

Habitat use and diet overlap of Blue Catfish and Channel Catfish populations in two northeastern  
Kansas reservoirs

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## Abstract

Blue Catfish *Ictalurus furcatus* have increasingly gained recognition as a recreationally valuable species resulting in widespread stocking throughout the midwestern and eastern United States. Successful establishment and proliferation of stocked populations prompts questions about their impacts on other species of management interest through competition and predation. Standardized surveys in Kansas reservoirs have revealed increasing abundance of Blue Catfish populations following stocking. We hypothesize that increasing abundance of Blue Catfish might increase competitive interactions with Channel Catfish *Ictalurus punctatus* because they possess similar morphologies, life histories, and feeding strategies. Acoustic telemetry and gastric lavage were used to quantify the spatial and temporal habitat and diet overlap of these species in two northeastern Kansas reservoirs in 2023 and 2024. Generalized linear models and multivariate ordination techniques revealed that each species had differing spatial distribution patterns ( $p < 0.001$ ) and, on average, Blue Catfish occurred in deeper water (6.84 m) than Channel Catfish (5.09 m;  $p = 0.048$ ). We detected similar movement patterns for both species based on detections on receivers upstream of the reservoirs. Stomach contents of both species were comprised of diverse prey, but Channel Catfish fed more frequently on crayfish ( $p = 0.001$ ) and terrestrial macroinvertebrates ( $p = 0.022$ ). Season had a strong effect on stomach contents ( $p = 0.001$ ) for both species because of the occurrence of spring hatches of Giant Burrowing Mayflies *Hexagenia limbata* and fish eggs produced by spawning Longnose Gar *Lepisosteus osseus*, followed by a shift to terrestrial macroinvertebrates ( $p = 0.001$ ) in the fall. Both species exhibit the potential to use a broad range of habitat and dietary resources; however, under high abundances of Blue Catfish, our data suggests that Channel Catfish might shift resource use to minimize interspecific interactions. Monitoring is necessary to evaluate populations trends and inform harvest management to prevent Blue Catfish populations from negatively impacting their own population and abundance and other species.

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# **Chapter 1 - Evaluation of Blue Catfish and Channel Catfish habitat use and stomach content overlap in two northeastern Kansas reservoirs**

## **Introduction**

Human-engineered reservoirs are a relatively new platform when considering the co-existence of native and introduced species over evolutionary time scales (Feiner et al. 2012; Havel et al. 2015). Stochastic weather events and varying water-level management practices prompt seasonal variability in reservoir conditions that shape the spatiotemporal dynamics of fish assemblages, further challenging our ability to understand and manage these fisheries (Miranda et al. 1984; Moyle and Light 1996; Gido and Mathews 2000, Mathews et al. 2004; Winters and Budy 2015; de Lima et al. 2017; Miranda and Faucheux 2022). Reservoir fisheries managers aim to create or improve recreational angling by stocking sportfish or species of conservation interest (Miranda and Bettoli 2010; Fonken et al. 2023). The resulting interaction between actively managed sportfish and the pre-impoundment fish assemblage are unpredictable because of the limited co-evolutionary history in this environment (Gido and Mathews 2000; Mathews et al. 2004). Specifically, the ecological effects of introducing or supplementing generalist or piscivorous sportfish populations might result in negative interactions among species. However, intensity of those interactions should be a function of the severity of niche overlap (May and MacArther 1970; McComas and Drenner 1982) and species ability to partition resources (Schoener 1989; Edds et al. 2002; Westrilen 2022).

Competitive interactions from introduced species can displace native species and other species of management interest leading to alterations in the fish community and conditions suitable to biotic homogenization (Rahel 2002; Clavero and Hermoso 2011; Petsch 2016; Hilling et al 2023). Competition and predatory interactions between established introduced species and native species can be stochastic, with coexistence dependent on resource availability (Juncos et al. 2015; de Andrade et al. 2024), resource partitioning (Werner and Hall 1977) or competitive exclusion of resources (Jackson et al. 2016). Resource availability can shift with seasonally abundant resources, such as insect hatches or when elevated flows inundate floodplain habitat, enabling coexistence of species that share similar niche space (Juncos et al. 2015; de Andrade et al. 2024). Alternatively, asymmetric resource exploitation during periods of reduced resource

availability can exclude less competitive species from using a resource (Langeland et al. 1991; Jackson et al. 2016), reducing the abundance or distribution of the less competitive species (Hindar et al. 1988). Partitioning can also allow for coexistence when competing species shift their resource use or feeding strategy to minimize exploiting similar resources (Werner and Hall 1977). Unfortunately, interactions between species exhibiting resource partitioning or competitive exclusion are challenging to directly study and become increasingly complex when attempting to identify interactions between introduced and native species occupying unknown but potentially overlapping niche space.

Introduced species often have generalist traits such as diet flexibility and high tolerance to habitat alterations that can result in prolific dispersal and population growth (Rahel 2002; Clavero and Hermosa 2011; Juncos et al. 2015; Schmitt et al. 2017; Dominguez et al. 2021). The strength of interspecific competition between coexisting species is generally greatest when species are functionally similar (Case et al. 2016), closely related (Newman 1956) or if shared resources are lost to environmental disturbances (Elliott 2006). As reservoirs age, they are increasingly losing water storage capacity, homogenizing benthic habitat, and reducing water quality (Gido et al. 2000; Rahmani et al. 2018; Pennock and Gido 2021; Miranda and Faucheux 2022), all of which can limit resources for competing species and potentially increase interspecific interactions. Understanding possible consequences and outcomes of interspecific competition between native and supplemented or introduced species is crucial to inform sustainable reservoir fisheries management.

One species that has garnered national attention over the last decade is the Blue Catfish *Ictalurus furcatus* because of its value as a sportfish but potentially negative ecological impacts and management uncertainties. Blue Catfish are native to the Mississippi, Missouri, Ohio and Rio Grande river drainages but have recently been stocked beyond their native range. Expansion of Blue Catfish populations outside of their native range warrants research to guide future management of the species. Blue Catfish populations in the eastern United States, particularly in the Chesapeake Bay, have earned the reputation of invasive because of the rapid proliferation outside of the initial tributaries in Virginia where the introduction occurred in the 1970s (Schmitt et al. 2019). Opinions regarding the success of established Blue Catfish populations vary greatly because the population has become a viable commercial and recreational fishery but also competes with species of interest. Blue Catfish are associated with the decline of native White

Catfish *Ameiurus catus* and are known to prey on other species of recreational, commercial, and conservation interest (i.e., Blue Crab *Callinectes sapidus* and Herring *Alosa spp.*; Schmitt et al. 2017; Fabrizio et al. 2021; Hilling et al. 2023). However, less attention has been given to increasing Blue Catfish populations within Midwestern reservoirs on the periphery of their native range, where less is known about their direct impacts on reservoir fish communities.

A notable trend in Kansas reservoirs is the increasing abundance of Blue Catfish over the last decade (Miller et al. 2022a). Increasing population abundance has been documented in annual gillnet and creel surveys across large impoundments, but factors contributing to increasing abundance are generally unexplained and not well understood. Blue Catfish is native to northeastern Kansas within the Kansas, Marias de Cygnes, and Missouri river drainages (Cross 1967; Miller et al. 2022a). By the late 1990s, natural recruitment in Milford Reservoir had become evident from back calculating lengths at age, providing support for population self-sustainment in the absence of stocking programs (Goeckler et al. 2003). Indications of natural recruitment following stocking events intensified stocking efforts in other large impoundments in eastern Kansas over the next several decades (Miller et al. 2022a). Despite the rapid population growth of Blue Catfish being favorable for recreational angling, effects on Kansas reservoir fish communities are largely unknown.

Implications of increasing Blue Catfish populations in Kansas impoundments are not clearly understood but competition for resources might exist with other sportfish, as hypothesized in other regions with well-established Blue Catfish populations (Graham 1999, Edds et al. 2002; Mauck and Boxrucker 2004; Schmitt et al. 2017). Blue Catfish and Channel Catfish *Ictalurus punctatus*, for example, coexist in reservoirs and possess similar morphological features, feeding strategies, habitat use, and spawning requirements (Tucker and Robinson 1990; Pflieger 1997; Graham 1999; Hubert 1999; Edds et al. 2002; Peterson 2015). Channel Catfish retain recreational importance and are often defined as the “bread and butter” of Kansas fishing (Stephen 2008; Steffen 2015; Miller et al. 2022a). The two Ictalurids share overlapping native ranges in Kansas (Pflieger 1997), likely resulting in a co-evolutionary history of competition and resource partitioning (Grinnell 1917; Hutchinson 1959; Schoener 1974; Edds et al. 2002). However, increasing populations of Blue Catfish have been associated with the decline of congeneric species such as the Channel Catfish (Bentley 2023) and White Catfish (Schloesser et

al. 2011; Schmitt et al. 2017), thus there are concerns of Channel Catfish abundance declines associated with increasing abundance of Blue Catfish.

Limited literature has quantified habitat use and overlap of Blue Catfish and Channel Catfish throughout their introduced and native range. A resource competition study by Edds et al. (2002) in Lake Texoma, USA, found spatial distribution patterns unique to Channel Catfish and Blue Catfish but also revealed seasonal overlap in habitat use between the two species from gillnet surveys, particularly in the spring. Little is known about Blue Catfish spawning, but it is assumed that they are cavity nesters, analogous to the Channel Catfish, so overlap during spring could be in association with movements into littoral habitats with potentially limiting nesting sites (Pflieger 1997; Graham 1999; Edds et al. 2002; Lee 2009). Despite some similarities in the habitat use by these species, distinct spatial distributions patterns indicate that Blue Catfish inhabit deep, offshore, and more pelagic habitat in main channel and creek thalwegs; differing from Channel Catfish that select for shallow, more littoral habitat (Edds et al. 2002). Blue Catfish often select for open, deepwater habitat in reservoirs or deep pools with swift current in large rivers (Pflieger 1997; Graham 1999; Edds et al. 2002), although some studies report use of shallow water and inflow regions in reservoirs (Gerber et al. 2019). Channel Catfish often occur at shallow depths and littoral zones of reservoirs but occasionally use pelagic and deep-benthic habitats (Pflieger 1975; Edds et al. 2002; Laughlin et al. 2016). Given the ability of Channel Catfish to exploit a wide range of habitats (Klaassen and Marzolf 1971), Edds et al. (2002) hypothesized that Channel Catfish will exploit more pelagic and deeper benthic habitat when isolated in a system without the presence or low abundance of Blue Catfish.

It is likely that Blue Catfish and Channel Catfish are competing for resources in Kansas reservoirs despite being described as opportunistic, generalist, and omnivorous (Graham 1999). Opportunistic feeding on seasonally abundant prey in productive reservoirs might not result in overexploitation of resources but would result in feeding niche overlap of coexisting species (Edds et al. 2002; De Andrade et al. 2024). Opportunistic and omnivorous feeding strategies allow Blue Catfish to feed at various trophic levels (Graham 1999; Schmitt et al. 2019) supporting a wide diet breadth comprised of fish, crustaceans, mussels, aquatic and terrestrial macroinvertebrates, and vegetation (Pflieger 1975; Graham 1999; Edds et al. 2002; Schmitt et al. 2017; Schmitt et al. 2019; Miller et al. 2022; Hilling et al. 2023). Channel Catfish also opportunistically feed on macroinvertebrates, fish, mollusks, crustaceans, and aquatic vegetation

(Davis 1959; Jearld and Brown 1971; Edds et al. 2002; Hilling et al. 2016). In addition to identifying distinct habitat use patterns, Edds et al. (2002) revealed near complete diet overlap between Blue Catfish and Channel Catfish. The potential diet overlap between Blue Catfish and Channel Catfish, as has been seen with Blue Catfish and other common sportfish (Graham 1999; Edds et al. 2002; Hilling et al. 2023), demonstrates the possibility of competition for food resources (Schmitt et al. 2019).

