Population Monitoring, Movement, and Removal of Common Carp in Lake Mattamuskeet, NC

Mattamuskeet National Wildlife Refuge
85 Mattamuskeet Road | Swanquarter, NC 27885

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United States Fish and Wildlife Service

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Introduction

Historically, Lake Mattamuskeet supported extensive beds of rooted submerged aquatic vegetation (SAV), which provided critical habitat and food resources for waterfowl, fish, and macroinvertebrates. However, SAV coverage declined dramatically beginning in the late 20th century and has progressively worsened over the last couple of decades. Moorman et al. (2017) and Lamb et al. (2020) both reported decreased Secchi depths, specifically median depths of 3.9” (0.1 m) – 13.78” (0.35 m) and a mean of 6.69” (17 cm) in 2017 and 2018, respectively. Both noted an increase in suspended solids, concentrations of nutrients, and phytoplankton as factors contributing to the loss of SAV. Thus, the loss of SAV is likely due to a complex suite of factors, including elevated turbidity, nutrient enrichment, wind-induced sediment resuspension, and bioturbation by Common Carp (*Cyprinus carpio*).

Common carp have been thought to be a major driver of degraded water clarity and SAV loss through benthic foraging behavior, where carp uproot vegetation, resuspend sediments, and increase nutrient availability in the water column, reinforcing a turbid, phytoplankton-dominated state (Rabaey et al. 2026). These feedback mechanisms reduce light penetration and inhibit SAV establishment, thereby limiting habitat quality for native species and waterfowl.

In response to long-term habitat degradation, USFWS and other managing agencies have implemented restoration and conservation efforts aimed at improving water quality and promoting SAV recovery in Lake Mattamuskeet. These efforts have included large-scale carp removal, water-level manipulation, and habitat management actions designed to shift the lake toward a clearer, vegetation-dominated state (Cahoon 1953; North Carolina Coastal Federation 2018). Reducing carp abundance was a large component of restoration strategies, as carp suppression was expected to decrease sediment disturbance, improve light availability, and facilitate SAV recolonization.

Prior to the current project, carp barriers were installed on the tide gates to prevent carp from the Pamlico Sound from returning to or entering Lake Mattamuskeet (USFWS 2021). It’s possible that these barriers may have effectively interrupted a part of their life history in terms of spawning, recruitment, and natural mortality.

Project Description

This study was conducted as part of ongoing efforts to evaluate baseline carp population dynamics, further assess the effectiveness of carp removal as a tool for ecosystem restoration and wildlife conservation, and remove as many carp as possible from Lake Mattamuskeet.

Objectives were as follows:

Objective 1 - Remove large numbers and weight of invasive common carp from Lake Mattamuskeet.

Objective 2 - Establish an array of bait traps and/or pound nets to remove carp at strategic locations on a semi-regular basis so that the density of carp in the lake can be monitored by catch rates.

Objective 3 - Conduct analyses to estimate baseline population dynamics parameters (i.e., age, growth, mortality, and biomass) to inform future modeling efforts aimed at better understanding carp population control over the long term.

Study Site

Lake Mattamuskeet is a large, shallow, coastal lake located within Mattamuskeet National Wildlife Refuge in Hyde County, North Carolina. The lake covers approximately 40,312 acres (16,000 ha) and has a mean depth of less than 3.28' (1 m), making it highly susceptible to wind-driven sediment resuspension and associated turbidity (Moorman et al. 2017). Lake Mattamuskeet is partly hydrologically isolated from adjacent estuarine systems by tide gates and is managed primarily for wildlife conservation, particularly migratory waterfowl and other wetland-dependent species (North Carolina Coastal Federation 2018).

Methods

Telemetry and Movement

Radiotelemetry was used to track movement and locate carp within the project area.

Advanced Telemetry Systems (ATS) series F1850B (35 ppm, 27 g) operating within the frequency range of 164 MHz fish implant transmitters were used during all telemetry and movement studies done on Lake Mattamuskeet for this project.

Thirty-nine carp were collected via electrofishing and seine netting during the third week of December 2023 for radio tag implanting. Each carp was captured, anesthetized, surgically implanted with a tag, then released after recovery. Carp were collected from and released to multiple areas within the main basin of Lake Mattamuskeet to minimize location bias. Approximately seven (7) different tagging sites were reported across the lake. Each tagging location comprised a random sample of carp used for the tagging procedure and were released close to where the individuals were collected.

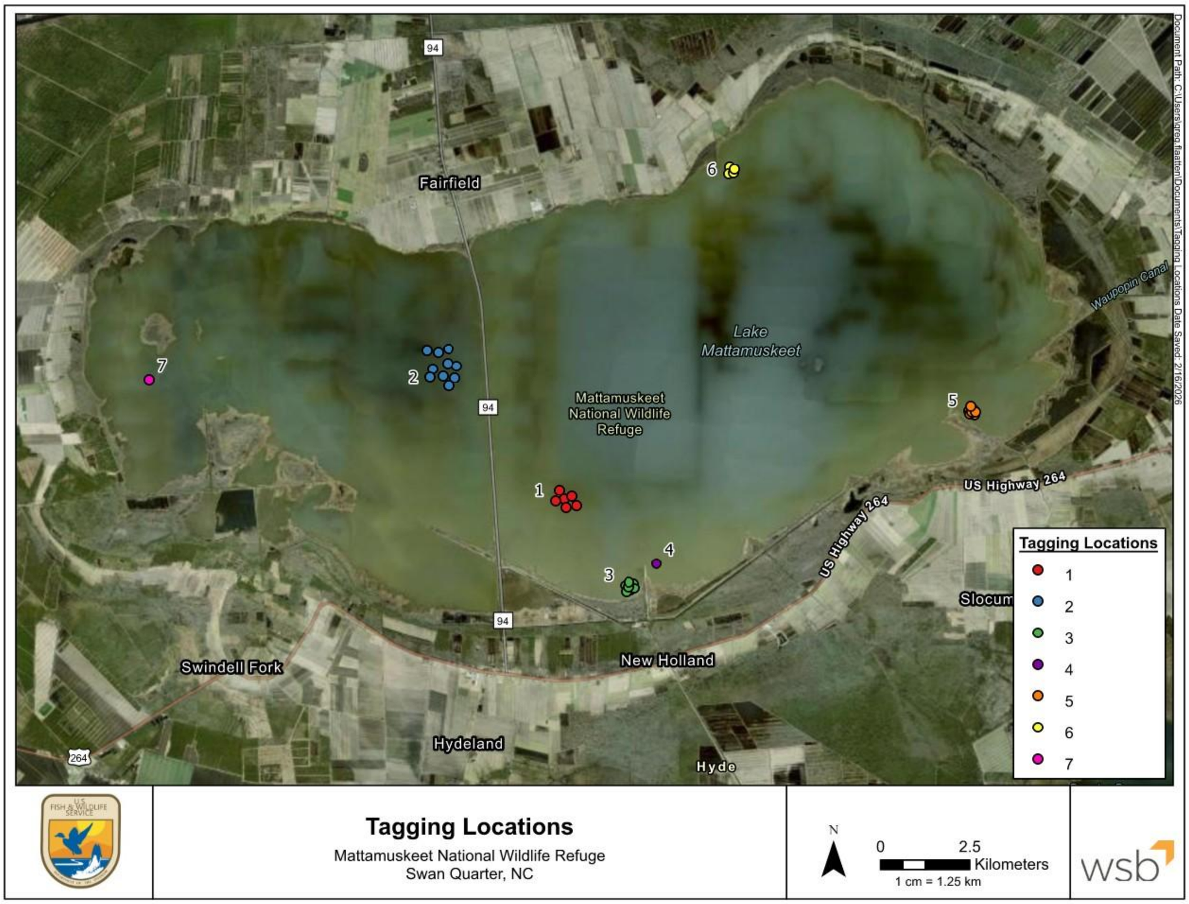

Figure 1. Capture, tagging, and release sites of carp in December 2023.

Radio-tagged carp were tracked using a 3-element yagi antennae and R410 (Advanced Telemetry Systems, Isanti, MN) from various points on land and on water. Crew members would manually track tags by standing at specific GPS points (listening points) and record detected frequencies, gain (or the amplification of the signal), and signal direction. In addition to handheld tracking, four stationary high-frequency receiver stations were constructed around Lake Mattamuskeet. ATS R4500 series receivers/dataloggers were utilized to continuously monitor when tagged carp would move within the detection range (~1/2 km). When a tagged carp was detected by one of the four stationary receivers, the data was sent remotely and later retrieved for analysis.

Telemetry surveys were conducted between February 4, 2024, through June 13, 2025. Within that period, telemetry surveys were completed on approximately forty-two (42) unique dates which were reported between three (3) agencies (USFWS, Biorn, and WSB). Over two hundred and twenty (220) distinct GPS locations (listening points) were used during this time to determine if tagged carp could be located throughout the basin.

Monitoring and Removal

Initially, commercial seines were the primary gear used in removing carp from Lake Mattamuskeet. These were 3,000’ nets with varied panels of 3–5” stretch mesh that varied between 9 and 25’ deep (the seine net from December 2023 also had a bag section with 6” stretch mesh). Prior to deploying the seine, a 100’ block net/backstop was constructed for each haul on a shoreline that was relatively free of obstructions or debris as these areas were more conducive to land fish and prevent snagging. These backstops served as a corral for any carp that attempted to outrun the seine as the net was pulled in. One end of this net also served as the start of the seine haul. Seining was conducted from a 25’ boat fitted with a winch used to pull the net into a semi-circle. Each seine event swept approximately 81 acres. Seining efforts occurred in winter and summer months; specifically, December 2023, May 2024, and February 2026. Seven total hauls were conducted in 2023 and 2024 and two hauls in 2026. Lengths and weights were collected from a subsample of carp from each event, while all other captured carp were composted in a space on site provided by USFWS. Other species that were captured as bycatch were immediately released.

As catch rates using seines were much lower than expected in December of 2023 and May 2024, WSB and Biorn staff began using other gear types to gather data and search for potential carp aggregations, while also continuing removal efforts. Hoop nets were a passive gear used in searching for carp throughout the lake while staff sampled elsewhere with other gears. These were either 3’ or 5’ hoops with 3” mesh. Six of each size were used for a total of 12 hoop nets. Most hoop net sets were baited with cracked corn in a laundry mesh bag tied to the upper part of the second to last hoop from the closed end. All available hoop nets were usually checked daily or every other day, barring extreme weather events. Nets that captured carp overnight were left to fish further, while an empty net was immediately removed and reset elsewhere. In total, 186 hoop nets were set throughout the survey period. Although hoop net catch rates remained relatively low over the duration of the project, there were times in which a small aggregation of carp, whether natural or artificially created, were found using hoop nets. Oftentimes, staff would then return and remove the carp in the area via other gear (i.e., gill nets and electrofishing).

Trap nets were another passive gear used, although to a lesser extent than hoop nets due to the ability of juvenile and adult carp to escape through the square panel openings at the entrance of the net. These standard trap nets (3/4” square mesh, 36” x 72” double square frame, 5- 30” steel hoops, and 3’6” deep x 60’ long leads) were usually set perpendicular to the shoreline with the start of the lead set in the phragmites or on a point. However, a couple of deeper nets were set with a 60’ lead tied between two nets. Configuring trap nets in this manner is often referred to as lead net sampling. As with the hoop nets, these were all baited with cracked corn. Only 6 standard trap nets were set over the duration of the project.

