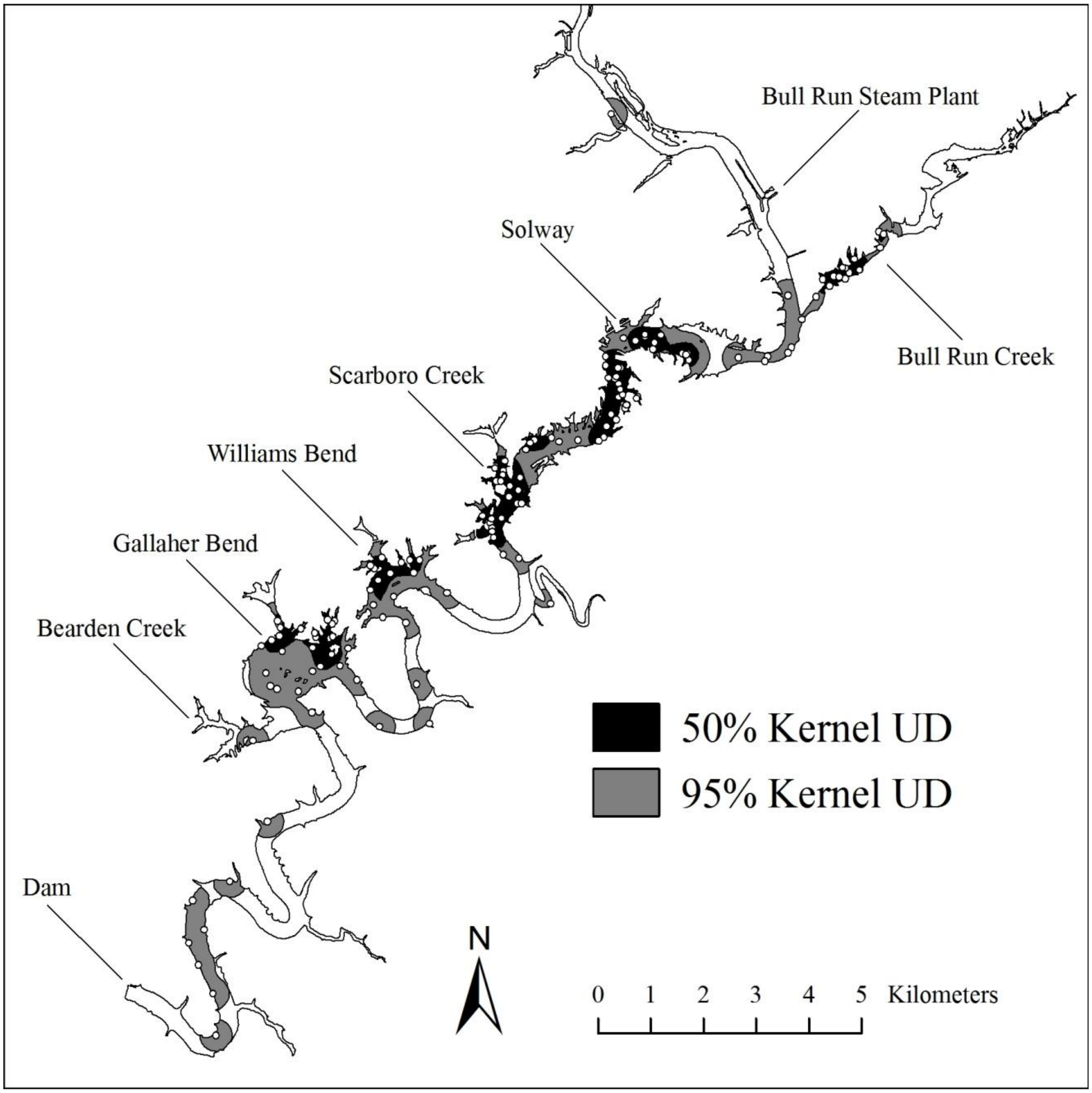


Figure 20. Map of 50% and 95% Kernel Utilization Distributions (UD) in summer 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