Our objectives were to use acoustic telemetry and stomach content analysis to quantify spatial and temporal interactions of Blue Catfish and Channel Catfish in two Kansas reservoirs. We hypothesize that coexistence of Blue Catfish and Channel Catfish results from similar use of abundant resources enabling opportunistic feeding on seasonally abundant prey despite widely overlapping habitat use. Findings of our study aim to build on the knowledge of complex interactions among reservoir fishes with implications for future management of native and invasive species that ensures the sustainability of recreationally important fisheries.

## **Methods**

### **Study Area**

Acoustic telemetry and stomach content studies were conducted in two reservoirs in northeastern Kansas (Figure 1.1). Milford Reservoir is the largest reservoir in Kansas (6,475 ha) with a maximum depth of 19.8 m and average depth of 7.4 m (Miller 2021). The reservoir impounds the Republican River just upstream of its confluence with the Smoky Hill River. Milford Reservoir began operation in 1967, primarily for flood control, although water is maintained at a relatively constant reservoir elevation for conservation management, recreation, and at times, to support navigation of larger waterways (Miller et al. 2022b; Shelley 2015). Tuttle Creek Reservoir was constructed by the U.S. Army Corp of Engineers in 1963 as a flood control reservoir but also is managed for conservation, recreation, and to support navigation of downstream waterways (Coleman 2023). It is the second largest reservoir in Kansas, impounding the Big Blue River just upstream of its confluence with the Kansas River. The reservoir is approximately 4,411 ha, has a maximum depth of 15 m and an average depth of 8 m (Klaassen and Townsend 1973).

### **Acoustic Telemetry**

### ***Fish Sampling and Tagging***

Channel Catfish and Blue Catfish were captured from each study reservoir by boat electrofishing in spring 2023 and 2024. Boat electrofishing for Blue Catfish included use of low-frequency range of settings of 15 pulses/s DC current (Brown 2009, Bodine et al. 2013). Channel Catfish are not as susceptible to low-frequency electrofishing; therefore, Channel Catfish were sampled with high-frequency electrofishing settings of 60 pulses/s DC current (Bodine et al. 2013). These settings enable electrofishing to occur in a wide range of habitats and depths to maximize the spatial distribution of samples. We spatially stratified our tagging effort by separating each reservoir into thirds (i.e., upper, middle, and lower).

We only tagged catfish in which tag burden was less than approximately 2% of the wetted fish mass (Winters 1983). Prior to tagging, individuals were anesthetized in a solution of MS-222 (Tricaine Methanesulfonate; Syncline Fish Anesthetic; Syndel, Ferndale, Washington) administered at 100 mg/L until each fish was immobilized. Fish were placed on a wetted surface and gills continuously irrigated with MS-222 solution throughout the surgery, which took approximately 2 min, and implanted with VEMCO V13-1x coded and/or continuous acoustic transmitters (13 x 30.5 mm, 9.2 g mass in air; Innovasea Systems Inc., Bedford, NS, Canada). Catfish are known to expel tags inserted in the peritoneal cavity and can have variable mortality rates depending on the invasiveness of the techniques used for tag implantation (Neely et al. 2020). To limit tag expulsion by aid of gravity, an incision was made on the left side of the fish just below and posterior of the pectoral fin but not perfectly along the abdominal medial plane to avoid transmitters resting and pushing on the incision site. Incisions (<25 mm) were closed with 2-4 interrupted absorbable monofilament sutures (3-0, PDO; UNIFY Surgical Sutures; AD Surgical, Sunnyvale, California). Implanted fish received a T-bar anchor (Floy) tag to notify anglers to release and report the fish. Fish were allowed to recover from anesthesia in a 64-L tank filled with reservoir water prior to release. Tag implantation, external tagging, and application of MS-222 were performed under the Kansas State University Institutional Animal Care and Use Committee (IACUC) Protocol #4967 and in accordance with the American Fisheries Society: Guidelines for Use of Fish in Research.

### ***Tag Allocation***

Fifteen individuals of each species were implanted with transmitters in both reservoirs each year. In 2023, 10 Blue Catfish and 10 Channel Catfish were double tagged (coded and

continuous transmitters) and 5 of each species received a single coded transmitter in both study reservoirs ( $n = 60$  total fish tagged). Continuous transmitters facilitated active tracking because of a shorter ping delay (5 seconds) while coded transmitters had a longer ping delay (80 – 160 seconds) but provided a unique code for each individual. In 2024, 15 fish of each species from each reservoir received double transmitters ( $n = 60$  total tagged fish). Four different frequencies on continuous transmitters were used to identify species and sex groups: 60 kHz indicated male Blue Catfish (adjusted to 75 kHz in 2024 due to interference at the 60 kHz frequency), 78 kHz female Blue Catfish, 81 kHz male Channel Catfish, and 84 kHz female Channel Catfish.

### ***Tracking Surveys***

Active and passive tracking techniques were used to monitor habitat use and movement of both species within the study reservoirs and determine entrainment of reservoir fishes and upstream movements into the major impounded rivers. Passive receivers (VEMCO VR2W-69kHz Acoustic Monitoring Receiver, Innovasea Systems Inc., Bedford, NS, Canada) were strategically placed 6-14 km upstream and at the inflow of the Big Blue River into Tuttle Creek Reservoir and the Republican River into Milford Reservoir to detect upstream movements from the reservoirs (Figure 1.1). Receivers were also placed just upstream of the dams and below the dams to detect if an individual left the study site through entrainment. Receivers in the reservoir were attached to mooring lines approximately 2 m above the anchor point. Deployments in rivers required the attachment distance to be shortened to approximately 0.5-1 m above the anchor point or directly attached to stationary rocks, pillars, or other infrastructure resistant to high flow conditions. Individual upstream movements during the winter months are not included because the receivers succumbed to potential ice flow movement and were lost. In Milford Reservoir, the length of time a receiver was recording detections was not continuous from May 2023 to October 2024 due to problems recovering a receiver originally placed approximately 7 km upstream of the reservoir in the Republican River and the low flows entering the reservoir in 2023 (Figure 1.1). The receiver position was moved to 14 km upstream of Milford Reservoir in the spring of 2024 to a more permanent location to limit disturbances. There was more consistent coverage of the upstream movements in the Big Blue River ~6.5 km upstream of Tuttle Creek Reservoir from April 2023 to October 2024 (Figure 1.1).

Active tracking was conducted monthly by surveying for and triangulating the position of continuous transmitters with a tracking acoustic receiver (VEMCO VR-100 Tracking Acoustic

Receiver, Innovasea Systems Inc., Bedford, NS, Canada). A 70% probability of detection was determined at 300 m (Appendix Figure 1.A.), as recommended by VEMCO to be an appropriate detection range. Using this detection probability, listening stations were created 600 m apart across each reservoir, including points that overlapped the shoreline (Figure 1.2). The omnidirectional hydrophone of the active tracking receiver was deployed in the center of each listening station throughout the reservoirs for approximately 190 seconds to cover the longest possible delayed transmission from a coded transmitter. During the 190 seconds, all 5 frequencies were monitored. When a continuous transmitter was identified, we used a directional hydrophone to triangulate its location. The boat was moved in the direction of the strongest signal strength until the signal strength was maximized. Once the strongest signal was located, the vessel was anchored, an azimuth bearing was recorded in the signal direction, and the latitude and longitude of the vessel was recorded. This process was repeated twice more, attempting to adjust the bearing by greater than 60 degrees for the best triangulation estimate. The three azimuth bearings and associated boat position were then entered in LOAS software (Location of A Signal; Ecological Software Solutions) to triangulate the location of an individual. In instances where there were not a sufficient number of intersecting lines, the best biangulation was recorded.

## **Diet**

### ***Diet Sampling***

Stomach contents were sampled in the spring, summer, and fall of 2023 and 2024 from each reservoir. Both species were sampled using boat electrofishing (see Methods: *Fish Sampling and Tagging* for specific electrofishing settings). Sampling was stratified by location in the reservoir (upper, middle, and lower) with the goal of capturing 10 Blue and 10 Channel Catfish from each strata. To focus on areas of sympatry between the two species, we targeted sampling 1-5 individuals of each species from the same approximately 11-ha sampling grids (Figure 1.3). This sampling design maximized collection of both species in areas where fish were presumed to have access to similar food resources. Pulsed, non-lethal gastric lavage was used to purge the stomach contents of captured fish. Samples were preserved in 10% formalin and returned to the laboratory for processing and sampled fish were released.

### ***Laboratory Processing***

Prey items from stomach samples were identified under a dissecting scope to the lowest practical taxonomic grouping and separated on a petri dish. Aquatic and terrestrial macroinvertebrates were identified to Class or Order, in rare instances Family, and unidentifiable organic matter were included as detritus. Fish prey were identified to Species when possible. Algae were not identified at a lower taxonomic resolution. Abundances of each prey item were quantified from the surface area occupying 1 x 1 mm grids, assuming that the surface area of diet items was proportional to their respective volumes (Hellawell and Abel 1971; Franssen and Gido 2006; Evelyn et al. 2022).

### **Data Analysis**

#### ***Habitat Use and Movement***

To test if Blue Catfish and Channel Catfish occupied different habitats in the two study reservoirs, we used triangulated locations to define habitat as the distances from major reservoir habitat features (dam, shoreline, and thalweg), presence in coves, and water depth. All analyses were performed using Program R Version 4.4.1 (R Core Team 2024) and distance from broad scale habitat features (thalweg, dam, shoreline, water depth, and presence in a cove) were measured using QGIS (QGIS Development Team 2024). We investigated relationships between catfish species and distance-based variables with a generalized linear mixed-effects model fitted with the “lmer” function from the package “lme4” (Bates et al. 2015). The model assigned catfish species as a fixed factor with two levels (Blue Catfish and Channel Catfish) including a random effect of unique identifier that accounted for multiple observations of individual fish across tracking surveys (Aarts et al. 2008). Residual plots for each habitat variable in the model were examined to assess assumptions of homoscedasticity and normality (Appendix Figure 1.B:1.F). Satterthwaite’s method was used to approximate the fixed effects degrees of freedom for p-value computation to test species effects at an alpha level of 0.05 (Satterthwaite 1946; Bates et al. 2015). To quantify if there were differences in each habitat variable between catfish species, we used a Tukey’s post-hoc pairwise comparison of standardized means, using Bonferroni adjustments for p-values, with the function “mcp” in the package “multcomp” (Hothorn et al. 2008).