Starting in spring of 2024, we also used mini-trap nets in an attempt to sample young-of-year and juvenile carp, as none had been found with any gear type across the lake. These nets included a 27’ x 39’ double frame, 1/4” square mesh, 4- 24” steel hoops, and a 50’ long x 3’ deep lead. The front or mouth of the net had a 2” square mesh panel designed to exclude turtles and, coincidentally, larger-bodied adult fish. These nets were checked daily. We also used these in surveying multiple impoundments on the refuge in suspected carp nursery habitat. Mini-traps were set over seven events in the main lake and 9 times in the impoundments.

Two types of electrofishing boats were used during electrofishing surveys dependent on the task and site location. A 30' aluminum boat (Kann Manufacturing, Iowa) with an ETS Trident electrofishing control unit and associated gear were used for capturing fish during radio tagging, all CPUE surveys, and other sampling in 2023 and 2024. As water levels were often too low in 2025 to use this standard electrofishing boat, spring canal sampling and other electrofishing surveys were completed with a 17' aluminum johnboat with a 15-hp outboard. Associated electrofishing gear for this boat was the same as above, except instead of being powered by a 5,000-watt generator, it used two 2200i Honda generators in parallel with combined peak output of 4,200 watts. Regardless of the boat or gear used, the operator attempted to maintain output at 1,600 and 2,000 watts at all times. All electrofishing surveys were completed with two netters.

Box nets were a specialized gear routinely used in removal of carp. These were 30' x 60' x 10' deep with 1 7/8" square mesh, baited, rectangular nets that lie flat on the substrate until triggered by pulling eight ropes which raise the sides of the nets and trap any fish within. These nets require the habituation of carp feeding on bait (i.e., cracked corn, soy cakes, etc.) to be an effective removal tool. Therefore, they were not moved often, as it takes time for carp to move into an area and utilize the food source. This timeframe seemed to be further extended for Lake Mattamuskeet carp, whether it be due to low density or other factors. Furthermore, although water depth in the lake was ideal for box netting, much of the substrate was not suitable. As we trialed exploratory box net sets around the lake, the 10' posts used as a leverage point for pulling the sides of the net up would sink to depths in which the net would barely, if at all, emerge from the water's surface. Understandably, this would result in escaped carp.

Another issue encountered with the substrate arose when wave action would bury the net overnight and prevent the sides of the net rising when triggered, again resulting in lost carp. Although we had a few other sites around the lake that were moderately successful, sites along the causeway seemed to be the most effective, in terms of access, trigger success, and the ability to create artificial aggregations of carp with bait. The sandy substrate held the posts much more solidly than other areas of the lake and fish seemed less readily "fished out" of a localized area, whether due to higher overall carp densities or gradual replacement.

Each of the nets were triggered, baited, and checked once per day, either in the early morning or at dusk. Anywhere from one to five nets were active at a given time. For most of summer/fall of 2024 and all of 2025, there were four active nets along the causeway: two on the east and two on the west. Prior to this, two nets were active on the causeway and other two were used in other parts of the lake. In total, box nets were triggered 112 times.

Gill nets were another gear routinely used during removal efforts, especially in fall 2024 through 2026. Gill nets were most often set in the deep holes on either side of the causeway culvert dependent upon wind direction but were also used extensively in the deep holes near the USGS gauges in the winter months. Monofilament nets of 4 different dimensions were used:

1) 3’ X 100’ (6”-mesh stretch) (2)
2) 15’ X 300’ (5”-mesh stretch (3)
3) 10’ X 300’ (5”-mesh stretch (2)
4) 20’ X 600’ (5”-mesh stretch (2)

These nets were used at varied amounts and levels of success. Many of the carp in Lake Mattamuskeet are thin enough to not be reliably caught in 6”-mesh (stretch), although it is commonly used in carp removal. Because of this, nets with 5”-mesh (stretch) were used the most often. Unless inclement weather interfered, nets were usually soaked from 1 – 2 hours, most often near the flow of the causeway culverts or in the deeper holes on each side of the lake in winter months. While many gill nets were set in a standard/random manner, we also used them in a few ways that may confound catch-per-unit effort (CPUE) somewhat. We often baited an area with cracked corn while soaking gill nets and then set in the same general area over the proceeding days until catch rates markedly declined. They were also used to set in relative proximity to box nets when artificial aggregations of carp had formed near a box net. Some of these carp seemed to feed nocturnally, but stage nearby, therefore the gill nets allowed us to capture those that were habituated to bait but left the box net in between triggers. Finally, they were also used as “block nets” when carp were suspected of moving up a canal during spawning season or in other similar situations.

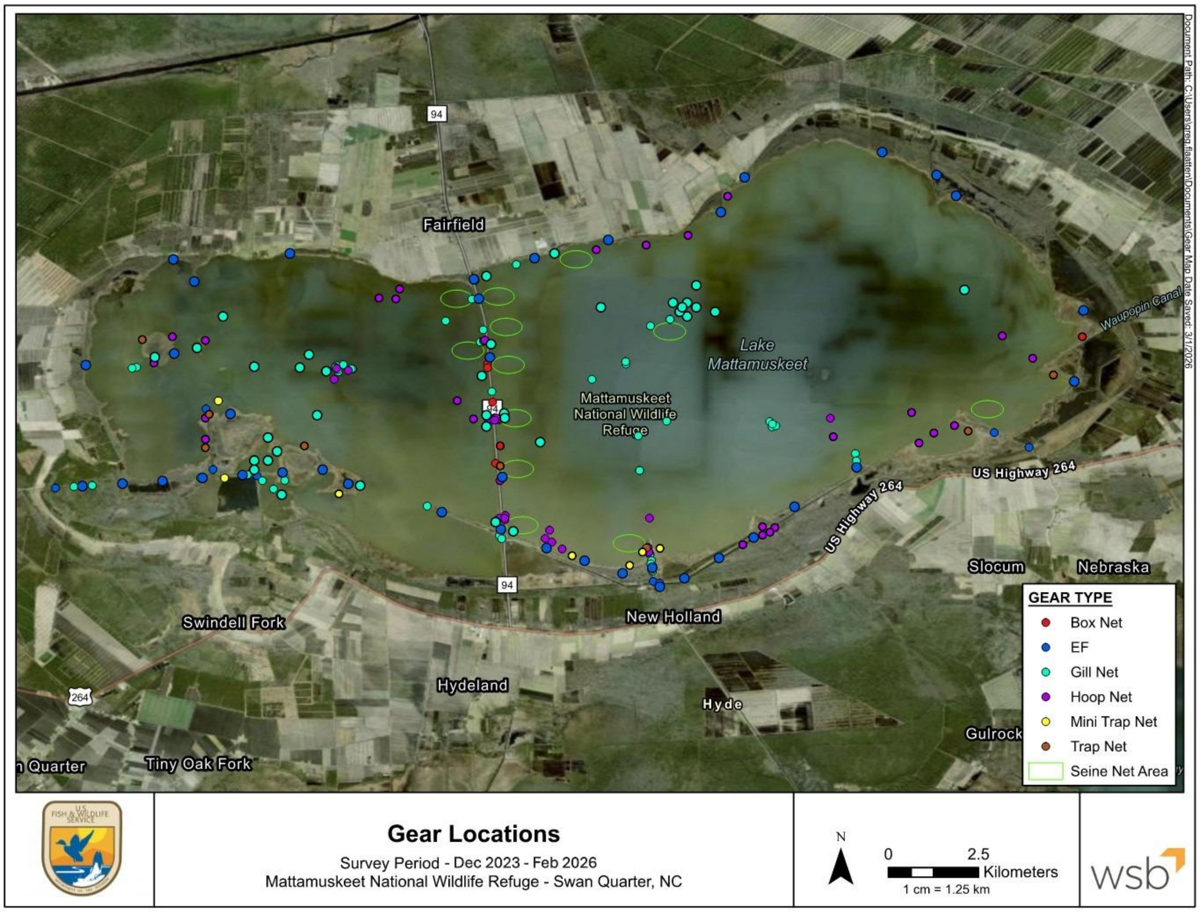

Figure 2. Location of gear sets of which GPS coordinates were available.

Catch-Per-Unit Effort (CPUE)

CPUE was calculated for all gear types to monitor catch rates across the lake and assess relative gear efficiency in capturing carp. Baited hoop net and trap net CPUE were calculated by net night:

$$CPUE = Number\ of\ Carp\ /\ Number\ of\ Consecutive\ Net\ Nights$$

An average and associated standard errors of the per net values was then calculated for reporting.

As box nets were a gear with both passive and active attributes, CPUE was simply calculated as follows:

$$CPUE = Number\ of\ Carp\ /\ Box\ Net\ Pull\ (or\ Lift)$$

An average and associated standard errors of the per pull values was then calculated for reporting.

Electrofishing CPUE was calculated using an average transect time of 0.29hrs (17.5min) over 36 transects. It was calculated as follows:

CPUE = Number of Carp / Average Transect Time

As mentioned above, gill nets were sometimes used in a manner in which they were set on or near small schools of carp and as such resultant CPUE values are likely biased to some extent. Caution is warranted if using these CPUE values for comparative purposes in the future. Nonetheless, gill net CPUE was calculated as follows:

CPUE = Number of Carp / (Soak Time x Net Length [ft])

An average and associated standard errors of the carp per net length, per hour values was then calculated for reporting.

Seine CPUE was calculated by dividing the number of carp caught in a haul by the length of the seine (3,000'), as follows:

CPUE = Number of Carp / Net Length (ft)

Across all calculations based on season, winter was defined as the months of December, January, February, and March, spring included April and May, summer was June, July, and August, and Fall was September, October, and November.

Abundance

Two methods were used in estimating carp abundance in Lake Mattamuskeet: an area swept calculation using the commercial seine data and a mark-recapture study akin to Lamb (2020).

In estimating carp abundance via the commercial seines, first, the area of a circle of 2,500' seine was calculated and the resultant value divided by two as a seine haul most closely geometrically approximates a semi-circle. Square footage was then converted to acreage. Each seine event approximately swept 81.14 acres. Density (carp/acre) was then calculated as follows:

N = Number of Carp / 81.14 acres

The average and associated standard error across all seine events were then calculated. This was extrapolated to a total lake value by multiplying by total lake acreage (40,312 acres).

Biomass was estimated similarly, using total pounds of carp from each seine haul as follows:

Biomass per Acre = Total Pounds / 81.14 acres

The average and associated standard error across all seine events were then calculated. This value was then extrapolated to a total lake value like the abundance value above.

In late September 2025, WSB and USFWS staff enclosed 135 acres of Rose Bay to update the mark-recapture estimate conducted in 2018 (Lamb 2020). T-posts and panel fencing were used in excluding the main lake and the opening to the canal was blocked off using a combination of t-posts, fencing and 3-4” mesh gill nets. The ~15’ portion blocked by gill nets was not fenced in so staff could enter and exit the enclosure while conducting the survey. Two gill nets, set parallel with each other and the fence line, were used here as a precaution against fish entering or exiting via the opening in the fence.

Initially, staff planned on conducting all mark-recapture efforts via electrofishing gear as done during the 2018 survey, however, average water depths of ~1’ made traversing the area while electrofishing inefficient, if not impossible. Efforts were then shifted to conducting the mark-recapture using gill nets and hoop nets. Three of the 5’ hoop nets mentioned above were set (unbaited) and remained at their set locations throughout the survey. Including the two gill nets at the canal opening, seven gill nets were used in capturing carp. Four of these nets were 10’ X 300’ with 4” mesh (5” stretch), another 10’ X 600’ with 3” mesh (4” stretch), and finally a 20’ X 600’ net with 6” mesh. While the latter was still soaked and monitored throughout the survey, we noted early on that the mesh size and “rigid” nylon material were likely allowing most carp to swim through (Figure 3). The only two carp caught in this net were captured by entanglement of the serrated dorsal spine.