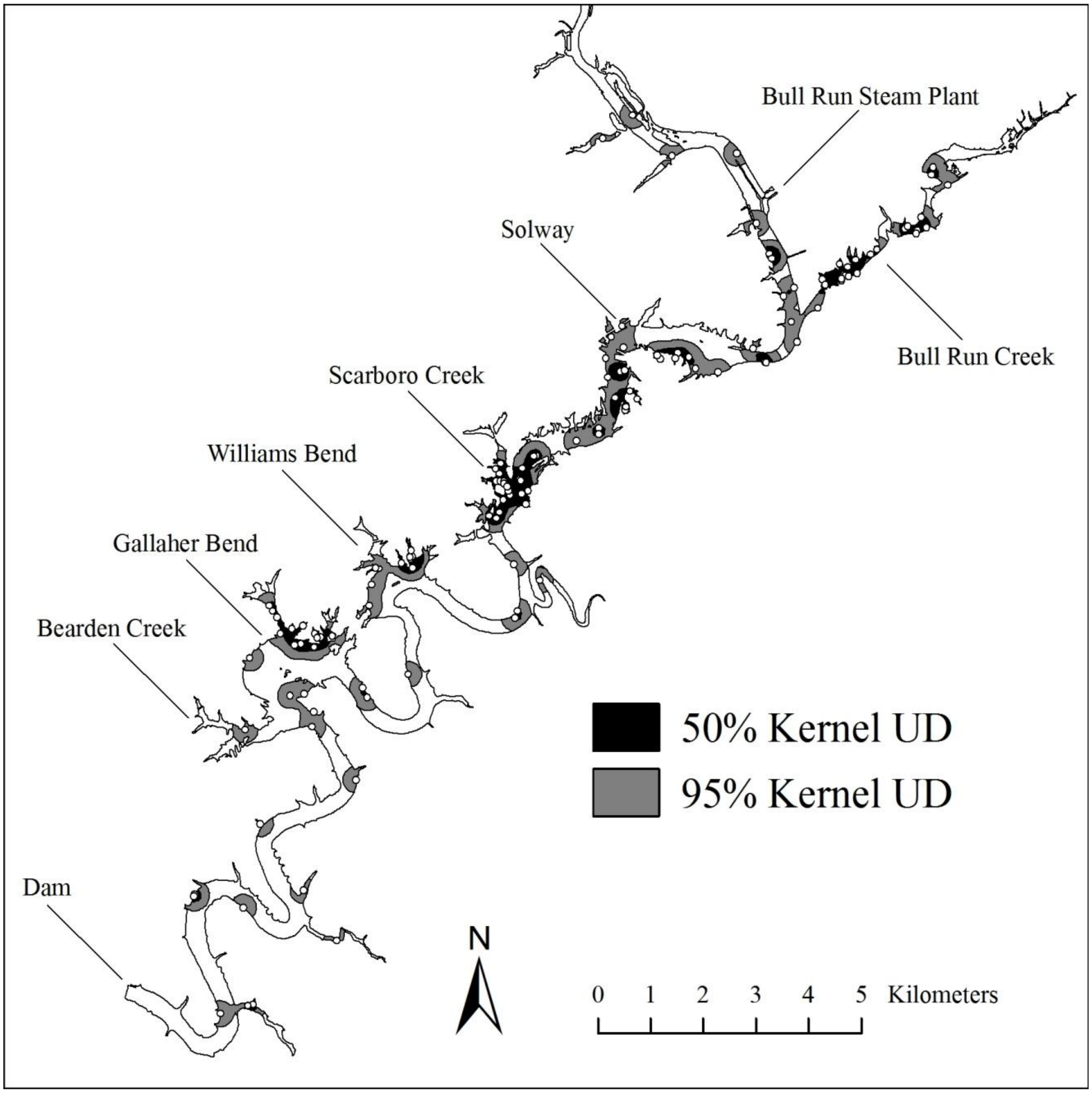


Figure 21. Map of 50% and 95% Kernel Utilization Distributions (UD) in fall 2010 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

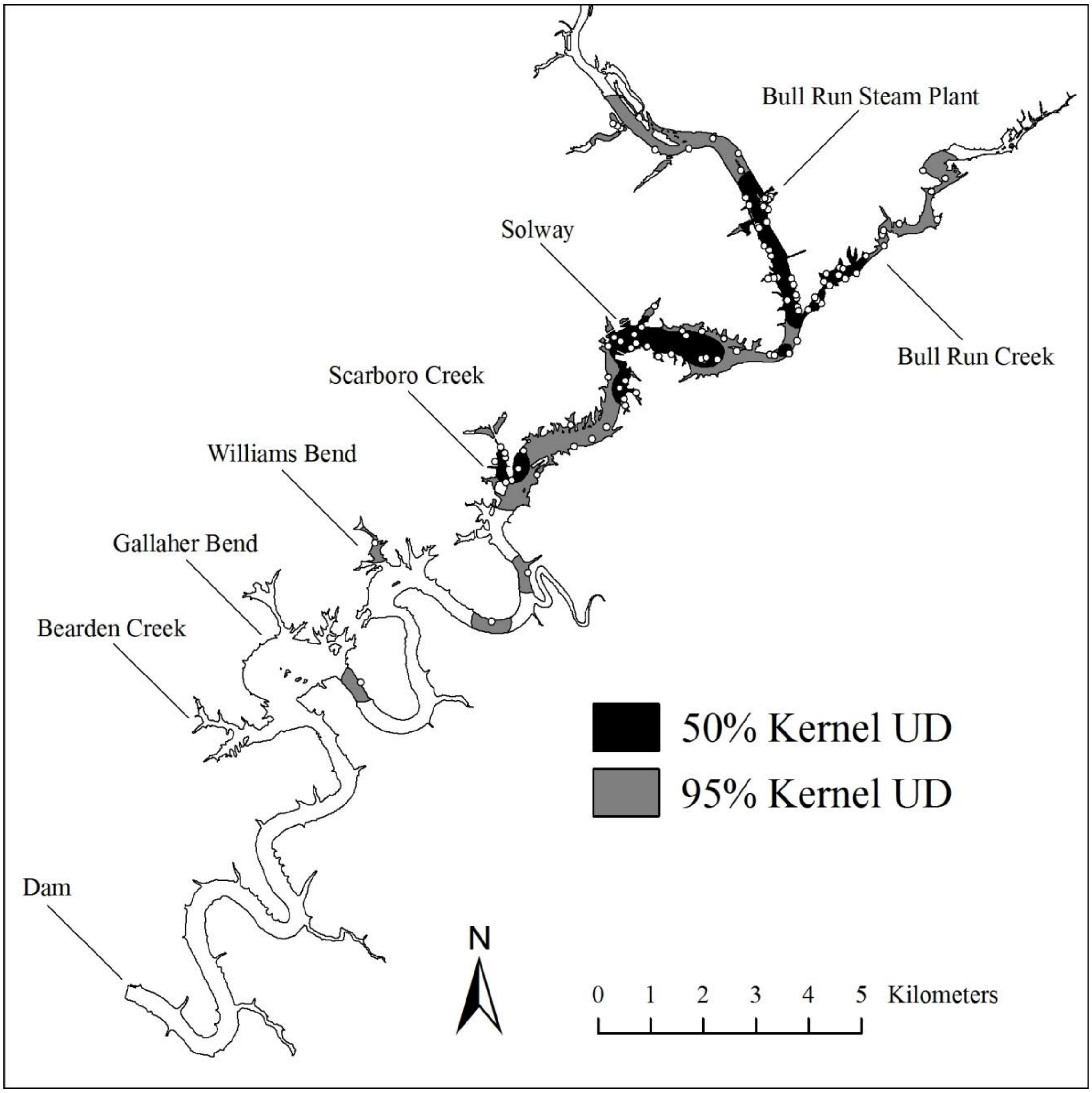


Figure 22. Map of 50% and 95% Kernel Utilization Distributions (UD) in winter 2010–2011 for muskellunge in Melton Hill Lake, Tennessee. Radio telemetry contact locations are indicated by white circles.