To visualize habitat use by individuals and their association with measured variables we constructed a principal components analysis (PCA) using the “prcomp” function in R (package

“vegan”; Oksanen et al. 2024) from standardized (z-score normalized) data. Differences in habitat use between species, tracking year and reservoir were assessed with a Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson 2017) of the standardized Euclidean distance matrix based on 10,000 permutations of residuals. PERMANOVA was conducted with the “adonis2” function in R (package “vegan”; Oksanen et al. 2024).

Fisher’s Exact tests (Fisher 1935), more robust to small sample sizes, were used to test if the proportion of tagged fish detected at upstream receivers differed between species. Tagged fish were identified making an upstream movement if unique coded transmitters were detected at the farthest upstream receivers at each study site (~ 6.5-14 km upstream) at least once.

### ***Stomach Content Analysis***

We excluded stomach content items observed in fish from 3 or fewer sample grids to limit the effects of rare diet items (Table 1.1). Additionally, large scales, anthropogenic debris, feathers, parasites (i.e., fish lice, tapeworms), and unidentifiable items were excluded from our analysis. We tested the additive effects of season (3 levels: spring, summer, and fall) reservoir (2 levels: Milford Reservoir and Tuttle Creek Reservoir), species (2 levels: Blue Catfish and Channel Catfish), and year (2 levels: 2023, 2024) in predicting the presence of diet items in the overall diet composition from sample grids using a generalized linear model (Wang et al. 2012), assuming binomial distribution (family = binomial(link=logit)) from the binary presence and absence data. A residual plot for the model was examined to assess assumptions of homoscedasticity and normality (Appendix Figure 1.G). The additive generalized linear model was created with the multivariate analysis function “manyglm” in R (package “mvabund”; Wang et al. 2022), by fitting a generalized linear model amid all diet items and the predictor variables to identify which best explains diet composition patterns and seek significant effects ( $p < 0.05$ ) of the predictor variables through resampling-methods (Wang et al. 2012). We used the function “anova.manyglm” and selected ‘p.uni = “adjusted”’ to identify significant effects of predictor variables for each individual diet item (package “mvabund”; Wang et al. 2022). The selected functions adjust each diet item by using an iteration of Holm’s step-down multiple testing method (Holm 1979; Westfall and Young 1993) that reduces Type I error by accounting for correlation between diet items by resampling-based procedures, returning an adjusted p-value and a test statistic for individual diet item comparisons (Wang et al. 2012).

We used distance based principal coordinates analysis (PCoA) using the function “pco” in R (package “vegan”; Oksanen et al. 2024) to visualize the similarities in diet composition among predictor variables. The distance matrix was created in R using function “vegdist” in the “vegan” package using the Jaccard similarity method for presence or absence of diet items that represent the proportion of shared items between samples. To assess seasonal, annual, species, and reservoir level differences, we again used the “adonis2” function in R (package “vegan”; Oksanen et al. 2024) to perform a PERMANOVA of the standardized Jaccard distance matrix based on 10,000 permutations of residuals.

## **Results**

### ***Habitat Use and Movement***

In 2023 and 2024 we tagged 60 Blue Catfish and 60 Channel Catfish of a wide range of sizes from the two reservoirs (Table 1.2). Of 133 triangulated fish locations, 5% ( $n = 7$ ) of transmitted codes were unable to produce a unique identifier, leaving 126 points for our analysis. Fifty percent of Blue Catfish ( $n = 30$ ) and 50% of Channel Catfish ( $n = 30$ ) of various sizes were detected over the multiple surveys. The low detection percentage was affected by detections of 38% of Blue Catfish ( $n = 23$ ) and 27% of Channel Catfish ( $n = 16$ ) moving beyond the reservoir tracking range and into the inflowing tributaries during tracking surveys (Figure 1.1). There also was one entrainment event of a Channel Catfish from Tuttle Creek Reservoir in 2023.

The first axis of the PCA, reflecting habitat use of the two species, explained 39.1% of the variation and was positively associated with water depth, distance from the shoreline and dam, but negatively associated with distance from the thalweg and presence in coves. The secondary axis explained 36.7% of the variation and contrasted distance from dam (positive loadings) and water depth (negative loadings). There was a high overlap in the distribution of both species along the first axis, but Blue Catfish were more associated with deeper water while Channel Catfish clusters were present in coves and further from the thalweg (Figure 1.4). Results from the PERMANOVA showed that centroids of variable groups differed by year, reservoir, and species (Table 1.3). Ordination and PERMANOVA results suggest that Blue Catfish are more associated with deeper water and less distance from the reservoir thalwegs, contrary to Channel Catfish that occur more in shallow water, coves, and at greater distances from the

thalweg. There are less distinct associations explaining the spatial distribution patterns of either species with the distances from shoreline or dam.

Results from the generalized linear mixed models confirmed the clustering patterns shown in the distribution of individual catfish observations in ordination space. Catfish species was a significant predictor for all of the tested habitat variables (all  $p$ -values  $< 0.05$ ; Tables 1.4; 1.5). Catfish species was a strong predictor in modelling the distribution of catfish at differing water depths, and on average Blue Catfish occurred in deeper water than Channel Catfish by nearly 2 meters (Table 1.6). Channel Catfish were found at farther distances from the thalweg, greater than double the average distance than Blue Catfish. Additionally, 22 Channel Catfish detections occurred in coves in comparison to detection of Blue Catfish in coves on 10 occasions. Further supporting the cluster in the ordination, the model and pairwise comparisons indicated a significant species effect in which Channel Catfish had a greater probability of occurring in coves. Catfish species was also a predictor for the distance from dams and shoreline, where Blue Catfish occurred at greater distances from the shoreline and from the dam. Both catfish species were observed closer to the thalweg ( $p = 0.012$ ) in Tuttle Creek Reservoir and observed in major coves more frequently in Milford Reservoir ( $p < 0.001$ ).

Of the 60 fish tagged in Tuttle Creek Reservoir in 2023 and 2024, 63% of tagged Blue Catfish and 43% of Channel Catfish were detected making an upstream movement of at least 6.5 km out of the reservoir. However, there was no evidence to support that one species moved out of the reservoirs more frequently than the other ( $p = 0.19$ ) according to Fisher's Exact test. The daily occurrence of unique transmitter codes detected on upstream receivers suggest similar seasonal patterns of movement between species, with a slight increase in the number of individuals of both species detected during periods of higher flows into the reservoir (Figure 1.5).

At Milford Reservoir, there were two consecutive months in the early summer of 2023 that the receiver was working; however, there were no detections during this time. The receiver location was moved approximately 14 km upstream of Milford Reservoir until low flows created conditions unfit for receiver deployment. Of the 60 fish tagged fish in Milford Reservoir, 13% of Blue Catfish and 7% of Channel Catfish were detected making at least one upstream movement. The Fisher's Exact test ( $p = 0.67$ ) indicated no difference in the movement patterns between

species. Despite the lack of complete coverage in the rivers during the study, the only recorded movements occurred during periods of increased discharge into the reservoir (Figure 1.5).

### ***Diet***

We performed gastric lavage on 321 Blue Catfish (214-988 mm TL) and 318 Channel Catfish (201-899 mm TL) across the two-year study period. Approximately 9% of Blue Catfish ( $n = 58$ ) and 12% of Channel Catfish ( $n = 76$ ) stomachs were empty and excluded from our analysis. The proportional occurrences of stomach content items of Blue Catfish and Channel Catfish were compared across 126 sampling grid combinations from the spring, summer, and fall of 2023 and 2024 in Milford Reservoir (27 grids) and Tuttle Creek Reservoir (33 grids; Figure 1.3).

Blue Catfish and Channel Catfish exhibited a broad diet of terrestrial and aquatic insects, algae, detritus, mollusks, fish, and crayfish (Figure 1.6; Table 1.1). The first PCoA axis explained 19.6% of the variation in the stomach contents across individuals and the second PCoA axis represented 14.7% of the variation (Figure 1.7). Results from the PERMANOVA suggest differences among season, species, year and reservoir (all  $p$ -values  $< 0.001$ ). In spring, Blue Catfish had larger axis 1 scores that were more closely associated with emerging mayfly and caddisfly larvae, indicating pelagic and benthic feeding. Channel Catfish appeared to be more closely associated with fish eggs and dipterans (negative axis 1 scores), representing more benthic feeding (Figure 1.8). This pattern held in summer, shifting to a more complete diet overlap in fall as Carpenter Ants *Formicidae* sp., various fish species, Zebra Mussel *Dreissena polymorpha*, and grasshoppers *Orthoptera* spp. become present in diets of both species (Figure 1.8). Prey that were more centrally located in the ordination were common diet items for both species regardless of season, reservoir or year such as detritus and dipteran. The ordination plot revealed that both species exhibited a shift in stomach contents associated with seasonally abundant diet items regardless of reservoir.

The generalized linear model (sample grid stomach contents  $\sim$  reservoir + species + capture season + year) confirmed the ordination that catfish species, season, year, and reservoir (all  $p$ -values  $< 0.001$ ) significantly contributed to explaining the variation in stomach contents. Post hoc comparisons of different diet items suggest differences in consumption of crayfish ( $p = 0.001$ ) and unknown terrestrial invertebrate ( $p = 0.022$ ) between species. Crayfish contributed each season to Channel Catfish stomach contents but were only present during fall of 2024 in

Blue Catfish. Unknown terrestrial invertebrates were present in the stomach contents of sample grids containing both species, but they were greatest in fall diets of Channel Catfish. Spatially, stomach contents from sample grids in Tuttle Creek Reservoir contained more fish prey ( $p = 0.003$ ) and fingernail clams ( $p = 0.039$ ) than Milford, which contained more samples with algae ( $p = 0.003$ ). Seasonal variation in spring diet items were associated with the emergence of the Giant Burrowing Mayfly *Hexagenia limbata* ( $p = 0.001$ ) and other aquatic macroinvertebrates ( $p = 0.001$ ), and egg production during spawning of Longnose Gar *Lepisosteus osseus* ( $p = 0.001$ ). Our analyses support that seasonality has a strong influence on the stomach contents of Blue Catfish and Channel Catfish and the annual and reservoir effects show that both species exhibit seasonal shifts in diet.

## Discussion

### *Habitat Use*

Our distinct spatial distributions patterns for these two species show agreement with patterns observed in other large reservoirs in that Blue Catfish occur in deeper, more pelagic habitats compared to Channel Catfish (Pflieger 1997; Edds. et al. 2002; Moran et al. 2021). However, it is not clear if differences in distribution are due to resource partitioning between the species. Klaassen and Marzolf (1971) noted that Channel Catfish were ensnared in deep, offshore gillnets in Tuttle Creek Reservoir, possibly indicating a broader range of habitat use prior to the introduction of Blue Catfish. Edds et al. (2002) predicted that separation in habitats could be a consequence of coevolved differences between catfish species. Similarly, Westrelin et al. (2021) revealed littoral-pelagic and water depth habitat partitioning among coexisting piscivorous species in European reservoirs that reflects the co-evolutionary history of those species. Blue Catfish and Channel Catfish share overlapping native ranges in northeastern Kansas so it is likely that these species have coevolved differences in habitat use, effectively minimizing interspecific interactions. Alternatively, Edds et al. (2002) hypothesized that large abundances of Blue Catfish could increase the competitive interactions for remaining habitat with Channel Catfish, potentially limiting their spatial distribution from resource exploitation. Increased competition from larger Blue Catfish could potentially cause Channel Catfish to shift their habitat distribution to limit interspecific interactions. This pattern of avoidance has also been observed among Centrarchid populations where the more dominant species dominated their

selected habitat, causing a shift of other species to a refuge habitat (Werner and Hall 1977). However, McCain et al. (2011) contributed habitat interactions between Blue Catfish and Channel Catfish in impounded regions of the Mississippi River to be a result of less distinct habitat separation compared to the more distinct habitat and spatial distribution patterns observed in unimpounded regions. These studies suggest a multitude of hypotheses for predicting catfish habitat use and causes for partitioning; however, environmental and coevolved differences likely confound our ability to test for direct habitat competition. We can conclude that if the abundance of Blue Catfish increases in Kansas reservoirs beyond a particular threshold, it is possible that the innate habitat selection differences resulting in the avoidance of the other species could reduce existing direct competition, allowing for coexistence.