Nets were checked twice a day (morning and evening) for two days. Each captured carp was given a left pelvic fin clip as a mark and all other species were released. After each net was checked, marked carp were transported in a live-well to an area in the enclosure as far as reasonably possible from nets.

In total 48 carp were captured, forty-five marks remained by the final recapture day after mortalities, and 18 were recaptured. The Chapmon-Robson modification of the Lincoln-Peterson method was used in estimating population size (N) within the enclosure. The equation was as follows:

$$N = \left(\frac{(M+1)(C+1)}{(R+1)}\right) - 1$$

where M was the number of marked carp, C was the total number of captured carp, and R was the number of recaptured carp. The resulting population estimate (N) was then divided by the acreage of the enclosure to produce a density (carp/acre) value. This value was multiplied by total lake acreage to produce a total abundance estimate. Biomass was calculated by multiplying this number by the mean weight of carp (4.52 lbs.) across all samples. Associated standard errors were then calculated as above.

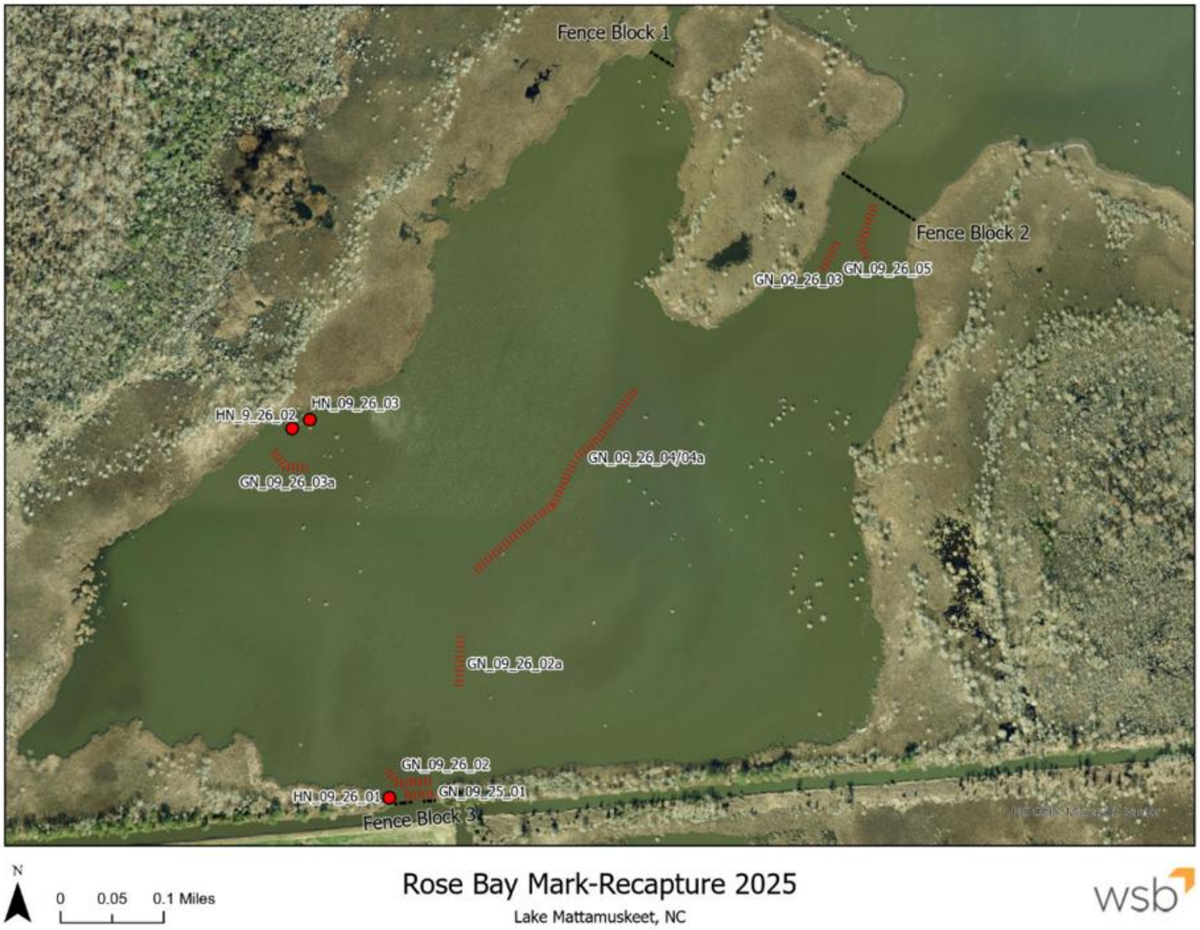

Figure 3. Map showing locations of enclosure fencing, gill nets, and hoop nets during mark-recapture efforts in September 2025.

Size Structure, Age Structure, and Population Dynamics

In assessing size structure, weights and lengths from 1,065 carp were recorded across all gear types. Average length and weight were calculated using these data and size structure and weight distribution graphs produced.

Subsets of carp were collected for age and growth analyses in October 2024 and February 2025. In total, 260 otoliths were removed for sectioning and ageing, however annuli on seven and twelve sectioned samples were illegible in 2024 and 2025, respectively, bringing the total of processed otoliths to 245. Twenty-eight of these otoliths were from carp caught in a nearby impoundment, therefore 217 otoliths came from fish in the main lake. These samples were used in assessing age structure, fitting a von Bertalanffy growth curve, and estimating mortality (2024 samples only). Parameters from these analyses will be used in carp biomass simulation modeling efforts by East Carolina University in the near future. Samples from 2025 will also be used in a comparative ageing analysis of hard-part structures, as dorsal spines were collected from carp in 2025 also.

Otoliths were embedded in West Systems 105 epoxy resin and sectioned with a Buehler Isomet low speed saw. After sectioning, otoliths were mounted to microscope slides and processed separately by two independent readers. Otoliths were viewed using an AmScope microscope under 4x magnification and an AmScope FMA037 camera and associated software. Samples for which reader agreement was not exact, a third “concert read” was completed. Agreed upon ages from the concert read were then finalized for analysis.

Total annual mortality (Z) of carp was estimated using a catch-curve analysis based on age-frequency data from the fall 2024 electrofishing surveys. Only fully recruited age classes were included in the analysis to meet the assumptions of catch-curve methods. This analysis was conducted according to Ogle (2016) using the FSA package in R Studio (R core Team, version 4.4.0).

The Chapman–Robson estimator was used to estimate instantaneous total mortality rate (Z), as this method, instead of a weighted regression, was used in 2020 and we desired to repeat the past analysis as closely as possible. Smith et al. (2012) found less than a 6% difference in the estimates of Z when comparing the two methods, while noting that the Chapman–Robson method performed better in terms of variance. This estimator assumes constant recruitment, constant mortality across fully recruited age classes, and equal vulnerability of those age classes to the sampling gear (Ogle 2016).

Age frequencies were truncated to exclude partially recruited younger age classes. The minimum fully recruited age was identified as the peak age at which the descending limb of the catch curve began and age frequencies declined with increasing age. The descending limb was also right-truncated by only including ages up until the first age with zero catch.

Age and growth of carp were evaluated using the von Bertalanffy growth model. Fish ages were estimated from otoliths from 2024 and 2025 and total length (TL; in) was recorded for each individual at the time of capture. Only fish with confidently assigned ages were included in growth analyses. However, due to lack of young fish in the dataset from the main lake, lengths and ages from 30 fish captured in a nearby impoundment were included to fit the curve.

The von Bertalanffy growth function (VBGF) was fit to observed length-at-age data:

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

where L_t is the predicted total length at age t, L_∞ is the asymptotic length, K is the Brody growth coefficient describing the rate at which L_∞ is approached, and t_0 is the theoretical age at which length equals zero.

Model parameters (L_∞, K, and t_0) were estimated using nonlinear least-squares regression in the R Studio FSA package (Ogle 2016). Initial parameter values were selected based on observed size distributions and previously published growth estimates for common carp. Model fit was evaluated visually by overlaying the fitted growth curve on observed length-at-age data and by examining residual patterns. Associated confidence intervals were bootstrapped with replacement using 1,000 iterations from the original length-at-age data.

As most carp captured throughout 2023 – 2026 appeared to be emaciated and/or of poor health, body condition of carp was evaluated using relative weight (*Wr*). Total length (TL; mm) and weight (W; g) were recorded for 970 individuals from the main lake at the time of capture. Relative weight was calculated as:

$$Wr = \left(\frac{W}{W_s}\right) \times 100$$

where W is the observed weight of an individual fish and W_s is the standard weight predicted from a common carp-specific standard weight equation ($W_s = -4.639 + 2.920 \times \log 10TL$) (Bister et al. 2000; Snow et al. 2020).

US Fish and Wildlife Service (USFWS) staff removed 30 adult carp from a nearby impoundment during a beach seine event after a drawdown. Lengths and weights from these fish were recorded and relative weights of these fish were calculated as above. Relative condition of these fish were then compared to the 970 individuals from the main lake via a one-way ANOVA, although results should be viewed with caution due to disparity between sample size of the two groups.

Fish Community Statistics and Bycatch

Throughout all carp sampling and removal efforts, other fish species were encountered and/or captured as bycatch. While no morphometric data was collected for any of these species as North Carolina Wildlife Resources Commission (NCWRC) monitors and manages sportfish populations and fish community assemblages for the lake, general abundance data was collected. These data were reported as total catch across all gear types and then broken down by each gear type. Understanding abundance of some of these species may be valuable to future carp management efforts in terms of potential predation upon young-of-year/juvenile carp, heterospecific competition, etc. For example, Poole and Bajer (2019) and other studies have documented the reduction in recruitment success of carp in habitats with strong bluegill populations. Although considering habitat use across life histories of other opportunistic piscivorous species (e.g., white perch, channel catfish, etc.) may not overlap with young carp and the general lack of understanding of their relationships, there may be some potential for predation and/or other deleterious impacts on carp abundance from other fish species.

Results

Telemetry and Movement

Of the thirty-nine (39) implanted radio tags, twenty-eight (28) unique frequencies were heard during field telemetry surveys

Heat maps using all telemetry survey data were produced to create a visual representation of carp densities or trends across seasons; specifically the spring/early summer spawning period and the remainder of the year. By plotting all listening locations where a handheld telemetry survey was completed and referencing the tag detection buffer range of 0.29 km (determined during the spring and summer months) assumptions on carp spatial distribution can be made. The heat maps represent detections of radio tagged carp across all listening points. All points from which tagged carp were listened for were included.