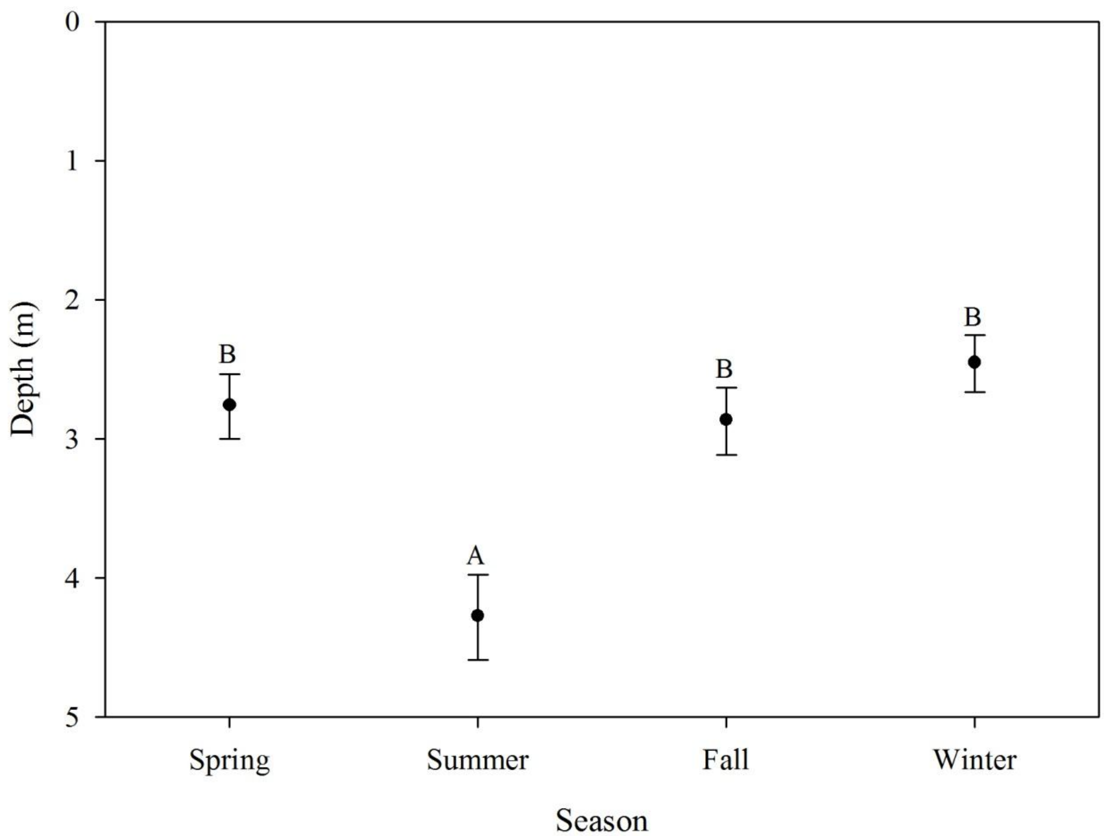


Figure 23. Geometric means and 95% confidence intervals for depth of water (m) where radio-tagged muskellunge were located each season in Melton Hill Lake, Tennessee from 2010 to 2011. Means with the same letter were not significantly different ($\alpha = 0.05$; Bonferroni multiple-comparisons procedure).

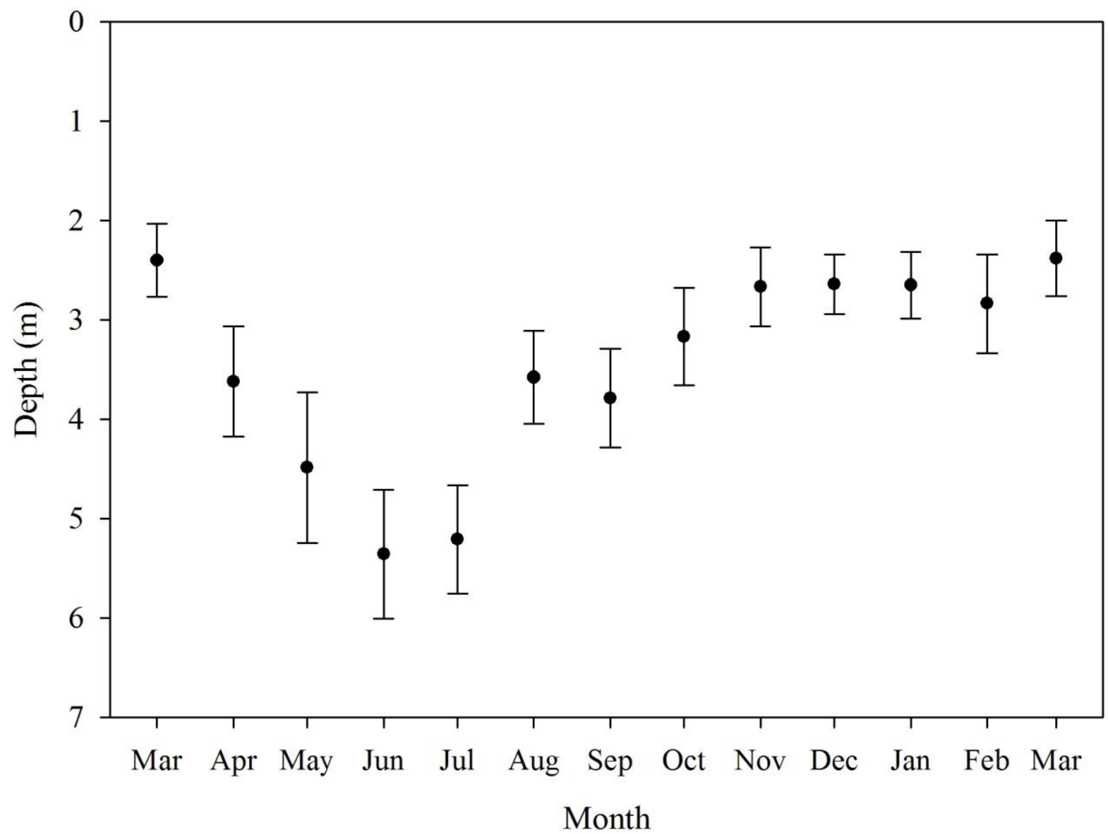


Figure 24. Monthly mean depth (m) of water with 95% confidence intervals where radio-tagged muskellunge were located in Melton Hill Lake, Tennessee from March 2010 to March 2011.