### ***Movement***

Our passive receiver array detected upstream movements of both species during periods of increased discharge from major river tributaries during spring. It is possible that both species were moving upstream in search of spawning habitat or exhibiting use of habitat in the connected rivers. Spawning migrations in response to seasonal flow and water temperature cues could provide a potential driver that would increase movement likelihood for Blue Catfish and Channel Catfish (Pflieger 1997; Graham 1999; Hubert 1999). Laughlin et al. (2016) used otolith microchemistry to determine major river and tributary contributions to Blue Catfish and Channel Catfish recruitment in the middle Mississippi River. It was determined that major rivers are crucial for the recruitment of both species and to a lesser extent smaller tributaries (Laughlin et al. 2016; Dean et al. 2022). Both species possess a strong movement potential (Pugh and Schramm Jr. 1999; Tripp et al. 2011) in response to seasonal temperature or flow fluctuations that cue movements to seek winter habitat or spawning migrations (Graham 1999). We detected individuals making upstream movements during descending flows and other seasons than the spring months. Dean et al. (2022) and Tripp et al. (2011) had reported the use of multiple river systems over many years for several Blue Catfish in mark and recapture studies, further supporting high movement potential that could extend to year-round movements. Enders et al. (2019) reported large home range areas and movements of Channel Catfish in the Lake Winnipeg River basin. Both species are capable of large-scale movements in response to temperature or flow indications or to utilize habitat with strong connectivity. It is possible that

Blue Catfish and Channel Catfish reduce inter- and intraspecific competition in the reservoirs with exploratory movements into upstream rivers.

### ***Diet***

Both species exhibited opportunistic and generalist feeding on a broad range of food items with no single dominant prey resource, similar to what has been observed in other studies (Cannamela et al. 1978; Edds et al. 2002; Braun and Phelps 2016; Schmitt et al. 2019). Furthermore, presence of particular diet items in the stomachs varied by season and reservoir, likely due to seasonal differences in prey availability and reservoir productivity. Catfish were more piscivorous in Tuttle Creek Reservoir and stomach contents contained more algae in Milford Reservoir. Tuttle Creek Reservoir might have lower algal productivity due to high rates of sedimentation from the Big Blue River that results in greater turbidity (Klaassen and Malzdorf 1971). Wind and sediment load from the Big Blue River keep sediments in suspension likely decreasing algae growth due to reduced light penetration levels (Thomas 1970). Conversely, Milford Reservoir is less turbid (Foster et al. 2017), likely supporting greater benthic fauna and algal growth than Tuttle Creek Reservoir. However, greater presence of fingernail clams in the Tuttle Creek Reservoir catfish stomachs suggest that benthic feeding of available resources occurs in both reservoirs.

Additionally, seasonal factors appeared to drive shifts in the diversity of stomach content items of feeding catfish. Late spring emergence of Giant Burrowing Mayfly provided a seemingly important prey resource. The emergence of burrowing mayflies occurs from late spring to early fall (Horst and Marzolf 1975) and during these events mayflies are located throughout the water column as they emerge, suggesting catfish will feed throughout the water column. Edds et al. (2002) at Lake Texoma, Cannamela et al. (1978) in several Kentucky Lakes, and Klaassen and Marzolf (1971) in Tuttle Creek Reservoir also found that diets of both species were largely dominated by burrowing mayfly nymphs in the spring and shifted to other prey resources that were seasonally available in the fall such as aquatic plants, algae, fish, and terrestrial insects. Our results confirm this with an observed shift to more overlap in stomach contents between species containing terrestrial and aquatic macroinvertebrate and fish prey. Contrary to the literature (Graham 1999; Edds et al. 2002; Bentley 2023), we did not detect a greater occurrence of fish prey (i.e., Gizzard Shad *Dorosoma cepedianum*) in Blue Catfish than Channel Catfish stomachs.

Seasonal differences in diets between species were attributed to the occurrences of crayfish and terrestrial insects. Crayfish, for example, contributed to the stomach contents of Channel Catfish across seasons, but only occurred during fall in Blue Catfish diets in 2024. Channel Catfish showed an increase in the presence of other terrestrial macroinvertebrates in fall during periods in which Blue Catfish consumption overlapped with crayfish prey, potentially suggesting a shift in resource use. Hilling et al. (2016) reported the use of terrestrial prey in fall from Channel Catfish diets in a West Virginia lake, likely associated with increased availability of terrestrial resources. Otte (1975) listed crayfish as a primary prey resource for Channel Catfish in warmwater fisheries in the spring and summer because of crayfish availability and activity in the littoral zones until burrowing during winter. Crayfish and terrestrial prey have been observed in the seasonally opportunistic diets of both species (Graham 1999; Edds et al. 2002) but the potential shift in Channel Catfish diets to use additionally available resources could suggest resource partitioning. Catfish and other species of interest might avoid negative interactions via resource partitioning of trophic and spatial resources, similar to avoidance behaviors exhibited in native and non-native fish communities (Juncos et al. 2015).

### ***Conclusion and Management Implications***

Opportunistic feeding strategies and variable habitat use of Blue Catfish and Channel Catfish likely allow either species to shift resource use enabling successful coexistence within reservoirs. However, several studies suggest abundant populations of Blue Catfish were associated with declines in White Catfish populations in the Chesapeake Bay (Schloesser et al. 2011; Schmitt et al. 2019) or poor condition of Channel Catfish in Ohio reservoirs (Bentley 2023). There are currently no direct indications of declining Channel Catfish abundances in Kansas reservoirs with expanding Blue Catfish populations. While continued monitoring will be necessary to better evaluate these population trends, our data suggests resource partitioning of spatial and food resources between these two species might mitigate competitive interactions. Regardless, harvest management might be necessary to prevent Blue Catfish populations from over-populating and causing the declines in their own growth and abundance as well as other declines in other species within these reservoirs. Management agencies should continue standardized sampling to monitor population trends and body condition of desirable sportfish and prey resources to assess the effectiveness of management actions, such as harvest regulations. Extreme environmental variation in water inflows combined with the longevity of Blue Catfish

with uncertain recruitment and spawning periodicity will make it difficult to identify population trajectories based on only a few years of sampling.

This study documented considerable upstream movement of both catfish species from each reservoir, and additionally, detected the entrainment of a Channel Catfish below Tuttle Creek Reservoir. Further research is needed to provide insights into the upstream contribution to spawning and recruitment, potential competition for spawning habitats by these species, and to guide management of reservoirs and connected upstream and tailwater fisheries. Internally fitting reproductively mature Blue Catfish and Channel Catfish with acoustic transmitter and intensively monitoring for upstream and riverine habitat use through receiver arrays would allow for the characterization of movements and spawning locations during predicted spring spawning movements (Graham 1999; Taylor and Litvak 2016). Moreover, standardized sampling and harvest regulations should extend into reservoir tributaries because of the upstream use of some species to complete life histories (Miranda 2008) and in tailwater fisheries to identify populations trends that could be influenced by unidirectional movement (Dean et al 2021). Actively sampling for larvae in reservoir tributaries also could aid in determining the extent of upstream migrations and correlations with environmental conditions that influence spawning and larval fish dispersal (Mu et al. 2014; Taylor and Litvak 2016). Understanding natural recruitment can help fisheries managers understand if populations are self-sustaining, further informing if stocking adjustments are required to replace sportfish lost to entrainment or if anglers should advantageously harvest entrained fish before they are lost downstream. Understanding entrainment, the timing of spawning and recruitment, and other population demographics and how they contribute to the longitudinal management of reservoir fisheries can help fisheries managers achieve their objectives for angler success and sustainable fish populations.

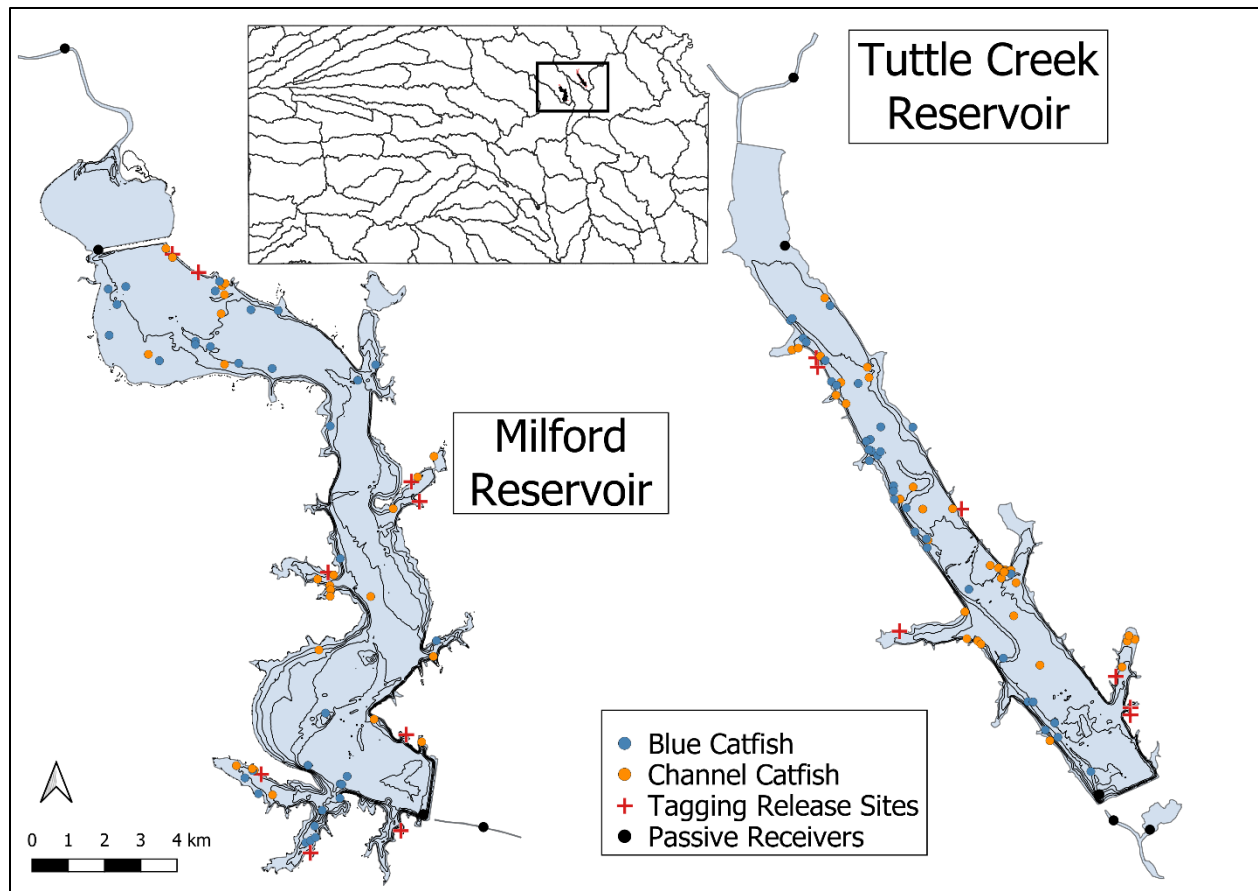


Figure 1.1. Blue Catfish (blue) and Channel Catfish (orange) were tracked in Milford Reservoir (left) and Tuttle Creek Reservoir (right) in northeastern Kansas, USA in 2023 and 2024. Catfish were triangulated during monthly acoustic telemetry tracking surveys. Red symbols indicate locations where catfish were released after tag implantation. Passive acoustic receivers (black) were strategically placed in the major upstream rivers and below the dams to monitor fish movement outside of the tracking reach.