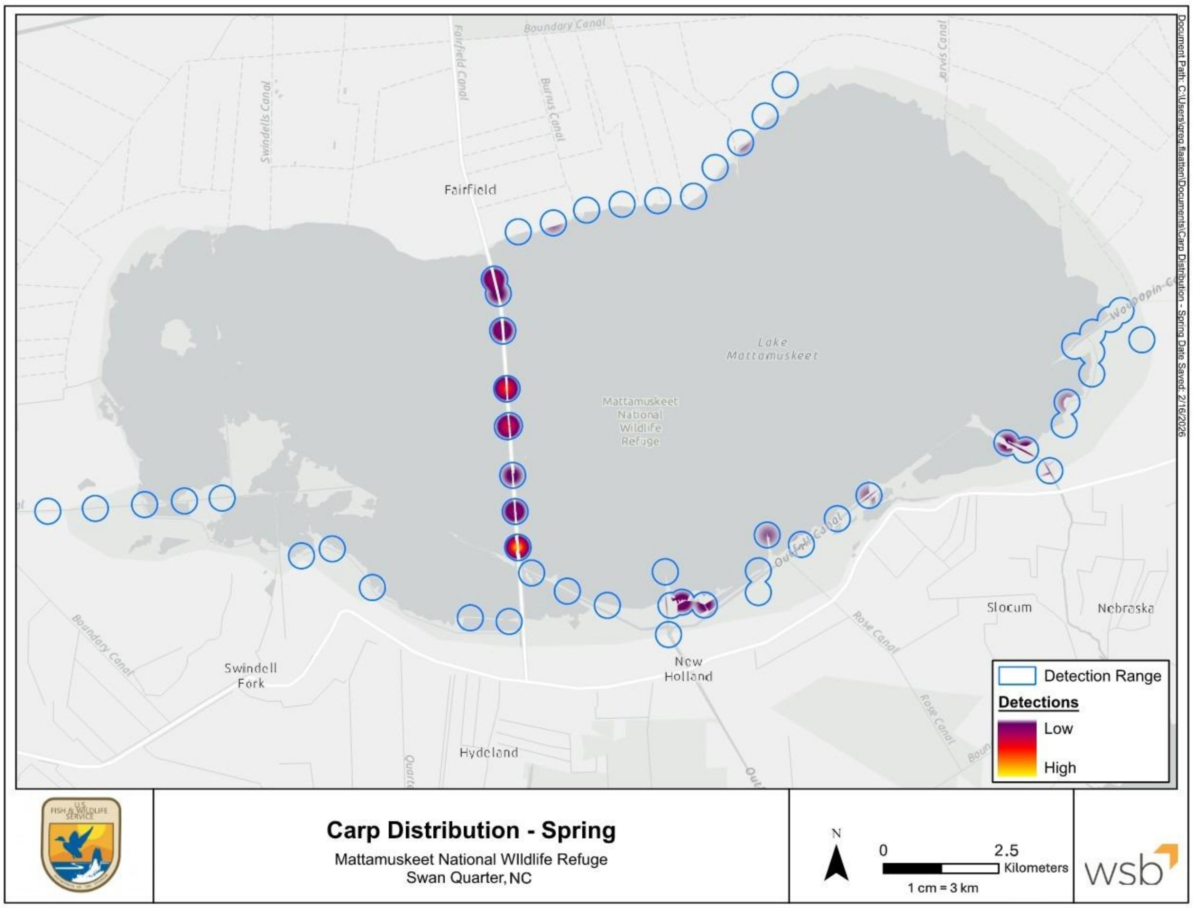

Figure 4. Heat map showing distribution of radio tagged carp detections during the spring/early summer spawning period.

The scale color gradient increases from purple (low number of detections) to yellow (high number of detections). These yellow areas show where radio tagged carp were most often distributed across all surveys during this period.

Spawning period distribution is greater along the causeway and in areas near canal outlets (Figure 4). This may indicate that carp are attempting to use the canals as migration routes.

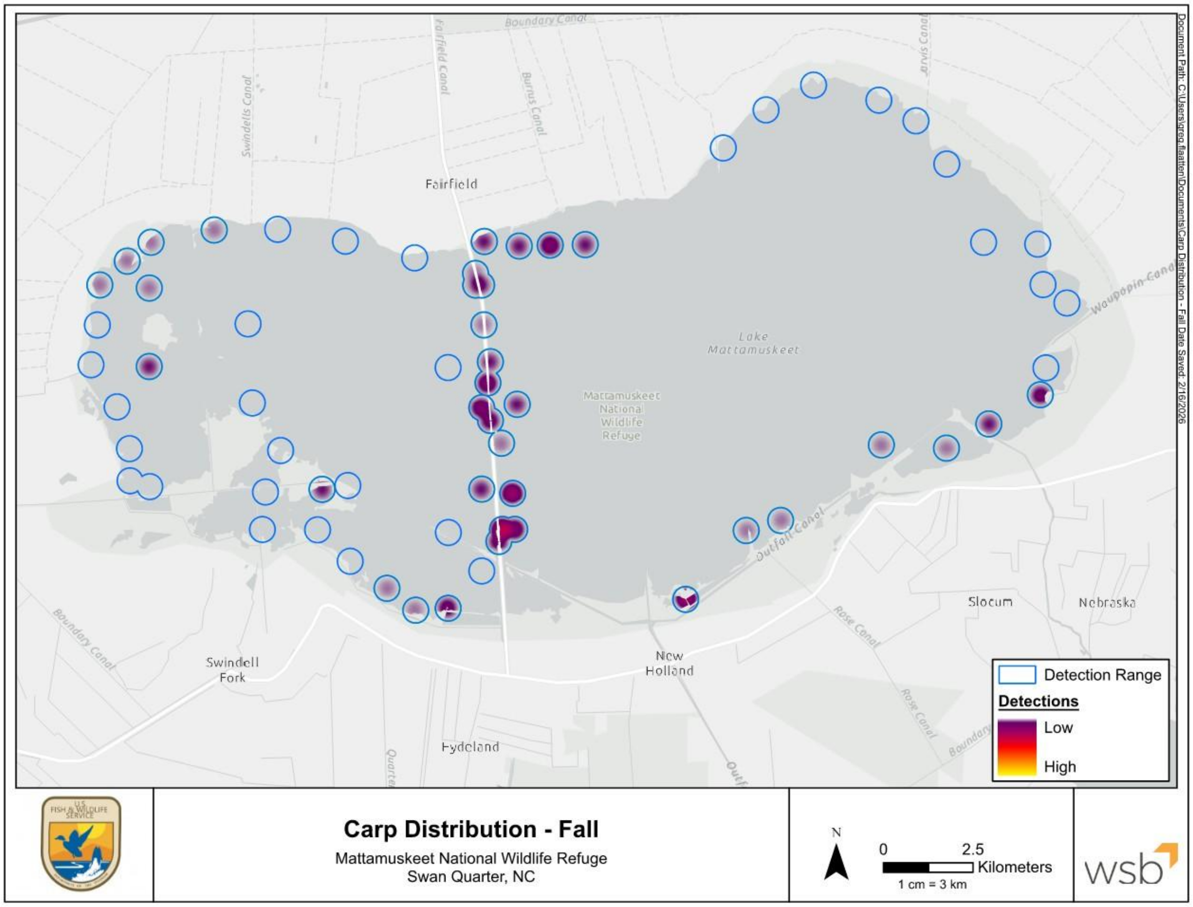

Figure 5. Heat map showing distribution of radio tagged carp detections during the spring/early summer spawning period.

The fall (remainder of the year) distribution shows carp more widely distributed (Figure 5). Primary distribution is still found along the causeway, but carp are found in most other areas of the lake and not found only near the outlet canals. This may be a function of carp foraging or responding to biotic or abiotic stimuli.

At the start of the project, we had planned to use radio tagged carp to identify when and where large aggregations formed and target those for large scale removal as in other similar projects, but radio tagged carp never formed an aggregation where more than 2 or 3 radio tags were found. This may be due to the homogeneity of the habitat across the lake.

Movement of tagged carp was determined by analyzing shifts in position of each radio tagged carp from its original position of the release in December 2023 (Appendix B). This analysis showed us that carp behaved individually with no pattern identified across all radio tagged carp. For example, radio tagged carp from group 1 (with the exception of 1 individual), were found to stay in a roughly 1.5 km radius of the release site, while radio tagged carp from groups 2 and 5 were found throughout all areas of the lake. No radio tagged carp were found outside the lake, in canals, or within impoundments. Maps showing distribution and movement of individual tags from each tagging group can be found in Appendix B.

A series of maps using hexagons sized to the same detection range used for the heat maps (0.29 km) were created to further understand distribution of radio tagged carp, telemetry survey effort, and number of unique detections.

To standardize telemetry survey effort, a hexagonal map was created to represent Lake Mattamuskeet in a grid-like structure to analyze spatial patterns. This was done to be able to normalize effort data where the number of telemetry surveys at each listening point was disproportionate. A total of 523 spatially valid detections were identified from the dataset. Detections were reduced so that each individual frequency was counted only once per listening event. This was to reduce inflated numbers and ensure that each carp was counted at a maximum of one time per location per day. The dataset then contained 252 unique carp detections after filtering. Listening events were used as the unit of sampling effort. This generated a hexagonal tessellation across the lake using a projected coordinate system for accuracy. The hexagons served as standardized spatial units for summarizing both telemetry efforts and carp detections.

Figure 6 displays listening events joined to the hexagonal grid to calculate the number of listening events per hexagon. The maximum effort observed within a single hexagon was 43 listening events. This map represents the spatial distribution of survey effort.

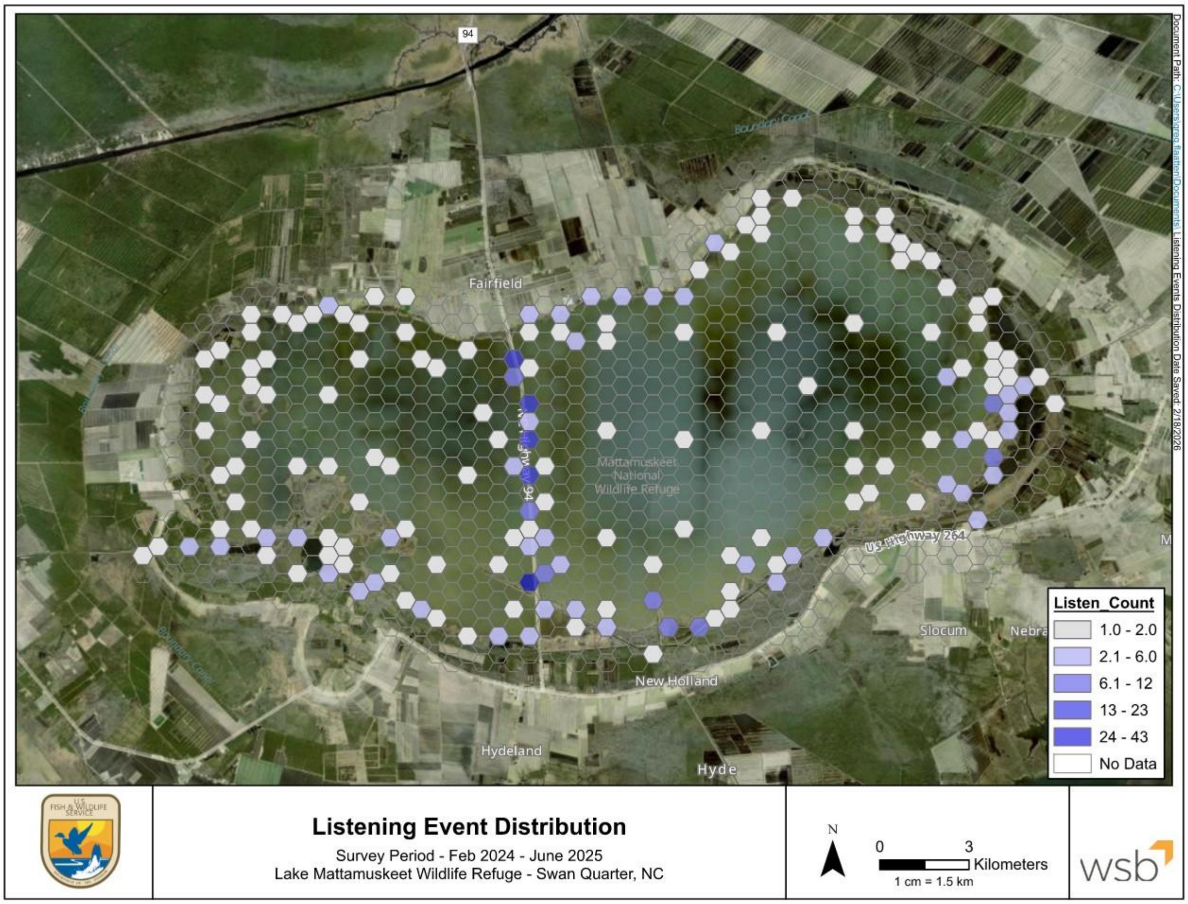

Figure 6. Hexagonal grid of telemetry survey effort (listening events).