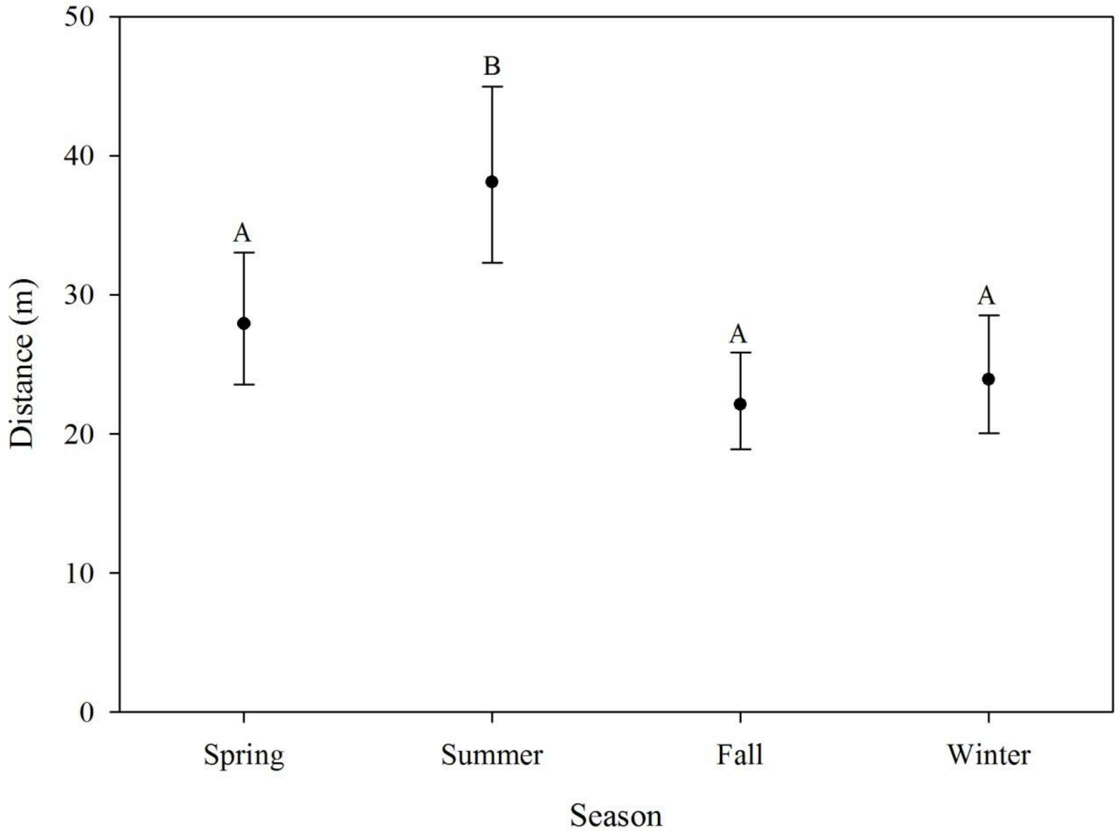


Figure 25. Geometric means and 95% confidence intervals of the distance to nearest shoreline (m) each season for radio-tagged muskellunge in Melton Hill Lake, Tennessee from 2010 to 2011. Means with the same letter were not significantly different ($\alpha = 0.05$; Bonferroni multiple-comparisons procedure).

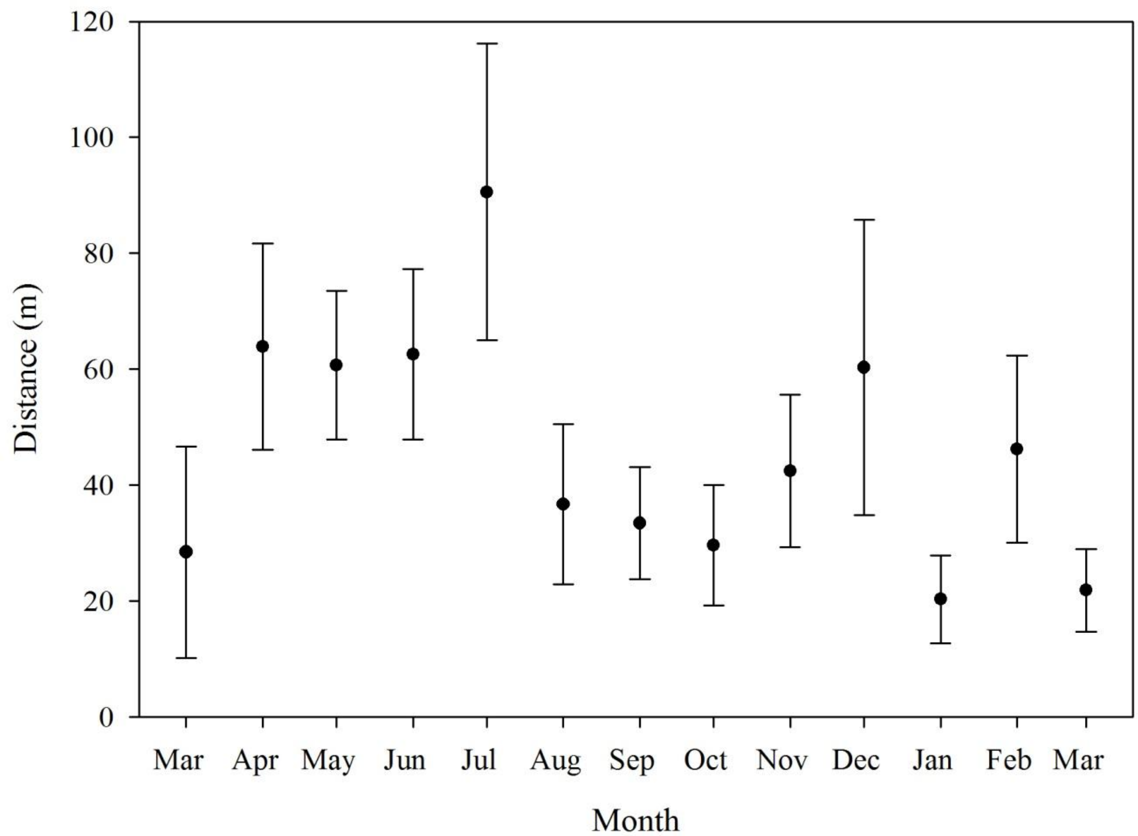


Figure 26. Monthly mean distance to nearest shoreline (m) with 95% confidence intervals for radio-tagged muskellunge in Melton Hill Lake, Tennessee from March 2010 to March 2011.