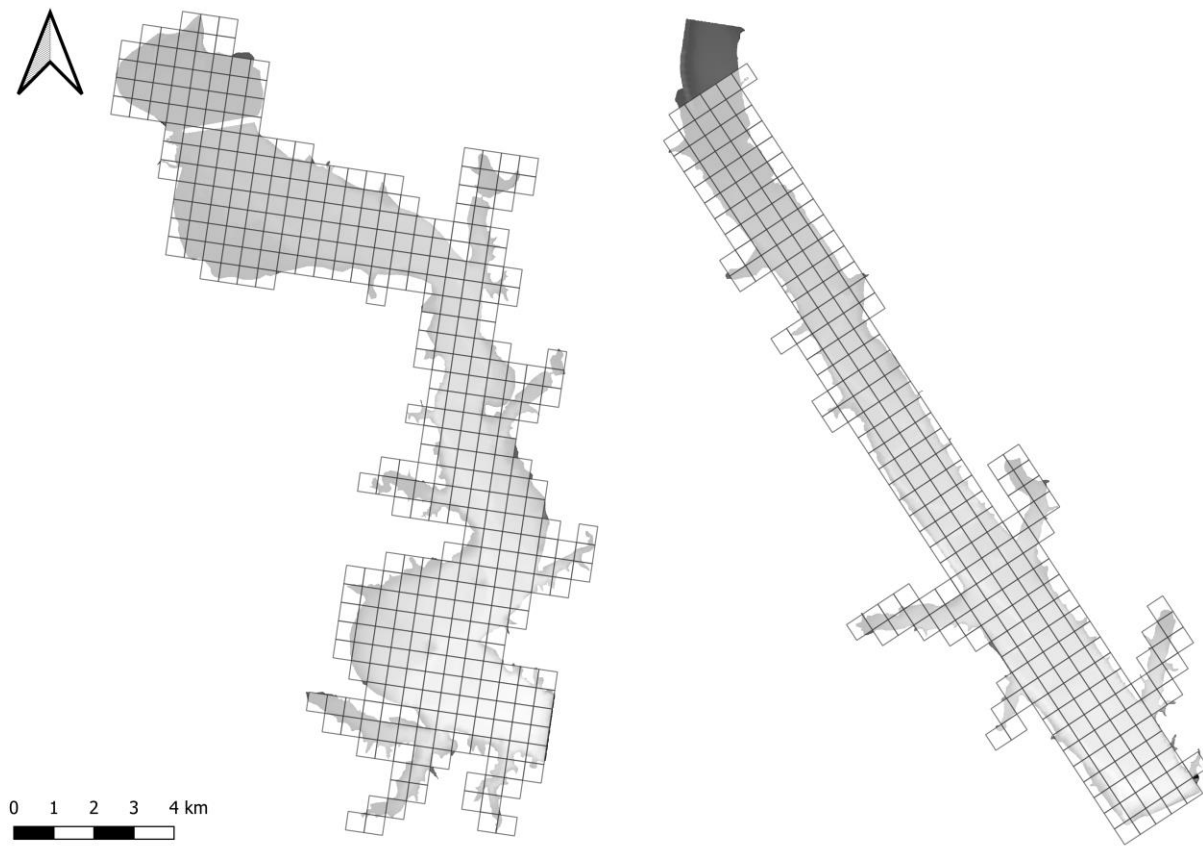


Figure 1.2. Using the 70% detection probability, listening stations were created 600 m apart, represented by the center of the grids overlayed on Milford Reservoir (left) and Tuttle Creek Reservoir (right). An omnidirectional hydrophone was placed in the center of each grid to strategically encompass the reservoir over a tracking period.

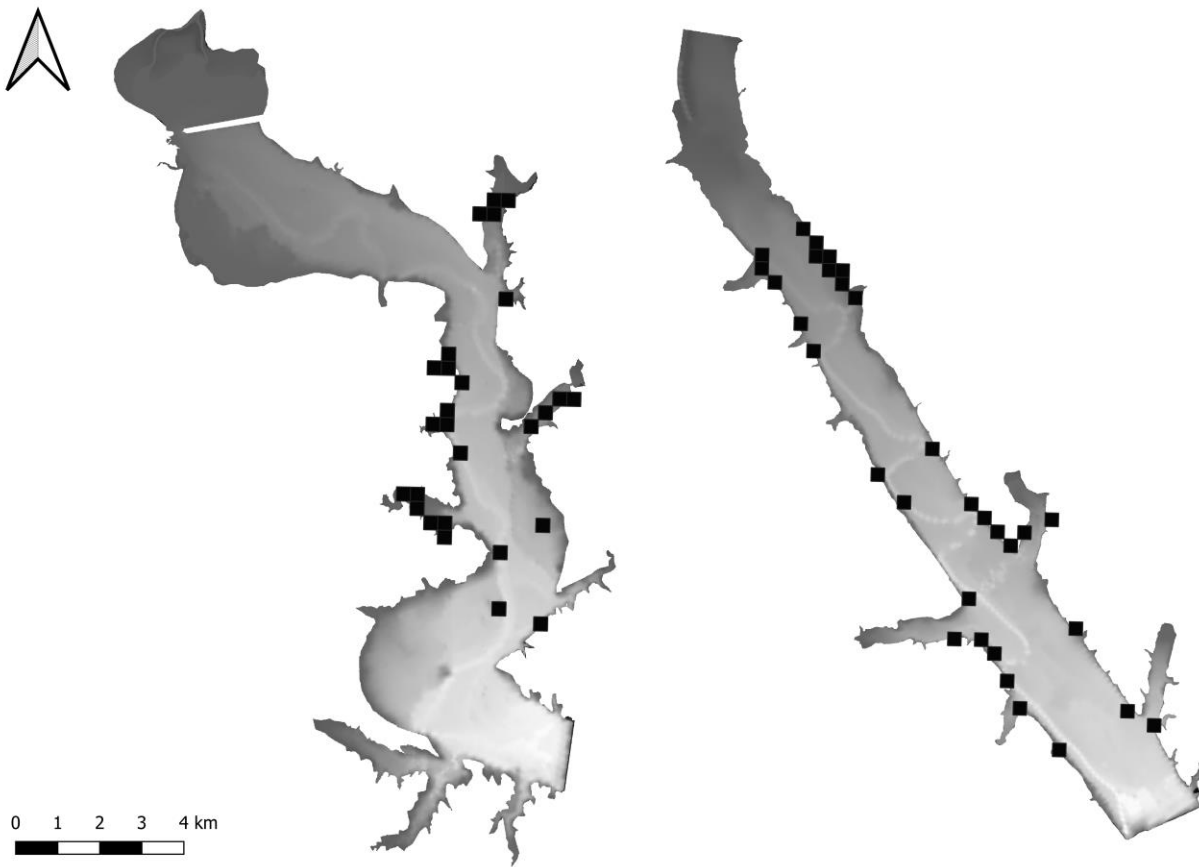


Figure 1.3. Blue Catfish and Channel Catfish were sampled from ~11-ha reservoir sampling grids to compare diets under conditions of sympatry. We sampled 27 unique grids in Milford Reservoir (left) and 33 grids from Tuttle Creek Reservoir (right), sometimes resampling grids over several seasons in 2023 and 2024.

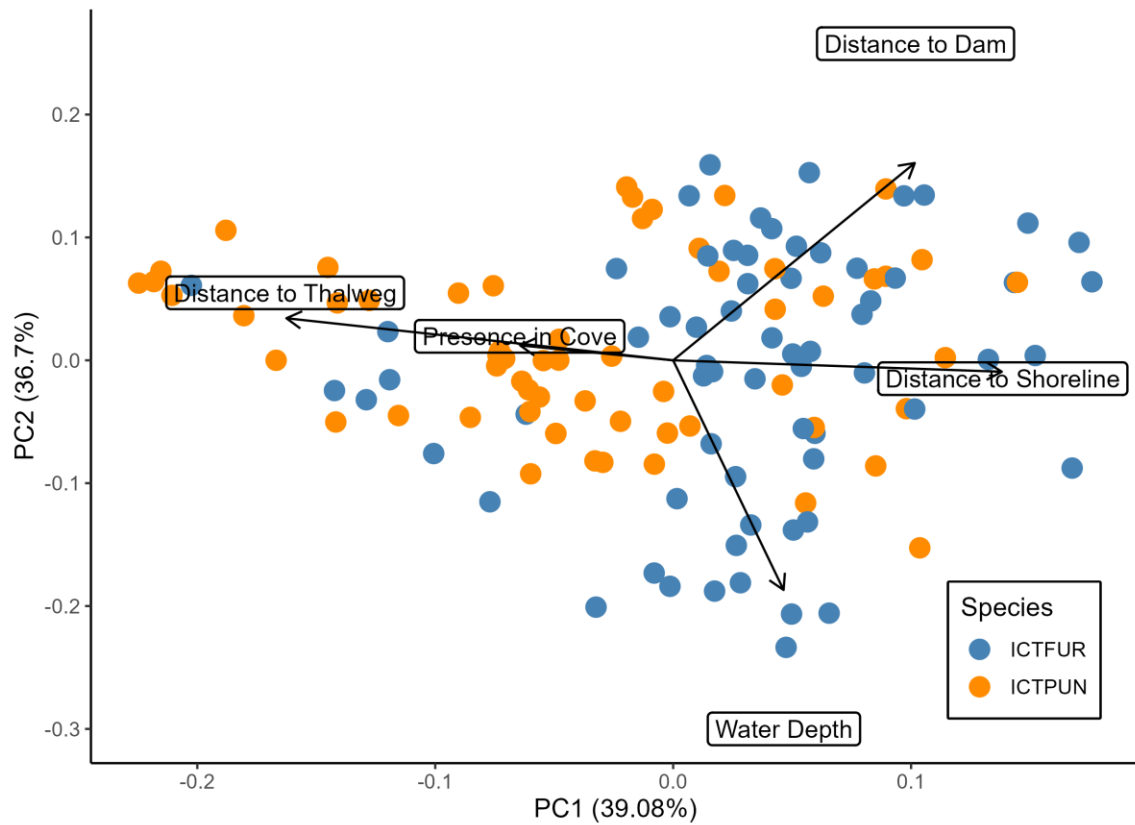


Figure 1.4. A principle components analysis (PCA) represents the distribution of triangulated locations of Blue Catfish (blue) and Channel Catfish (orange) in ordination space across Milford Reservoir and Tuttle Creek Reservoir in 2023 and 2024, where centroids closer in proximity to one another or a habitat variable indicate a positive association. Clustering patterns showed a positive association for Blue Catfish with water depth and increased occurrence of Channel Catfish at greater distances from the thalweg and in coves.