Most of the effort was expended along the causeway and land-based listening points as these were more easily accessible than those on the water and could be completed when wind (or other weather) prevented staff from being able to access points on the water.

The second map was joined to the filtered carp detection layer and to the hexagonal grid to calculate the number of unique carp detections per hexagon. Figure 7 represents absolute detection counts without adjusting for effort. The maximum number of unique carp detections within a single hexagon was 40.

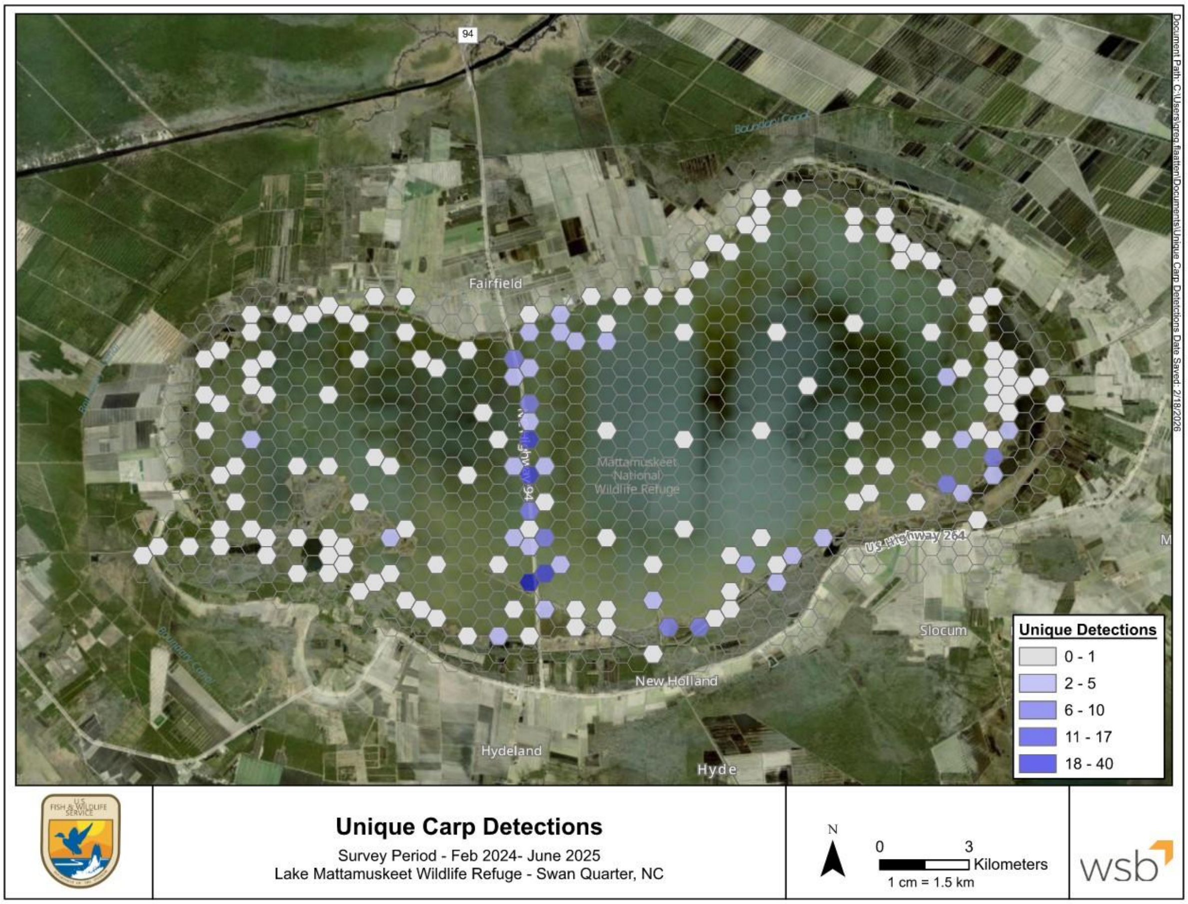

Figure 7. Hexagonal grid of telemetry survey results showing number of detections per cell.

Lastly a DPUE (detections per unit effort) metric for each hexagon was calculated by dividing unique carp detections by listening events (DPUE = Unique Carp Detections ÷ Listening Events) (Figure 8). This produced an effort-adjusted index representing that average number of unique carp detected per listening event within each hexagon. This approach accounts for uneven sampling effort and allows for meaningful spatial comparison of carp activity across the lake.

Each map was symbolized using graduated color classification with the Jenks Natural Breaks method. Jenks classification minimizes within-group variation and maximizes the between-group variance allowing natural grouping in the data to determine the breakpoints. Because ecological datasets are often spatially clustered and non-normally distributed, this method provides a defensible and data-driven classification. Hexagons with zero listening effort were excluded from CPUE classification or symbolized separately to prevent distortion of the effort-adjusted scale.

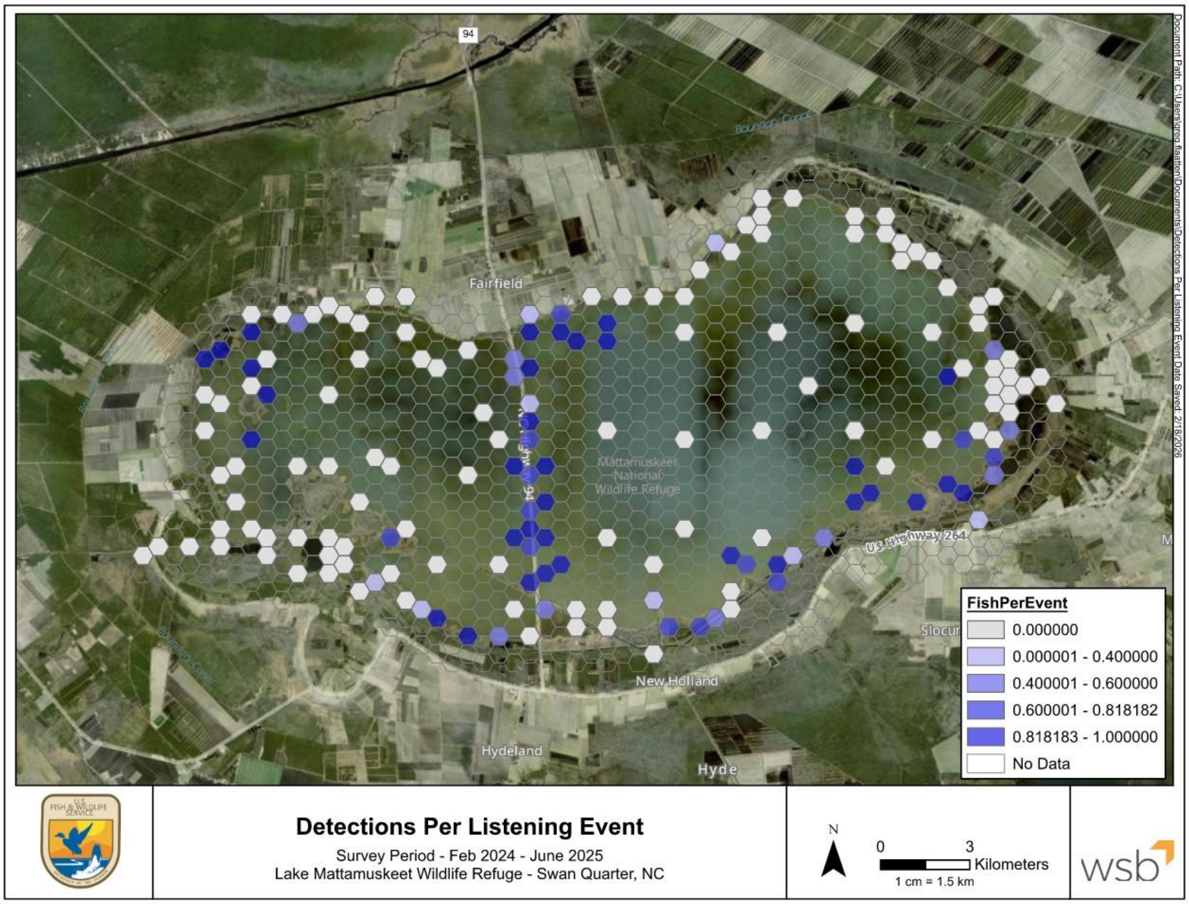

Figure 8. Detections per Unit Effort.

Together the three maps represent survey effort (events), raw detection intensity (detections), and effort-standardized detection intensity (CPUE), providing complementary perspectives on spatial carp activity.

Monitoring and Removal

Size Structure

Of the 1,065 carp measured, average length was 21.9” with a range of 6” – 34”. Less than 14% of these individuals were below 18” TL with the majority being 20 to 25” (Figure 9). Average weight of these fish was 4.52 lbs. (Figure 10). As some of the gears used were likely biased towards larger individuals, size structure from the electrofishing surveys was assessed separately also. Average length of the carp captured during electrofishing were 20.8” with individual lengths ranging from 6” – 28.13”. Weights of these fish ranged from 0.5 lbs. to 9.5 lbs.

Average length of the carp removed from the impoundment was 19.3”, with lengths ranging from 15” – 27”. On average, impoundment carp weighed 3.63 lbs. Weights ranged from 1.63 lbs. to 9.48lbs.

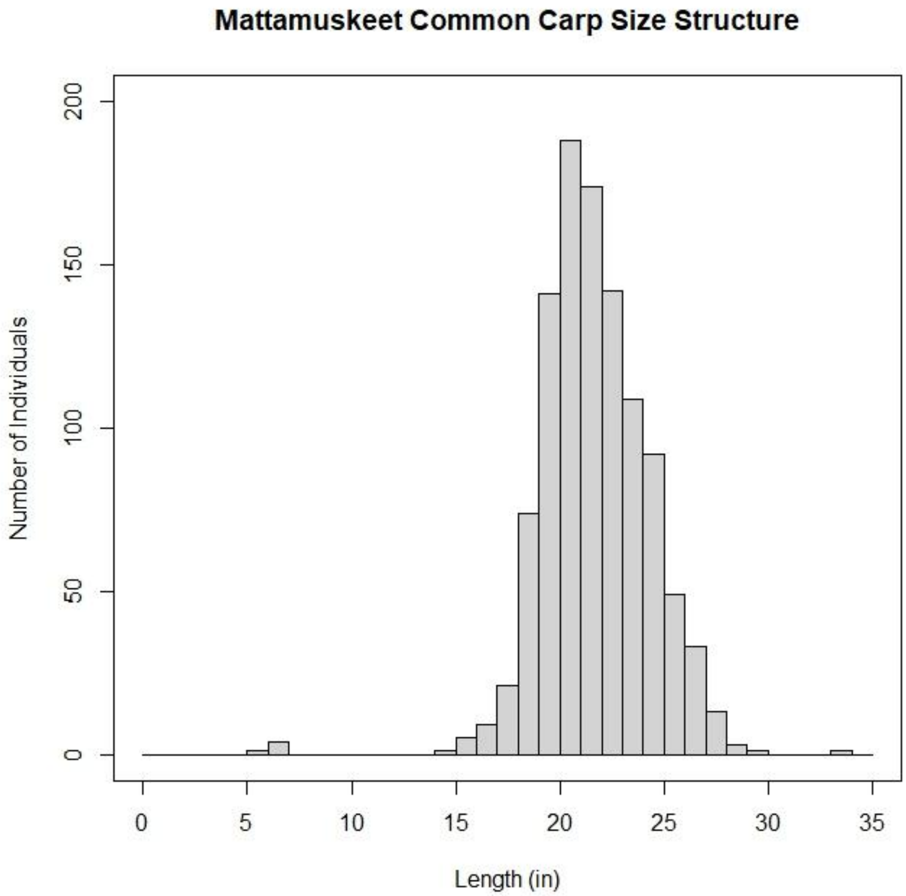

Figure 9. Length distribution of common carp measured from December 2023 to January 2026.