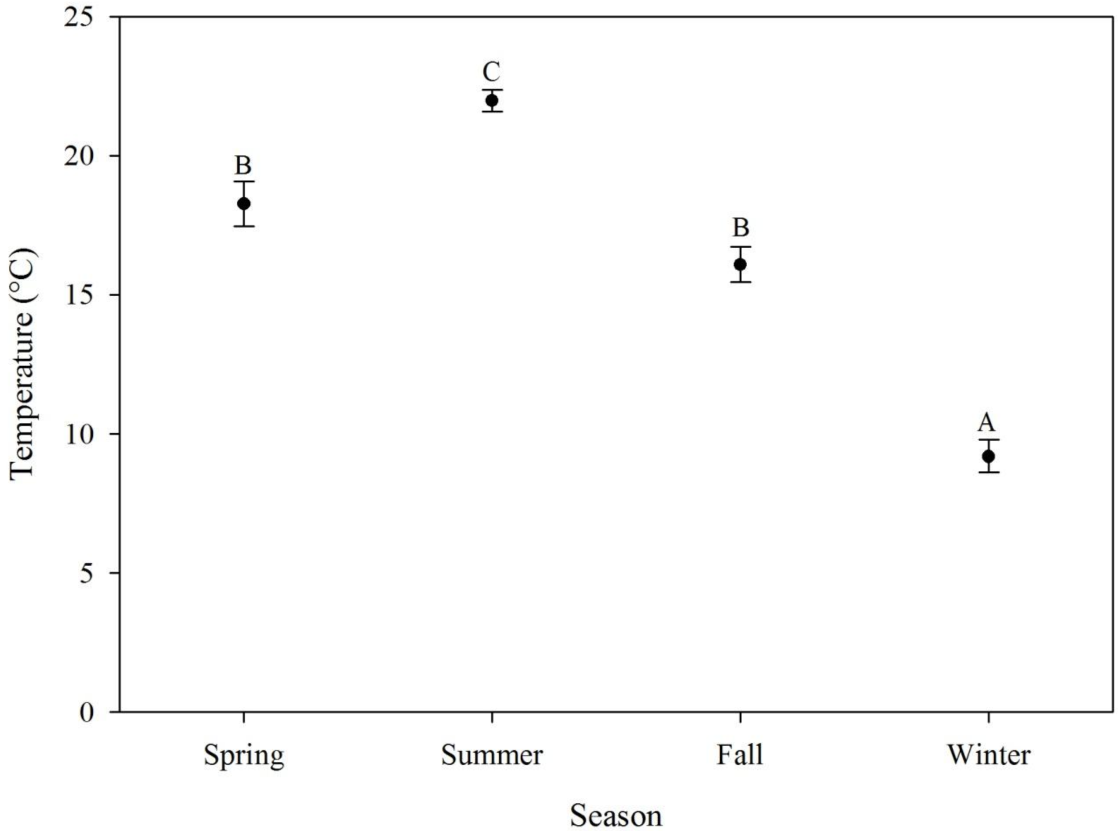


Figure 27. Geometric means and 95% confidence intervals of tag temperature (°C) each season for radio-tagged muskellunge in Melton Hill Lake, Tennessee from 2010 to 2011. Means with the same letter were not significantly different ($\alpha = 0.05$; Bonferroni multiple-comparisons procedure).

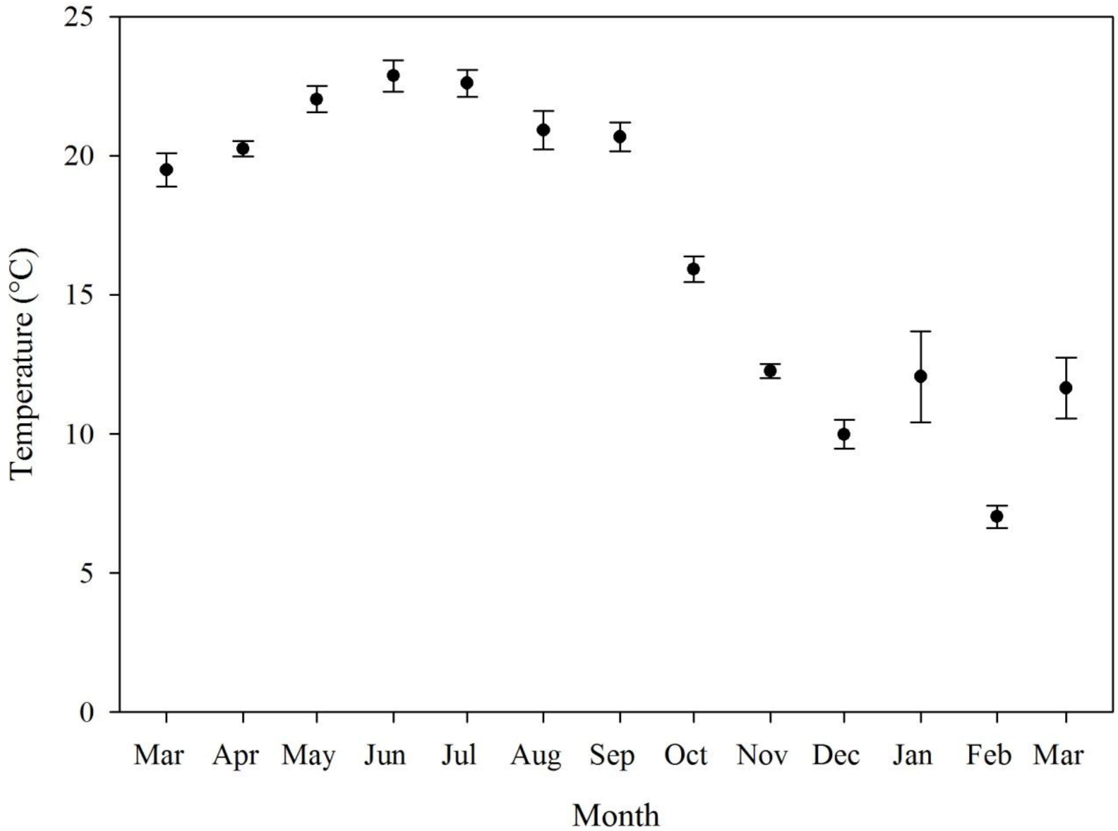


Figure 28. Monthly mean tag temperature (°C) with 95% confidence intervals for radio-tagged muskellunge in Melton Hill Lake, Tennessee from March 2010 to March 2011.