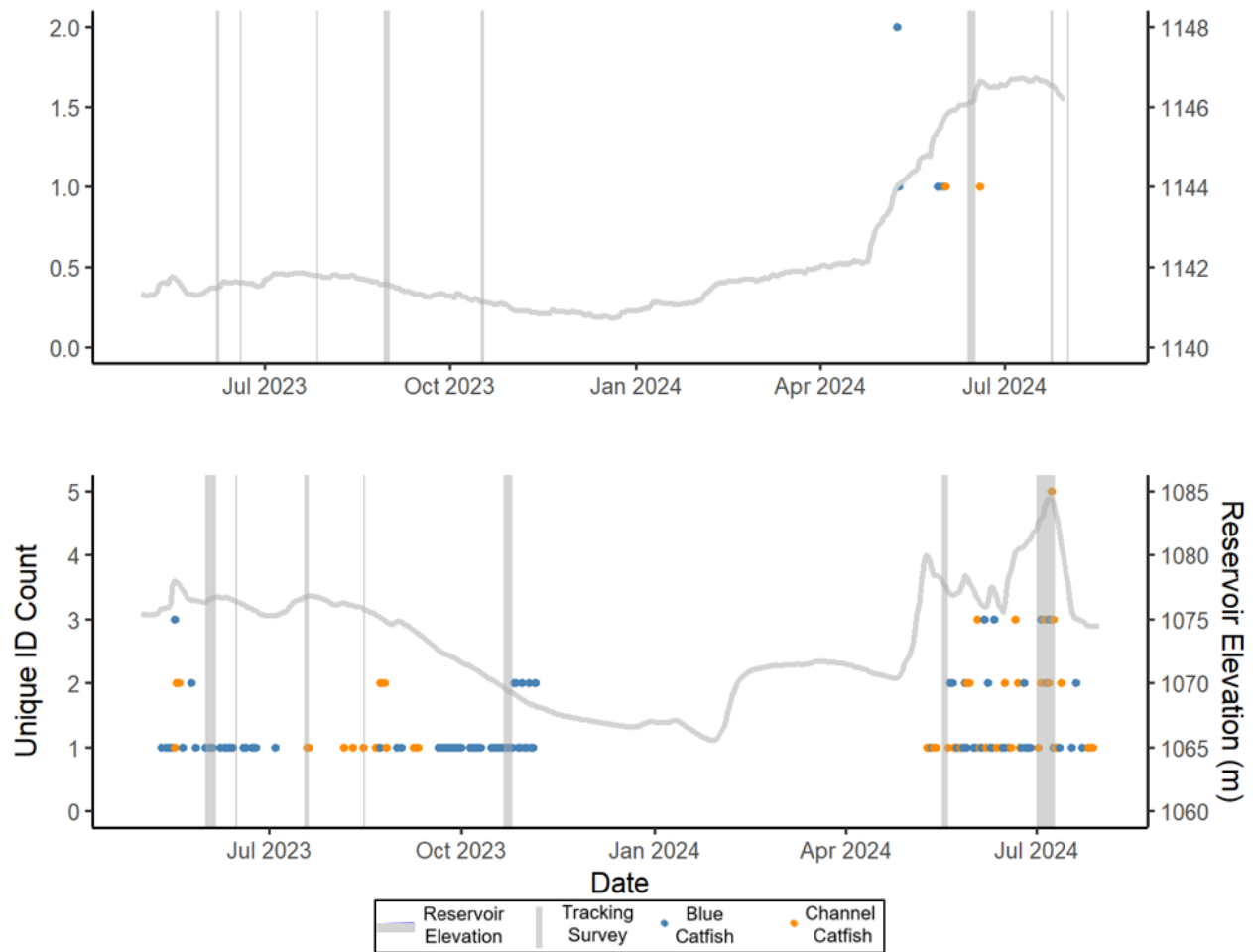


Figure 1.5. Unique detections of Blue Catfish (blue) and Channel Catfish (orange) were observed for both species, indicating a movement out of the Tuttle Creek Reservoir (bottom) study area ~6.5 km upstream into the Big Blue River or ~14 km upstream of the Milford Reservoir (top) study area into the Republican River. Receivers were operating in Tuttle Creek Reservoir from April 2023 to August 2024 with the exception of November 2023 to April 2024 and only from April 2023 to July 2023 and again in April 2024 to July 2024 in Milford Reservoir. An increase in unique individual detections were observed during increased flows from major reservoir tributaries (lateral grey line). Tracking surveys (vertical grey bars) were conducted at periods when individuals of either species were detected outside of the tracking radius.

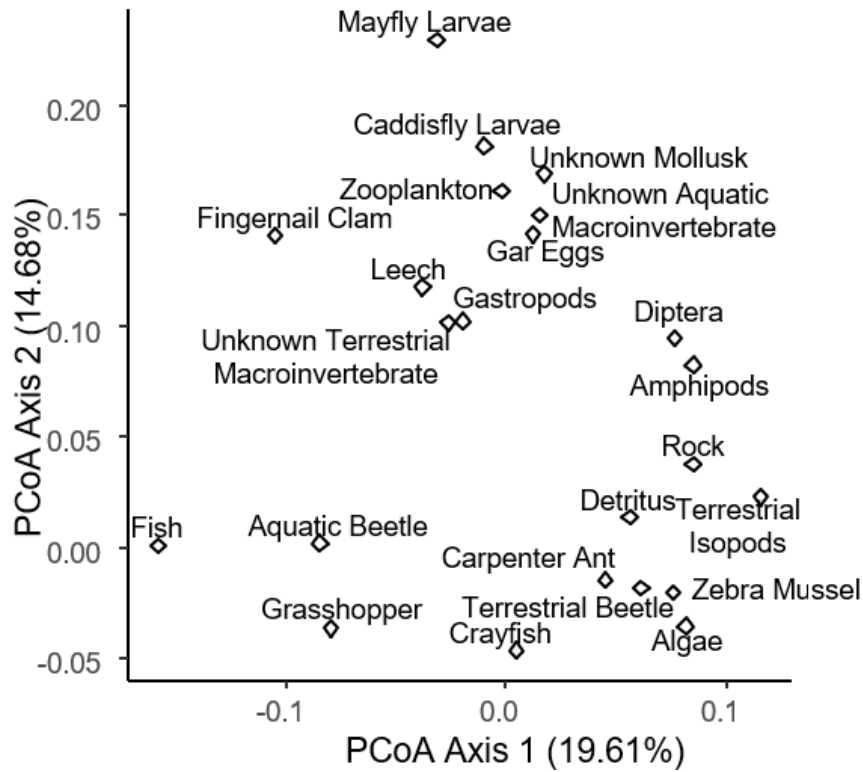


Figure 1.6. Weighted averages of stomach content scores represents the contribution of each diet item to explaining the distribution of points in the principal coordinates analysis only for diet items that occurred in  $\geq 3$  sample grids from gastric lavage sampling in 2023 and 2024 at Milford Reservoir and Tuttle Creek Reservoir. There was a catfish species effect along the primary axis in which Blue Catfish fed at the more negative axis scores and Channel Catfish along the positive loadings. Diet items more commonly occurred in stomach contents in the spring and summer with the positive axis loadings on secondary axis, shifting to fall occurrences along the negative loadings.

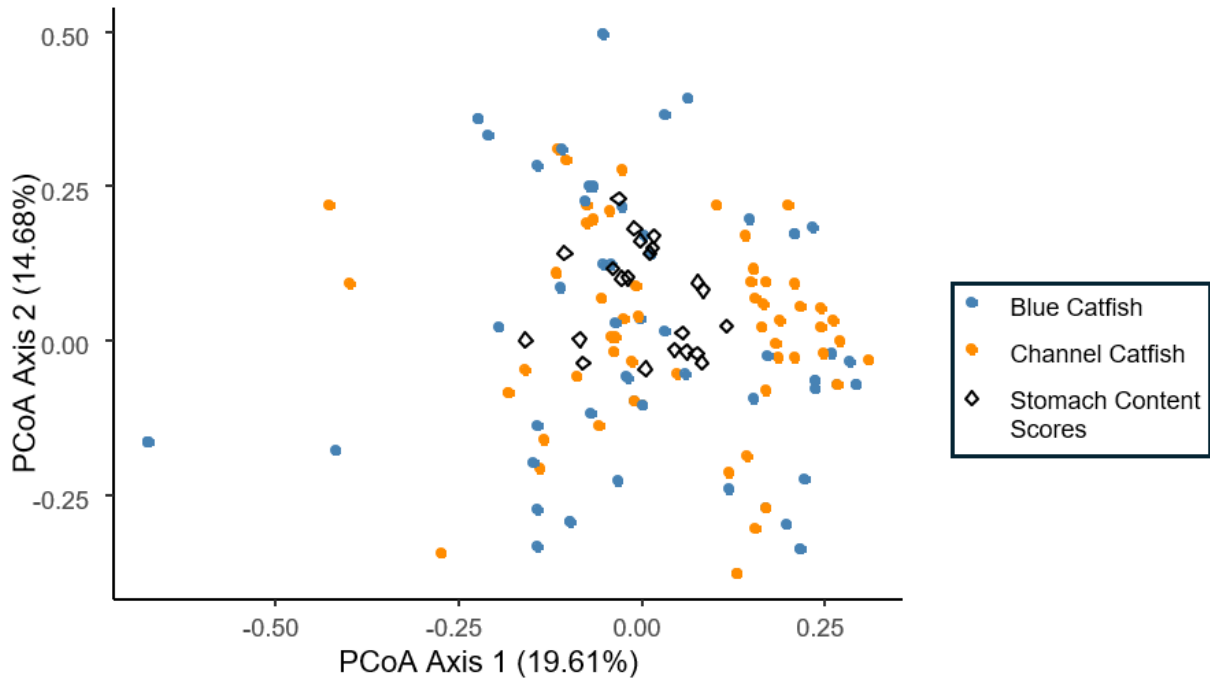


Figure 1.7. A principal coordinates analysis represents the distribution of stomach contents in sample grids containing Blue Catfish (blue) and/or Channel Catfish (orange) across reservoirs, years, and seasons along gradients. The weighted averaging stomach content item scores (grid occurrences > 3) most common diet items (black) were included to visualize the contribution to explaining observed gradient of species along the PCoA axis 1, ranging from stomach contents more associated with Blue Catfish with negative axis scores and Channel Catfish as the axis score becomes more positive. Similarly, the seasonal gradient observed suggests a shift from diet items with positive PCoA axis 2 scores in the spring and summer to items with more negative axis scores in the fall. Approximately 19.61% of variation is explained on the primary axis and 14.68% is explained by the secondary axis.