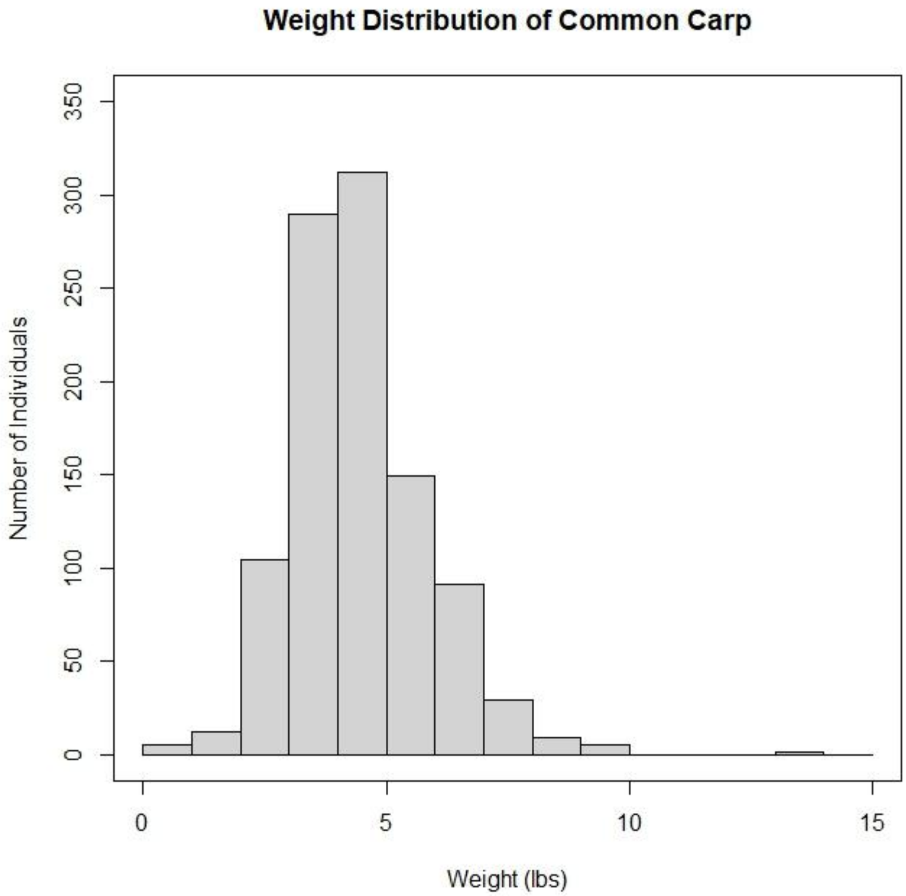

Figure 10. Weight distribution of common carp weighed from December 2023 to January 2026.

Catch-Per-Unit Effort (CPUE)

CPUE was calculated for each gear type used over the course of the study period and was generally low (Table 1). Trap nets were the least used gear, as this gear seems to lack efficiency in terms of adult carp capture. Average carp CPUE over the six sets was 0.49 carp/net night (SE, 0.20).

Baited hoop net CPUE was also low at 0.87 carp/net night (SE, 0.088) (Table 1). These hoop nets were set all over the lake but seemed to be the most effective in the outflow from the causeway culverts.

The CPUE value for box nets would also be considered low if compared to other lakes with high densities of carp (Table 1). Over 112 box net pulls, 10.69 carp (SE, 1.82) were caught per pull. Average box net CPUE was steady across seasons, except during the winter months. Highest CPUE was in the fall (18.67; SE, 3.80), followed by summer (18.33; SE, 11.21), spring (14.07; SE, 4.16), and winter (1.80; SE, 0.74) (Figure 11).

Average CPUE of the seine hauls was 0.047 (SE, 0.012).

Table 1. Catch-per-unit effort (CPUE) by gear type. Electrofishing values are from 2024 CPUE/abundance sampling and do not represent results of all electrofishing surveys. Comparing these values with future CPUE values should be done so with caution, as many of the gears were baited.

Gear Type	Equation	Number of Sets/Transects	CPUE	SE
Trap Net	# of Carp / # of Days	6	0.49	0.20
Hoop Net	# of Carp / # of Days	186	0.87	0.088
Box Net	# of Carp / Pull	112	10.69	1.82
Electrofishing	# of Carp / # of Hrs	35	19.11	3.11
Gill Net	# of Carp / (# of Hrs x Net Length)	165	0.012	0.0022
Seine	# of Carp / Net Length	9	0.047	0.012

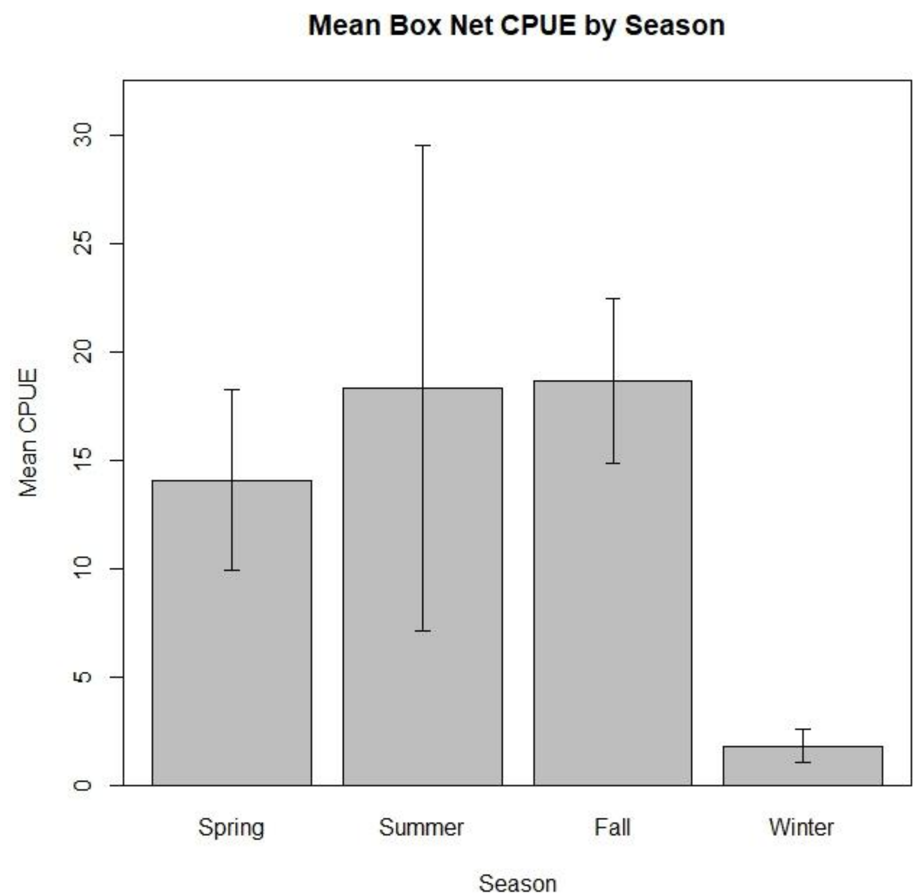

Figure 11. Average box net CPUE across seasons. Error bars represent standard error (SE). Sample size for summer was notably lower than the other seasons.

Gill net CPUE was 0.012 carp per hour per net length (SE, 0.0022) (Table 1). Seasonally, gill net CPUE was consistent with fall (0.020; SE, 0.003) being the highest, followed by spring (0.012; SE, 0.0026), and winter (0.011; SE, 0.0041) (Figure 12). Winter gill net catch rates remaining consistent compared to the other seasons were likely due to the relative efficiency of netting in the deep winter holes on each side of the basin during the winter months. This seems to show, to some degree, that carp form some semblance of aggregations in these areas during sustained colder temperatures. The decline in winter box net catch rates may lend to this thought, as some of the causeway carp may have left for the wintering holes. Equally plausible, though not mutually exclusive, is that winter box net catch rate declined due to carp feeding activity declining during the winter.

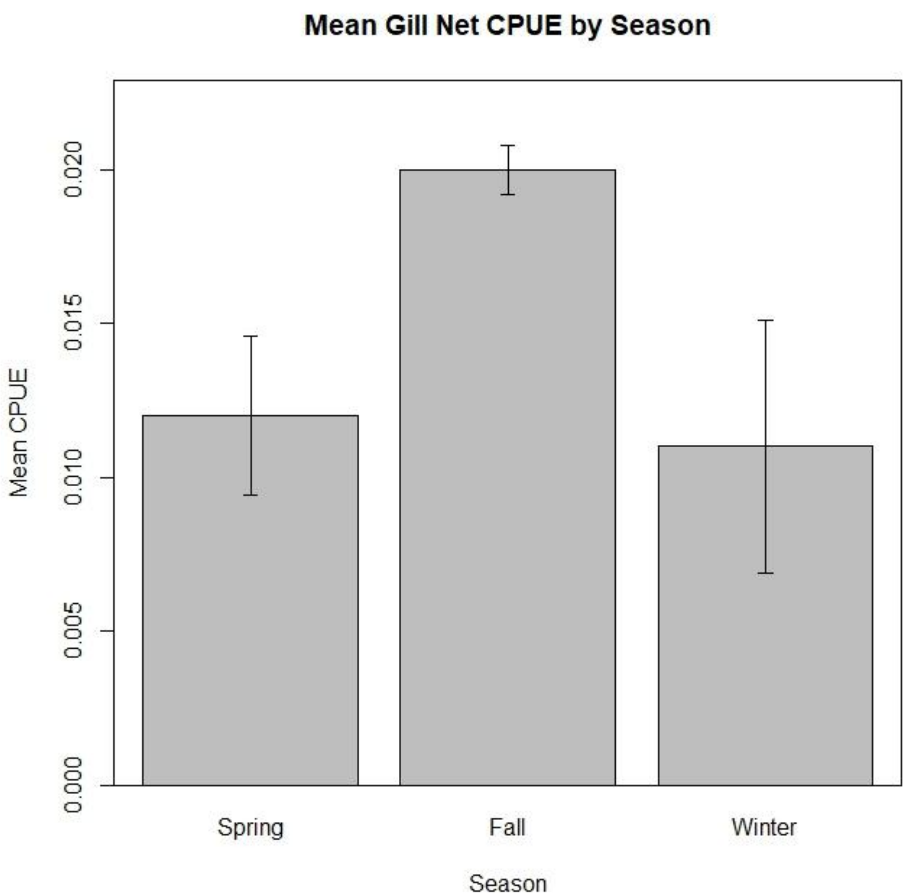

Figure 12. Mean Gill Net CPUE across seasons. No gill nets were set during the summer months. Error bars represent standard error (SE). CPUE values are carp per hour per length of net (ft).