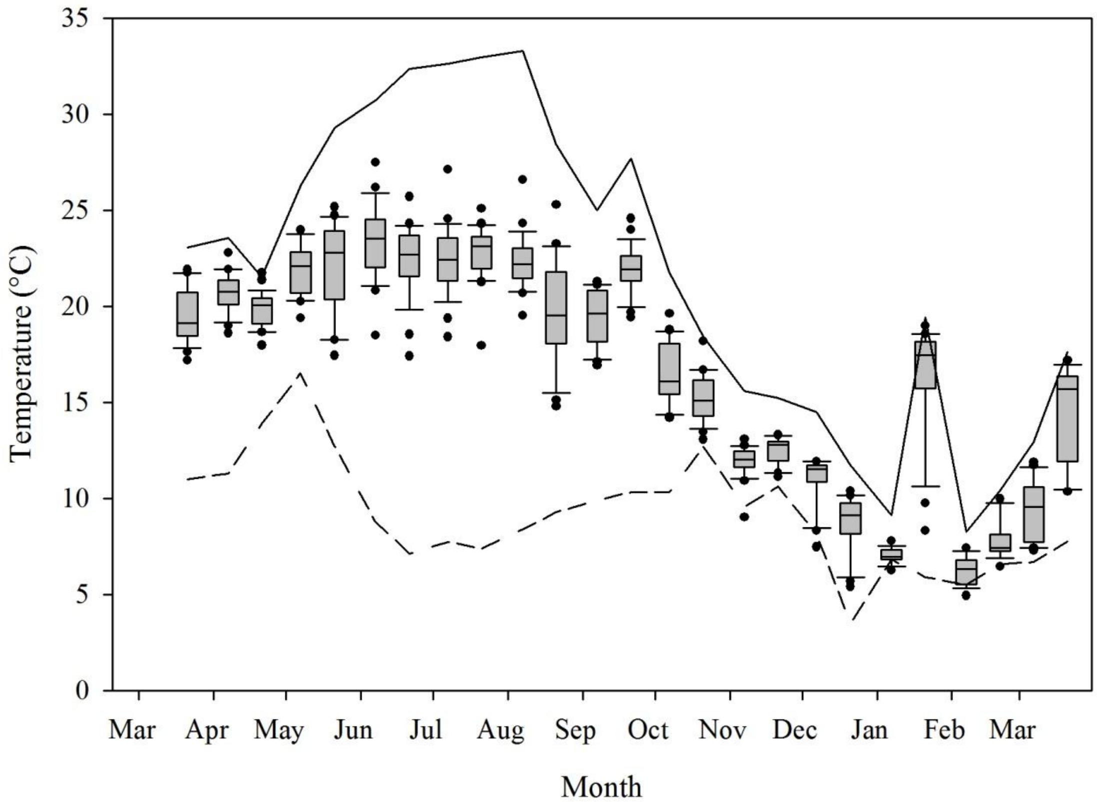


Figure 29. Box and whisker plots of tag temperature (°C) of radio-tagged muskellunge in Melton Hill Lake, Tennessee from March 2010 to March 2011. The lines represent the maximum and minimum temperature observations for the respective tracking events. Each box plot represents an individual tracking event. The lower and upper boundaries of each box indicate the 25th and 75th percentiles, respectively, and the median value is shown as a line within the box. The whiskers below and above each box represent the 10th and 90th percentiles. All outliers are presented as points.

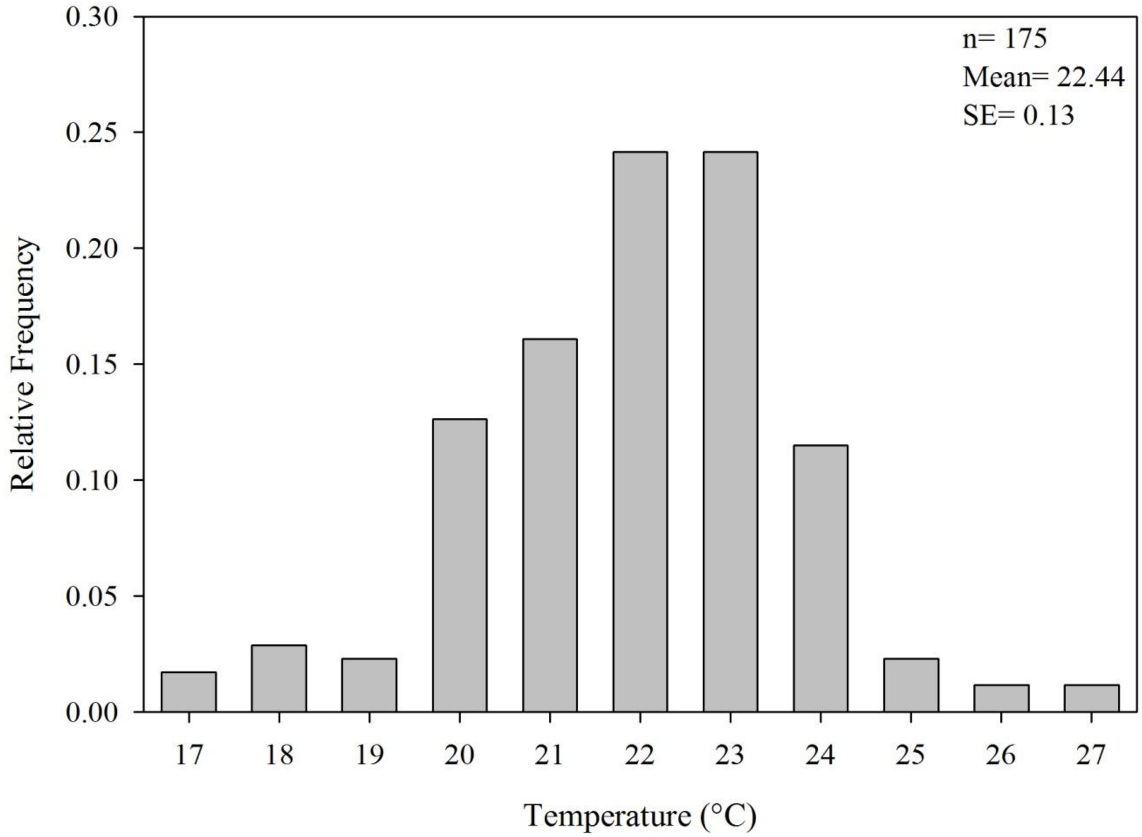


Figure 30. Relative frequency distribution of temperatures (°C) selected by radio-tagged muskellunge in Melton Hill Lake, Tennessee, during May to early August 2010