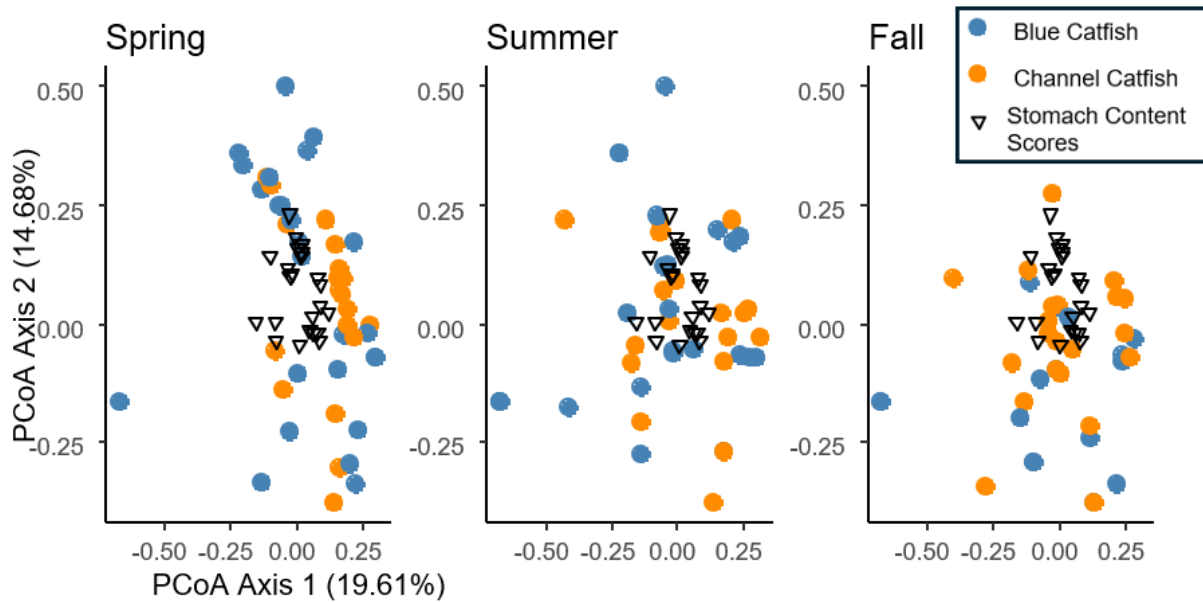


Figure 1.8. Patterns observed in the seasonal distribution of stomach contents suggest that Blue Catfish (Blue) were more associated with stomach content items along the negative PCoA axis 1 scores and clustering around the positive PCoA axis 2 scores, unlike Channel Catfish that are fed at a narrower range of scores centered near 0 and along the positive PCoA axis 1 scores. This patterns holds in the summer but shifts to more complete overlap in the fall.

Table 1.1. The most common diet items (grid occurrence < 3) found in sample grids used in analysis that contained Blue Catfish and/or Channel Catfish during sampling in 2023 and 2024 at Milford Reservoir and Tuttle Creek Reservoir.

| <b>Diet Items</b>                 | Amphipod        | Leech                                 | Aquatic Beetle   |
|-----------------------------------|-----------------|---------------------------------------|------------------|
| Grid Occurrence                   | 7               | 6                                     | 4                |
| Detritus                          | Crayfish        | Diptera                               | Zebra Mussel     |
| 94                                | 19              | 78                                    | 22               |
| Fish Eggs                         | Mayfly Larvae   | Fish                                  | Zooplankton      |
| 15                                | 37              | 60                                    | 5                |
| Carpenter Ants                    | Snail           | Terrestrial Isopod                    | Grasshopper      |
| 13                                | 8               | 4                                     | 5                |
| Rock                              | Fingernail Clam | Terrestrial Beetle                    | Caddisfly Larvae |
| 45                                | 6               | 6                                     | 8                |
| Unknown Aquatic Macroinvertebrate | Unknown Mollusk | Unknown Terrestrial Macroinvertebrate | Algae            |
| 15                                | 16              | 36                                    | 97               |

Table 1.2. Total length ranges of Blue Catfish and Channel Catfish fitted with acoustic transmitters from two reservoirs in Kansas, USA, in 2023 and 2024.

| Tag Implantation            | Blue Catfish (mm TL) | Channel Catfish (mm TL) |
|-----------------------------|----------------------|-------------------------|
| Milford Reservoir 2023      | 425-981              | 408-610                 |
| Tuttle Creek Reservoir 2023 | 352-936              | 525-788                 |
| Milford Reservoir 2024      | 515-985              | 427-560                 |
| Tuttle Creek Reservoir 2024 | 496-960              | 545-838                 |

Table 1.3. Permutational multivariate analysis of variance test results from the principal components analysis suggests that year, reservoir, and species had statistically significant differences in their contribution to explaining the spatial distribution of both species.

| PERMANOVA Test | R <sup>2</sup> | F Statistic | (Pr(>F)) (P-value) |
|----------------|----------------|-------------|--------------------|
| Year           | 0.027          | 3.806       | 0.008              |
| Reservoir      | 0.032          | 4.481       | 0.004              |
| Species        | 0.062          | 8.633       | <0.001             |

Table 1.4. Type III analysis of variance with Satterthwaite's method for predicting degrees of freedom for the generalized linear mixed effects models predicting the habitat association by catfish species. Catfish species was a significant predictor for each of the measured habitat variables; however, distance to the thalweg is best supported.

| Habitat Variable      | df | Denominator df | F      | (Pr(>F)) |
|-----------------------|----|----------------|--------|----------|
| Distance to Thalweg   | 1  | 59.757         | 17.383 | <0.001   |
| Distance to Dam       | 1  | 61.573         | 4.137  | 0.046    |
| Distance to Shoreline | 1  | 52.995         | 5.045  | 0.029    |
| Water Depth           | 1  | 50.482         | 4.046  | 0.049    |
| Cove Occupancy        | 1  | 57.552         | 6.129  | 0.016    |

Table 1.5. A Tukey's post-hoc pairwise comparison was used to assess how species differed in habitat use. Blue Catfish were found at closer distances to the thalweg and a greater water depths and distance from the dam, while Channel Catfish were located closer to the shoreline and at higher occurrences in coves.

| Habitat Variable      | Contrast      | Estimate | Std. Err | Z ratio | Pr(> z ) |
|-----------------------|---------------|----------|----------|---------|----------|
| Distance to Thalweg   | ICTPUN-ICTFUR | 0.8859   | 0.213    | 4.169   | <0.001   |
| Distance to Dam       | ICTPUN-ICTFUR | -0.466   | 0.229    | -2.034  | 0.042    |
| Distance to Shoreline | ICTPUN-ICTFUR | -0.452   | 0.201    | -2.246  | 0.025    |
| Water Depth           | ICTPUN-ICTFUR | -0.4167  | 0.207    | -2.012  | 0.044    |
| Cove Occupancy        | ICTPUN-ICTFUR | 0.56     | 0.226    | 2.476   | 0.013    |

Table 1.6. Summary of habitat variables measured from acoustic-tagged Blue Catfish and Channel Catfish from two reservoirs Kansas, U.S.A. in 2023 and 2024. Average and standard deviations are based on triangulated locations made during active tracking surveys throughout the study period.

| Reservoir  | Year            | Species         | Water Depth (m) | Distance to Shoreline (m) | Distance to Dam (m) | Distance to Thalweg (m) | Observations in Coves |
|------------|-----------------|-----------------|-----------------|---------------------------|---------------------|-------------------------|-----------------------|
| Milford    | 2023            | Blue Catfish    | 5.92 ± 4.60     | 385 ± 302                 | 10831 ± 6514        | 962 ± 944               | 7                     |
| Milford    | 2023            | Channel Catfish | 3.68 ± 3.05     | 223 ± 250                 | 10286 ± 5544        | 1205 ± 971              | 8                     |
| Milford    | 2024            | Blue Catfish    | 9.16 ± 5.17     | 246 ± 238                 | 8810 ± 5317         | 691 ± 670               | 2                     |
| Milford    | 2024            | Channel Catfish | 4.12 ± 1.70     | 65 ± 51                   | 7758 ± 3916         | 2440 ± 818              | 7                     |
| Tuttle     | 2023            | Blue Catfish    | 6.62 ± 3.69     | 217 ± 115                 | 10785 ± 5124        | 268 ± 169               | 1                     |
| Tuttle     | 2023            | Channel Catfish | 4.84 ± 2.72     | 178 ± 191                 | 9983 ± 4501         | 1121 ± 1206             | 7                     |
| Tuttle     | 2024            | Blue Catfish    | 8.26 ± 3.74     | 319 ± 241                 | 10849 ± 4484        | 294 ± 252               | 0                     |
| Tuttle     | 2024            | Channel Catfish | 9.21 ± 2.66     | 255 ± 309                 | 7015 ± 2130         | 983 ± 371               | 0                     |
| Grand Mean | Blue Catfish    |                 | 6.96 ± 4.35     | 309 ± 249                 | 10577 ± 5571        | 608 ± 726               | 10                    |
|            | Channel Catfish |                 | 5.14 ± 3.27     | 191 ± 225                 | 9139 ± 4583         | 1277 ± 1067             | 22                    |