Electrofishing CPUE across all sites sampled in 2024 was comparable to past years of electrofishing surveys at 19.11 carp per half hour (SE, 3.11) (Figure 13). This is the lowest value since 2017 (13.33 carp/half hour), as 2016 and 2018 values were 21.51 and 21.75, respectively. As a caveat, far fewer transects were surveyed during 2017 and 2018 than in 2016 and 2024. Because of this and the high proportion of crossover between sample sites (22) in 2016 and 2024, these values were compared directly.

Comparisons of CPUE values from the 22 analogous sites in 2016 and 2024 showed that carp per half hour values were lower in 2024 (17.87; SE, 2.88) than in 2016 (20.22; SE, 4.11) (Figure 14).

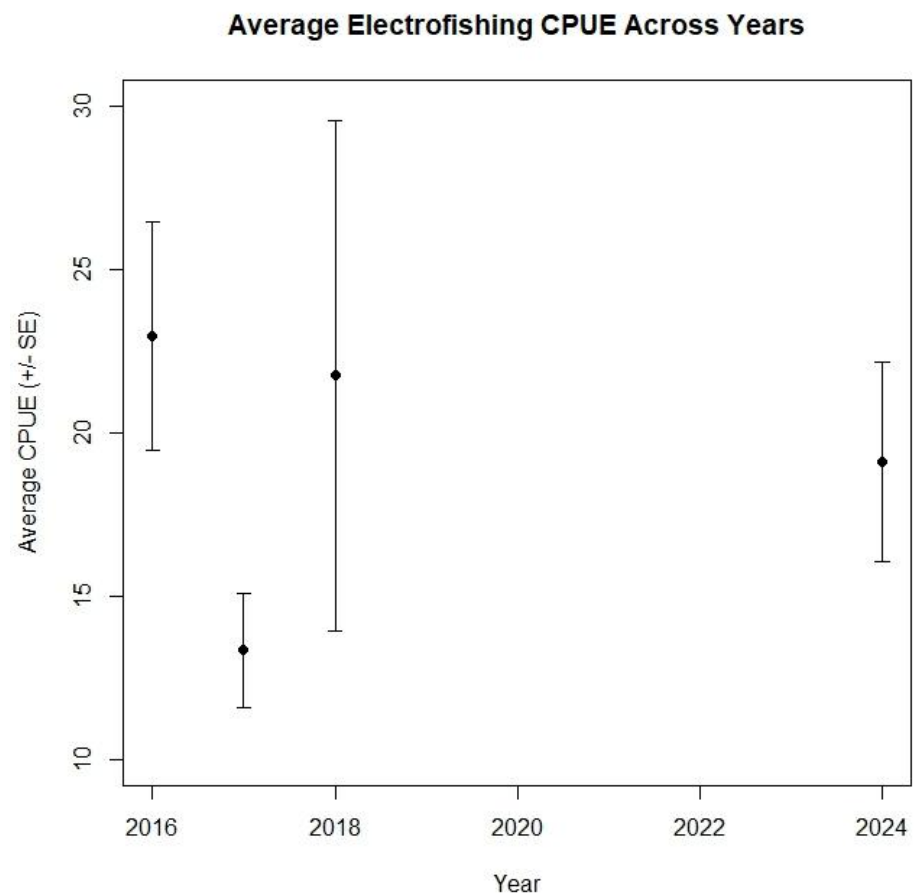

Figure 13. Average electrofishing CPUE across survey years. Number of transects sampled differed between years with the largest number of surveys and the highest degree of transect site correspondence being between 2016 and 2024.

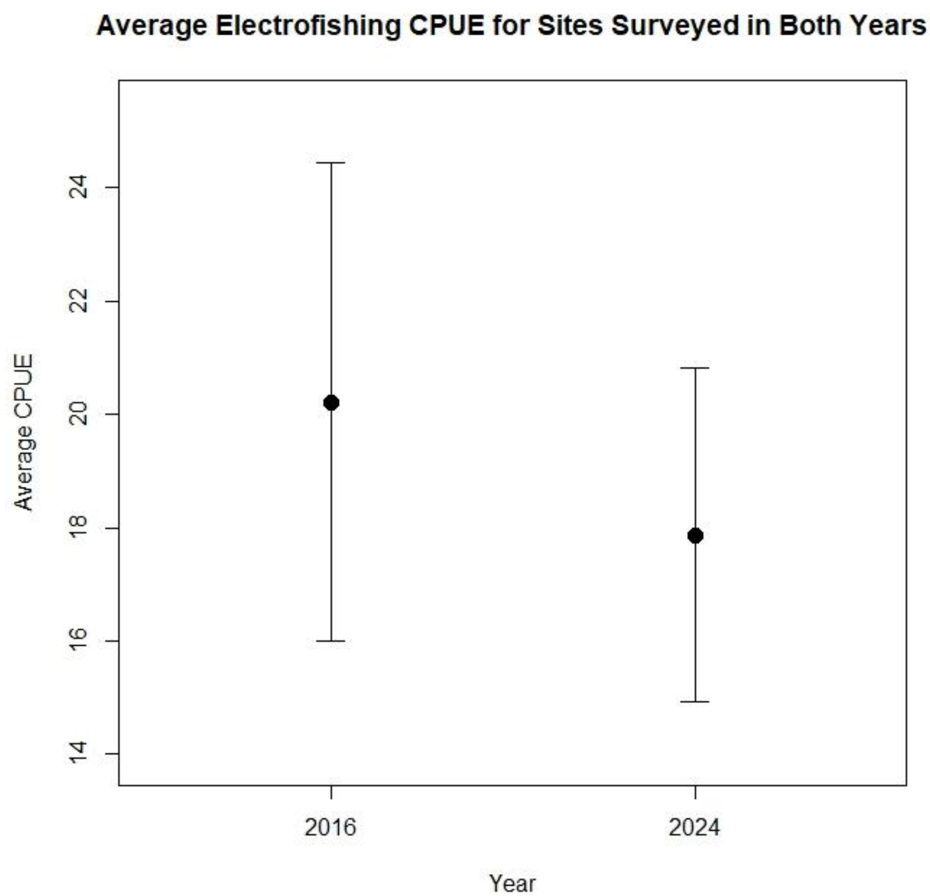

Figure 14. Comparison of electrofishing CPUE including only sites sampled (n=22) in both 2016 and 2024.

Abundance

In updating the Lake Mattamuskeet carp abundance estimate, two methods were used: an area swept calculation using catch data from the seine hauls and a mark-recapture survey in Rose Bay, similar to the 2018 effort (Lamb 2020) (Table 2).

Density (carp/ac) was estimated to be 1.73 (SE, 0.44) by the area-swept method. This value multiplied by total lake acreage (40,312 ac) produced an abundance estimate of 69,554 carp (SE, 17,716). Biomass (lbs/ac) was estimated to be 8.51 (SE, 1.97). This value multiplied by total lake acreage yields a total biomass estimate 343,258 (SE, 79,475).

From the mark-recapture survey, density was estimated to be 0.88 carp/ac. This value multiplied by total lake acreage yielded a total lake abundance estimate of 35,474 carp (Table 2). Biomass (lbs/ac) was 4.52 lbs/ac. In this case, total lake biomass would be 182,210 lbs. We were unable to calculate standard errors for these values as it was a simple mark-recapture survey, thus analyzed as one event.

Table 2. Comparison of abundance and biomass estimate by method.

Gear Type/Method	Density (carp/ac)	Biomass (lbs/ac)	Number of Individuals	Total Biomass
Area Swept (seine)	1.73 (SE, 0.32)	8.51 (SE, 1.42)	69,554	343,258
Mark-Recapture (gill nets)	0.88	4.52	35,474	182,210

Removal

Across all gear types, 3,821 individual carp were removed from Lake Mattamuskeet. This accounts for an approximate 18,142 pounds of carp biomass removed from the system. The majority (1,239 carp; 6,141 lbs.) were removed using box nets followed by seines (1,124 carp; 5,247 lbs.), gill nets (828 carp; 3,938 lbs.), electrofishing (336 carp; 1,473 lbs.), hoop nets (260 carp; 1,217 lbs.), beach seine (30 carp; 109 lbs.), and trap nets (4 carp; 17 lbs.) (Table 3).

Dependent upon the abundance/biomass estimate method applied, this represents 5.5% and 5.3% of the abundance and biomass removed, respectively, according to the area swept calculation and 10.8% of the abundance and 10.0% of the biomass removed according to the mark-recapture estimate.

Table 3. Number of common carp and biomass removed by gear type.

Gear Type	Number of Individuals	Biomass Removed (lbs)
Trap Net	4	17
Hoop Net	260	1,217
Box Net	1,239	6,141
Beach Seine	30	109
Electrofishing	336	1,473
Gill Net	828	3,938
Seine	1,124	5,247
Total	3,821	18,142

Age Structure and Population Dynamics

Understanding age of the Lake Mattamuskeet carp population was a data gap near the end of 2024. Lacking this information inhibited the ability to understand growth and age structure of the population, making determining if the population is made up of young individuals or older adults undergoing suppression of growth due to lack of food resources or density-dependent limiting factors difficult. Stunted carp will often be of comparable size as younger fish past age-3. It also means that information about recruitment, or the survival of fish from larval stage to sexual maturity, is unknown or anecdotal at best. In terms of carp removal as a management tool, all these data are important in determining the need and viability of removal efforts.

From the 217 otoliths processed from the main lake, average age was 15 years old and ranged from 1 – 33 years old. Seventy-nine percent of the individuals aged were between 10 and 18 years old and 96% were 10 years old or greater. Four percent of the aged individuals were less than 10 years old (Figure 15; Figure 16). Five of these individuals were age-1 fish and were captured via electrofishing near the Lake Landing Canal tide gate. USFWS staff had raised the gate slightly for a study focused on carp use of the canal under varying flow conditions.

It is possible these age-1 fish came from the other side of the control structure as they were small-bodied (5”-7”) and may have avoided mortality unlike the larger carp that go through the pumps and receive mortal wounds. It is also possible that they went through the gap at the bottom of the gate. Young carp have not been captured elsewhere in the lake. There were no fish of the ages 7 – 9. In general, recruitment over the last 10 years seems to be low and the Lake Mattamuskeet carp population largely comprised of older adults.

Many of the gravid females’ ovaries observed in the main lake over two spawning seasons showed signs of egg resorption (Figure 28). Given the energetic demands of reproduction, spawning success is highly dependent on physiological health of individuals (Horvath 1986). Carp may forgo spawning when underweight, highly stressed, or in poor health. This is another potential limiting factor of successful recruitment in Lake Mattamuskeet.

Of the twenty-eight carp aged from the impoundment, ages ranged from 2 – 33 years old with an average age of 9 years old. Fifty-seven percent of these fish were less than 3 years old and 68% less than 6 years old. The remaining nine carp were all over 15 years old (Figure 17; Figure 18). Although the ageing data from the impoundment was limited, there does appear to be recent recruitment and possibly fairly steady recruitment unlike the main lake population over the last ten years.

While this may be due to lower densities of YOY carp predators in the specific impoundment, Pumpkinseed and Bluegill Sunfish were abundant in other impoundments sampled with trap nets. It seems more probable that it is a product of greater availability in spawning/nursery habitat (i.e., SAV), better access to food resources, or most likely, both. *Wr* values seem to indicate this also (Figure 21).