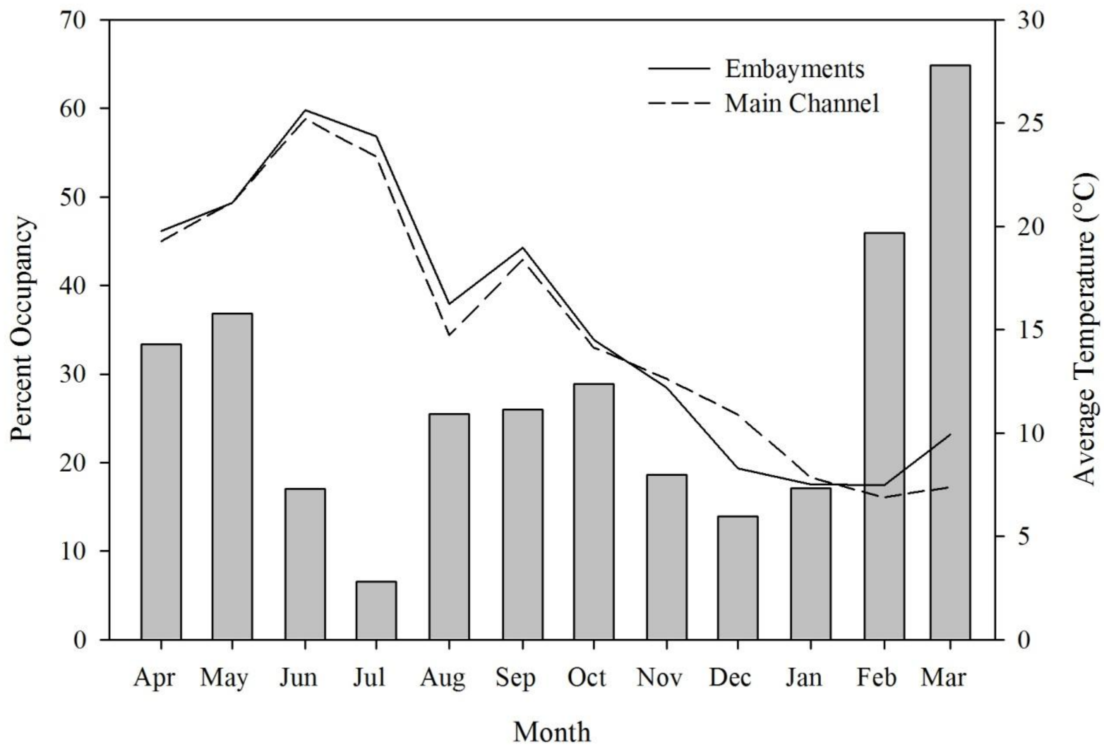


Figure 31. Monthly percent occupancy by tagged muskellunge in the Bull Run Creek and Scarboro Creek embayments (number of locations in embayments/total number of observations) and monthly mean water temperatures (°C; top 5 m pooled) of embayments and main channels from April 2010 to March 2011.

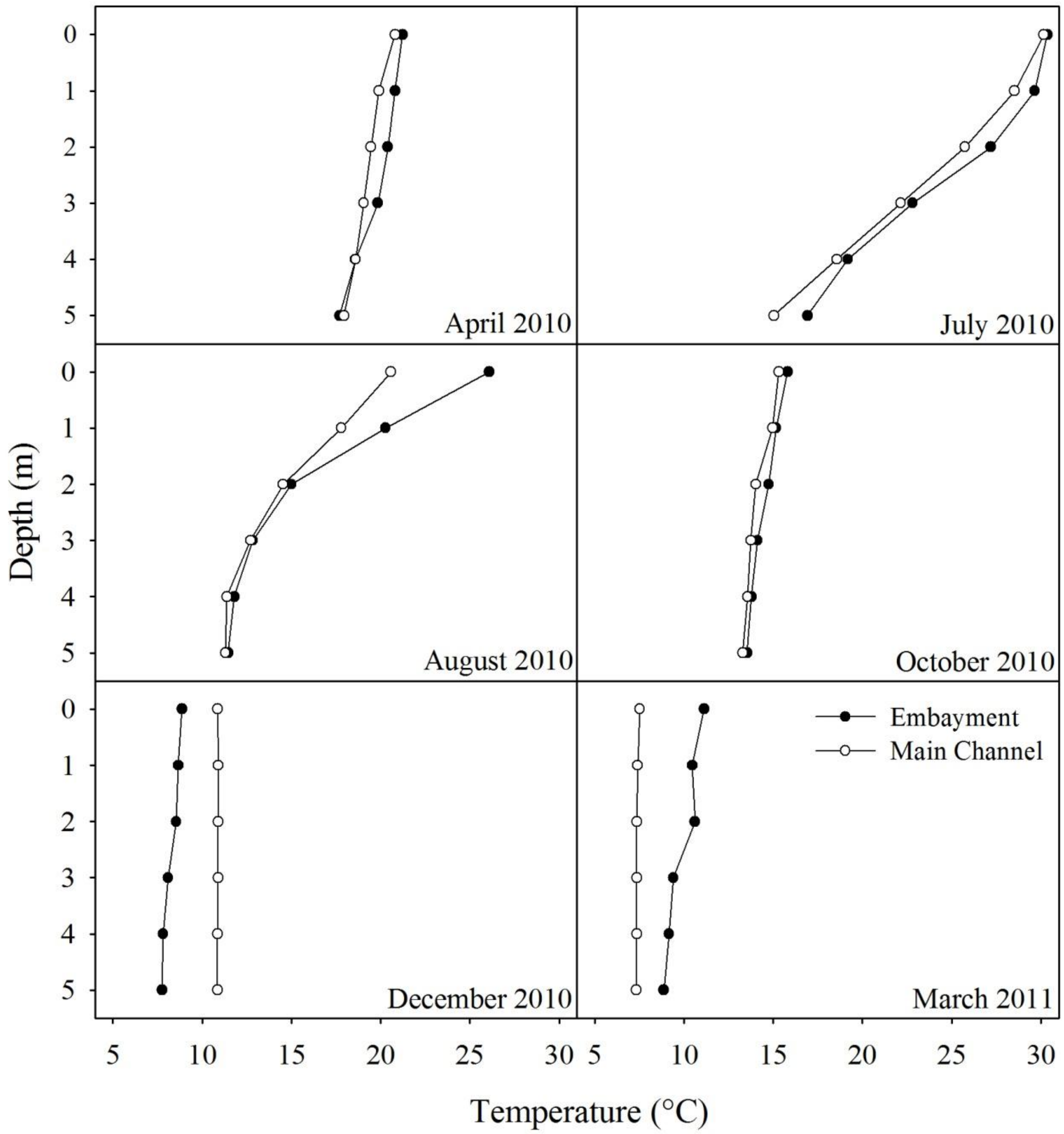


Figure 32. Mean water temperature (°C) in the Bull Run Creek and Scarboro Creek embayments and their adjacent main channels, April 2010 to March 2011.