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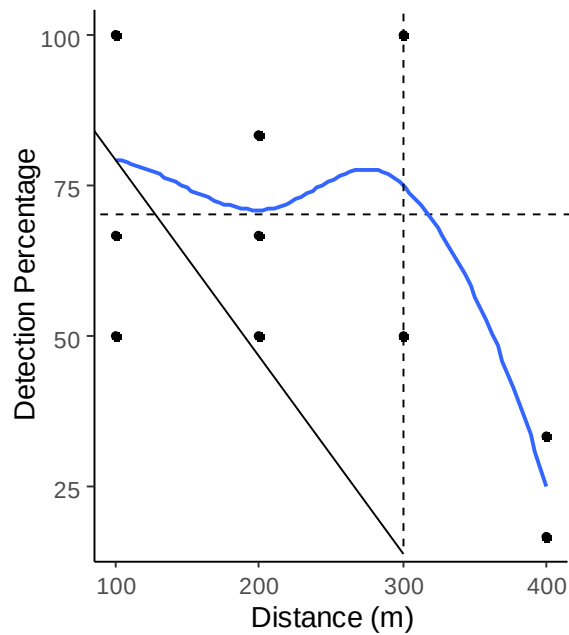
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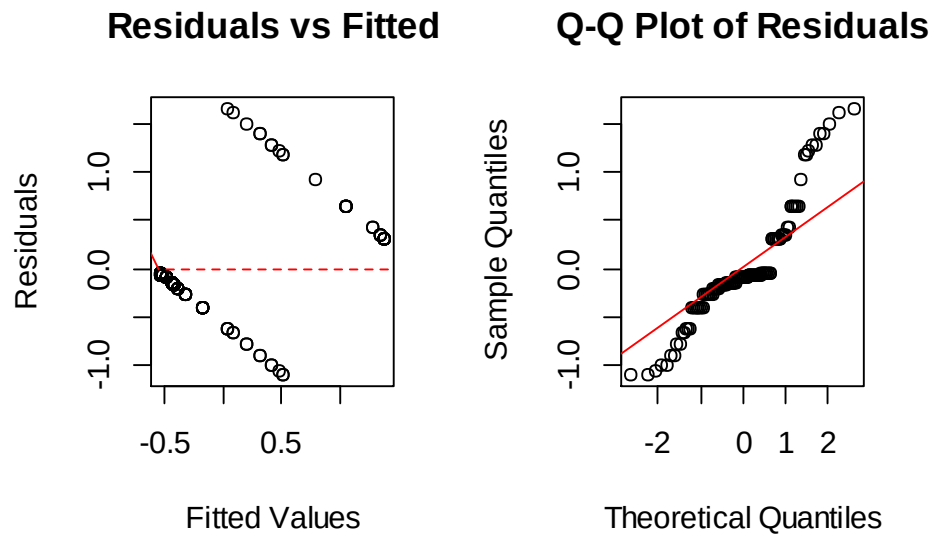
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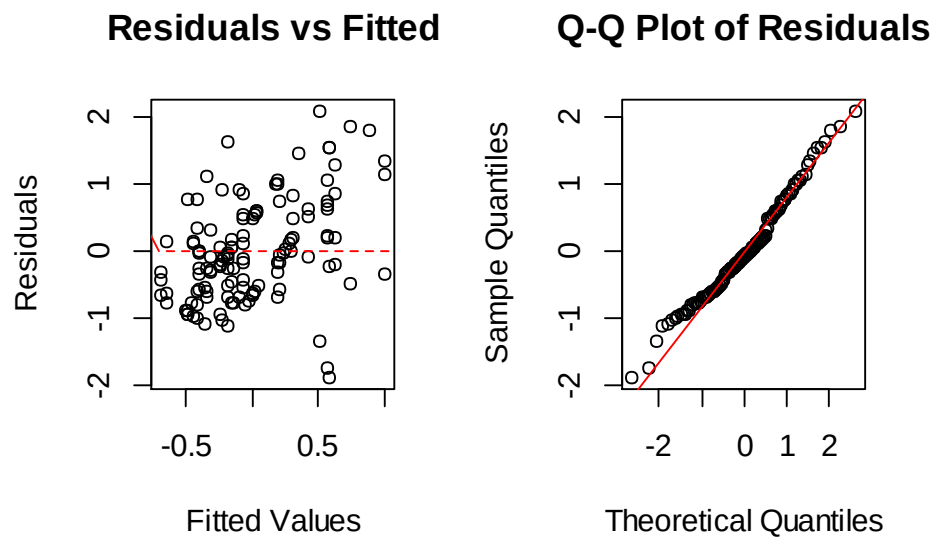
## Appendix A - Supplementary Material



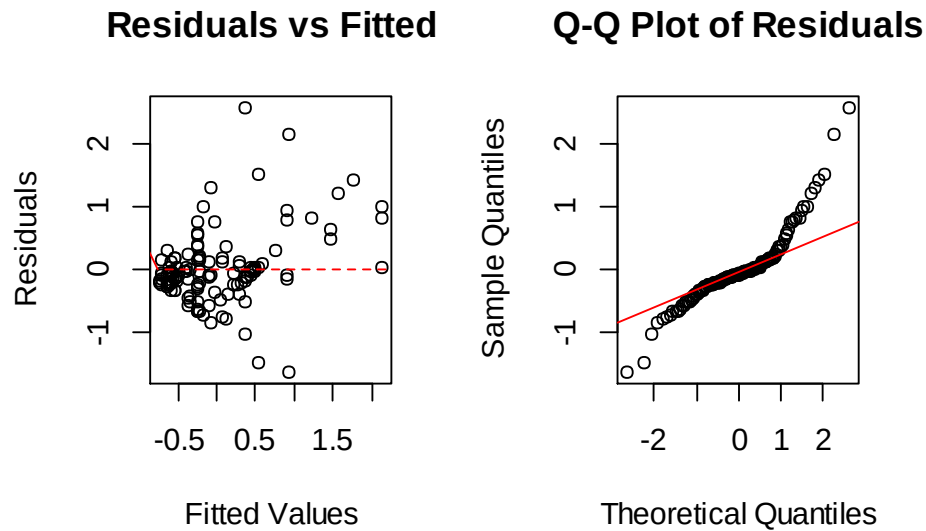
Appendix Figure 1.A. Range testing was conducted with coded acoustic transmitters to determine the range at which active tracking gear could successfully detect and record a code signal. It was determined that a radius of 300 m was appropriate for tracking surveys at the 70% detection probability, as recommended by Vemco.



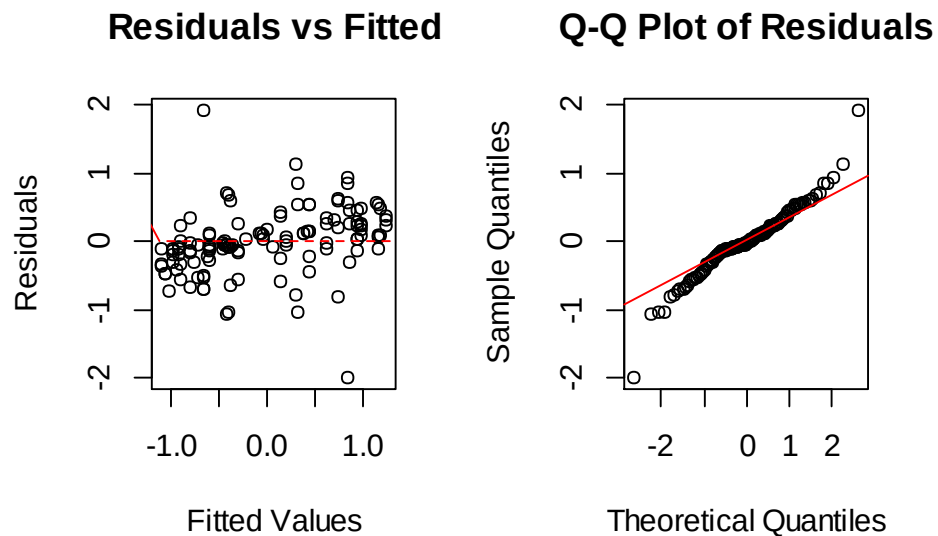
Appendix Figure 1.B. Diagnostic plots for the linear mixed effects model predicting occurrence in a cove by catfish species as the predictor variable and unique catfish identifier a random effect. The response variable of cove is standardized.



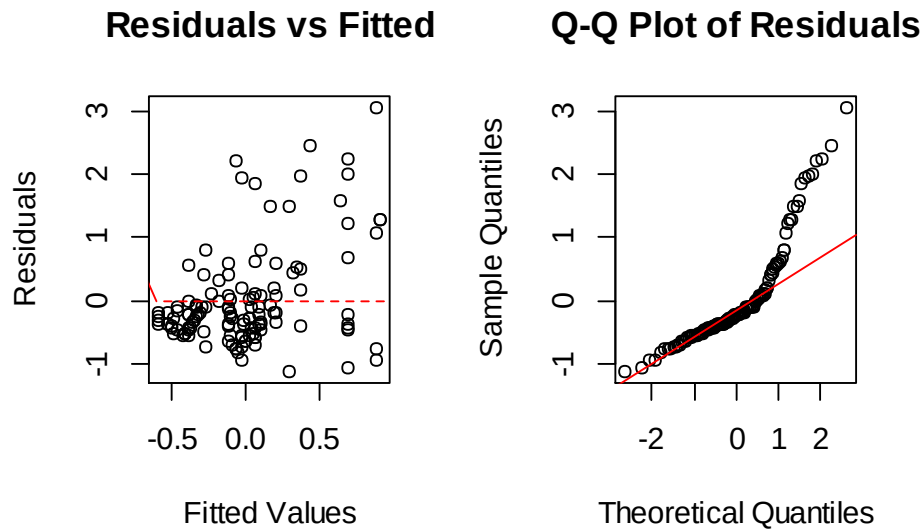
Appendix Figure 1.C. Diagnostic plots for the linear mixed effects model predicting depth by catfish species as the predictor variable and unique catfish identifier a random effect. The response variable of depth is standardized.



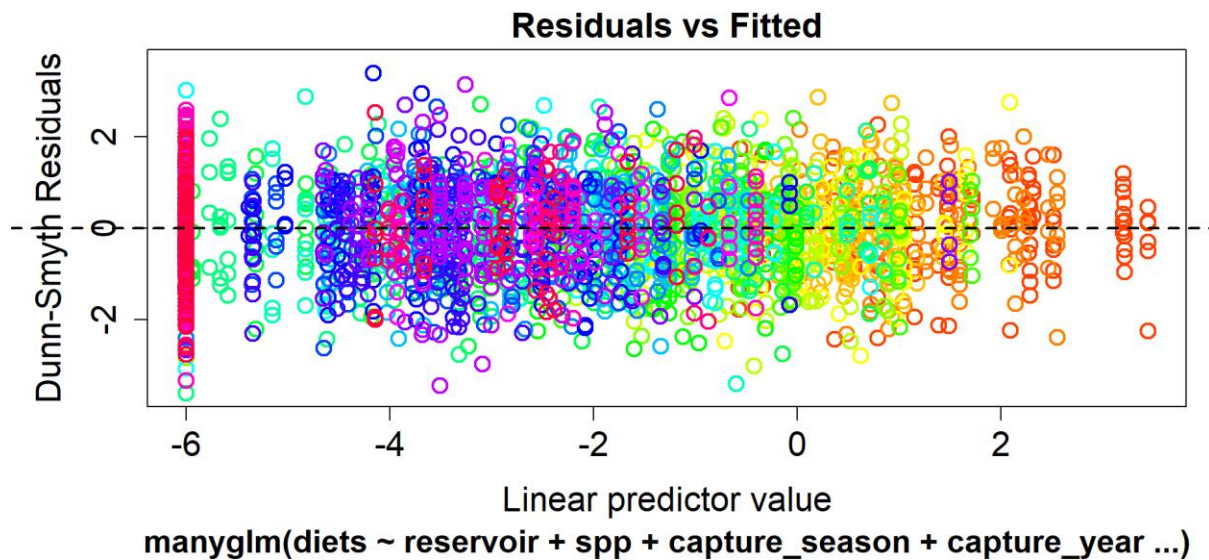
Appendix Figure 1.D. Diagnostic plots for the linear mixed effects model predicting the distance from thalweg by catfish species as the predictor variable and unique catfish identifier a random effect. The response variable of distance from thalweg is standardized.



Appendix Figure 1.E. Diagnostic plots for the linear mixed effects model predicting distance from reservoirs dam by catfish species as the predictor variable and unique catfish identifier a random effect. The response variable of distance from dam is standardized.



Appendix Figure 1.F. Diagnostic plots for the linear mixed effects model predicting distance from shoreline by catfish species as the predictor variable and unique catfish identifier a random effect. The response variable of distance from shoreline is standardized.



Appendix Figure 1.G. Diagnostic residual plot for the generalized linear model predicting stomach contents from sampling grids containing Blue Catfish and/or Channel Catfish by reservoir, species, sampling year and season.