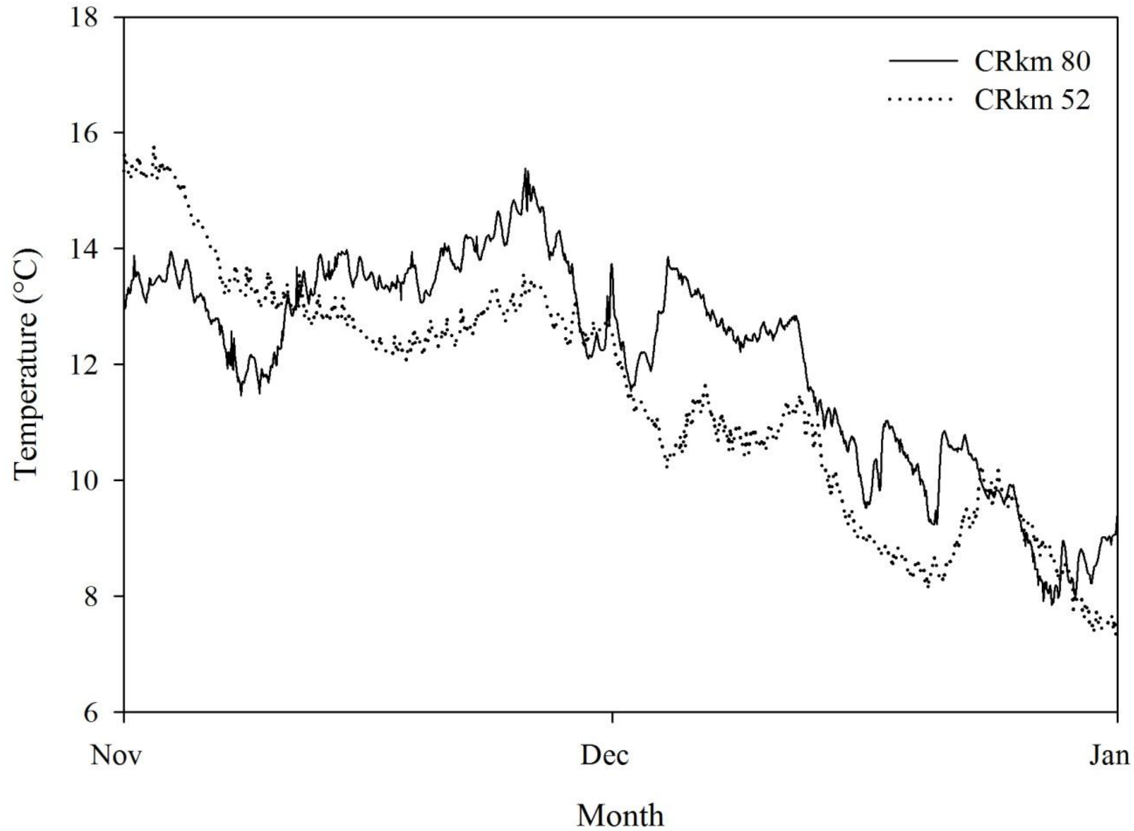


Figure 33.  Hourly water temperatures (°C)  at CRkm 80 and 52 in Melton Hill Lake, Tennessee, November 2010 to January 2011.

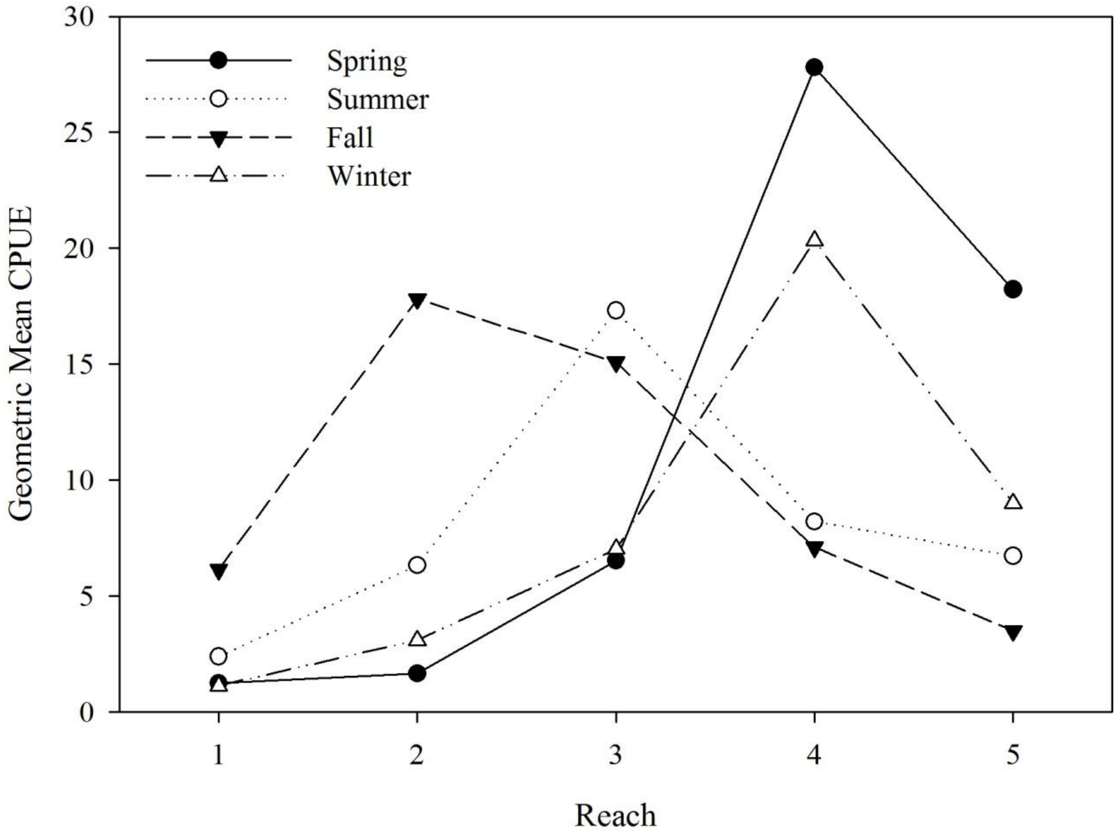


Figure 34. Geometric mean total catch per unit effort (CPUE) by river reach of all potential forage fish (≤ 450 mm TL) from electrofishing samples in Melton Hill Lake, Tennessee 2010–2011.

# VITA

Aaron J. Cole was born on May 24, 1984 and grew up in Manchester, Iowa. He graduated from West Delaware High School in 2003. He received his Associate of Applied Science degree in Natural Resource Management from Hawkeye Community College in 2005 and his Bachelor of Science degree in Animal Ecology with the Fisheries and Aquatic Sciences option at Iowa State University in 2007. He entered Tennessee Technological University in August 2009 and is a candidate for the Master of Science degree in Biology.