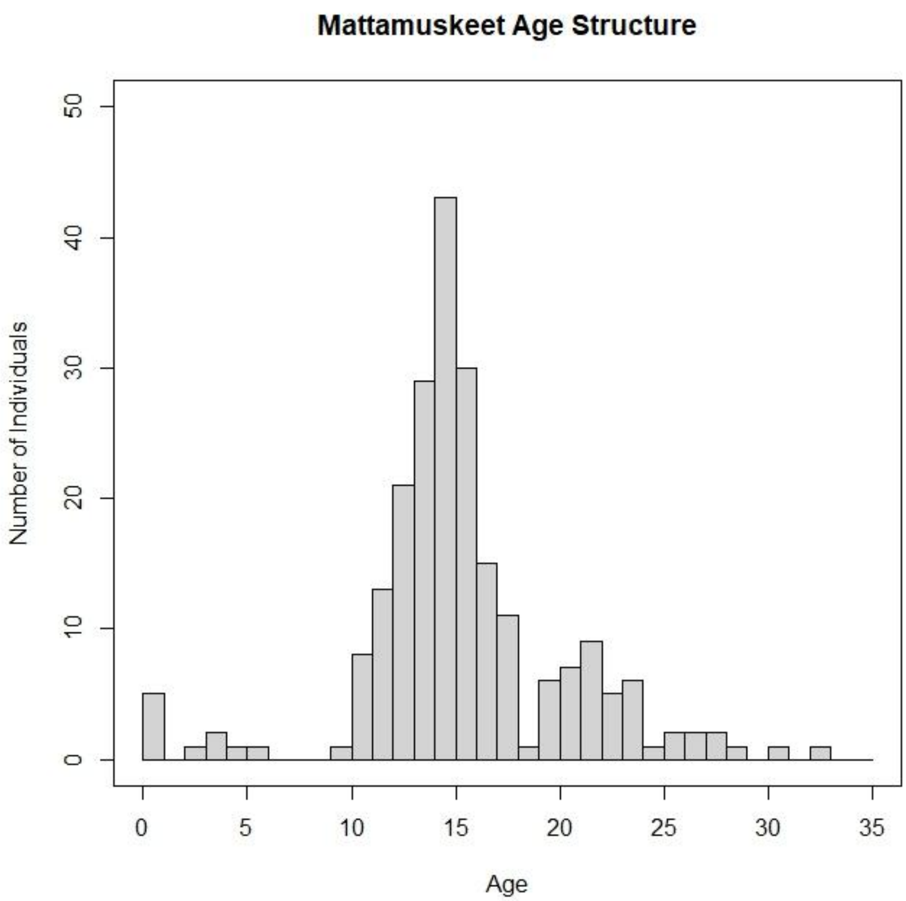

Figure 15. Distribution of ages of common carp captured from the main lake. Year-1 fish came from Lake Landing canal near the tide gates.

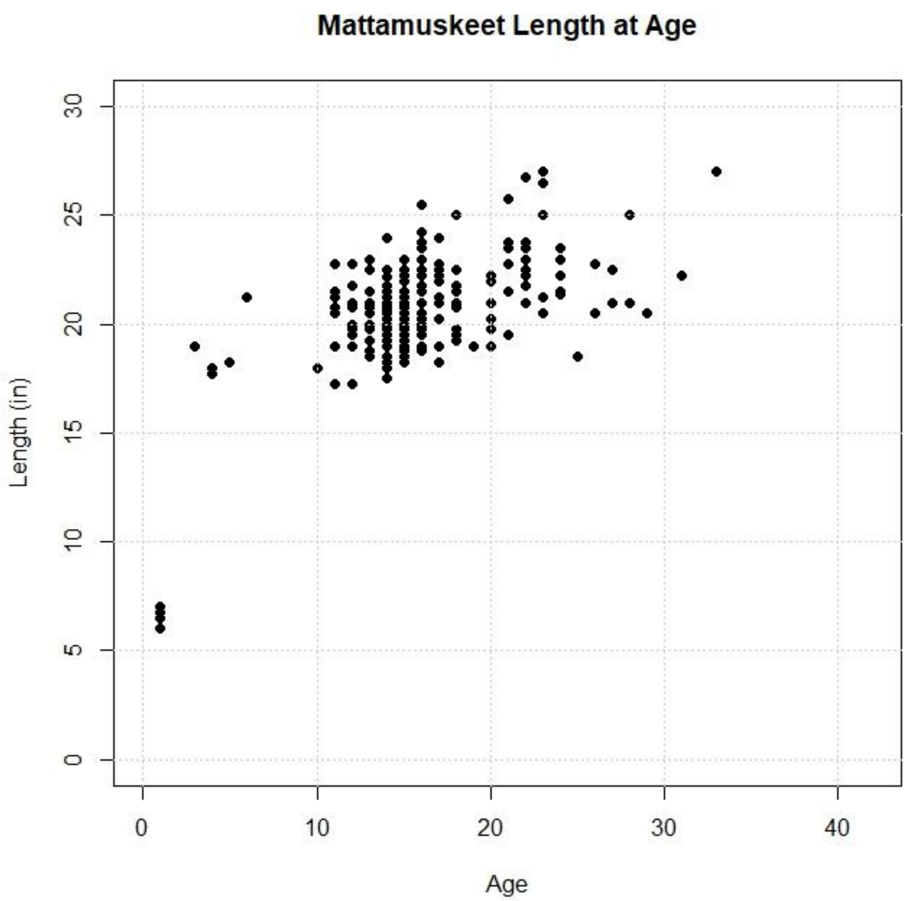

Figure 16. Length-at-Age of common carp captured from the main lake. Year-1 fish came from Lake Landing canal near the tide gates.

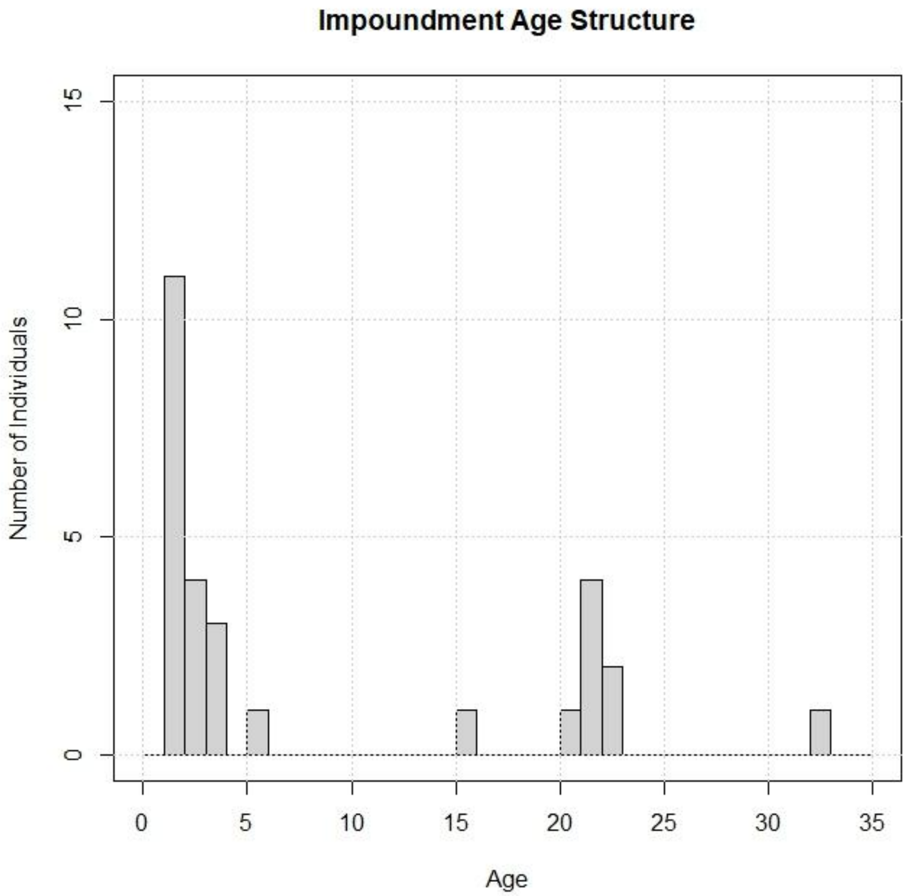

Figure 17. Age structure of common carp captured in impoundment (n=28).

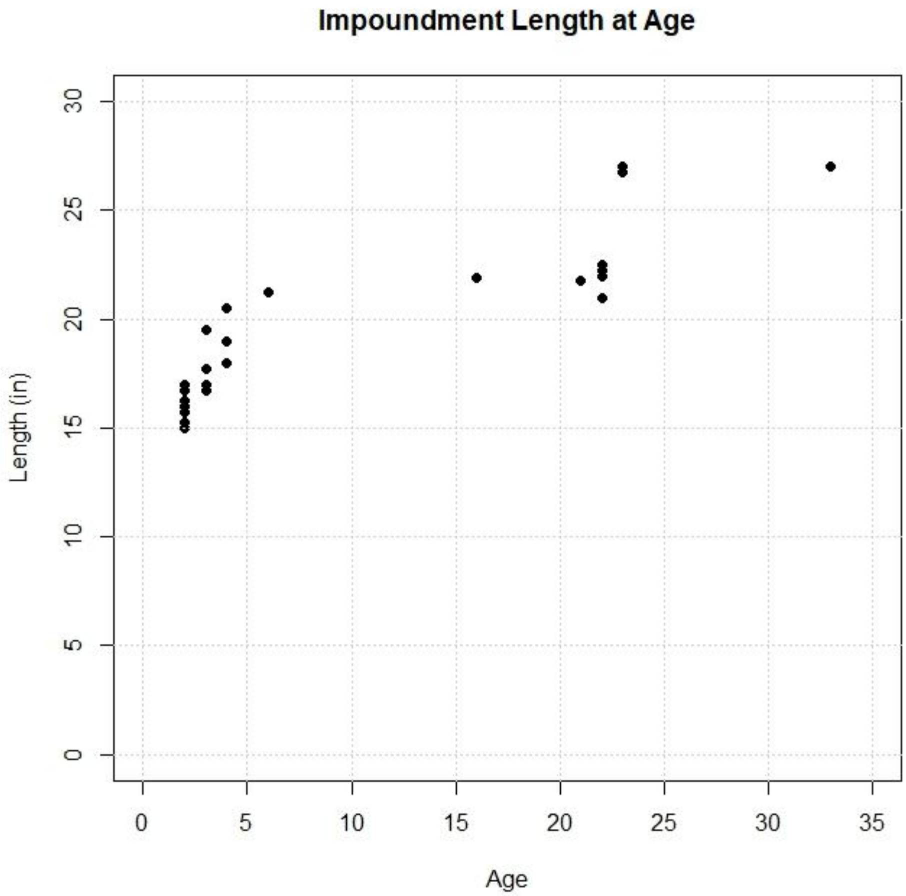

Figure 18. Length-at-age of common carp captured in impoundment.

Catch-curve analysis using the Chapman–Robson estimator produced an instantaneous total mortality estimate (Z) of 0.26 (95% CI, 0.22 – 0.30) for carp. The corresponding annual survival rate (S) was 0.772 (95% CI, 0.721 – 0.822), and annual mortality (A) was estimated at 0.227 (95% CI, 0.201 – 0.259) (Figure 19).

These estimates indicate relatively high annual survival of fully recruited age classes, with approximately 77% of individuals surviving from one year to the next. Such survival rates suggest that adult carp persist in the population for many years, contributing to a stable age structure dominated by older individuals. Under these conditions, population reduction through natural mortality alone is likely to occur slowly. However, at least in recent years, recruitment seems to be minimal, so, presently, there may be few young carp to replace the older stock in the future.

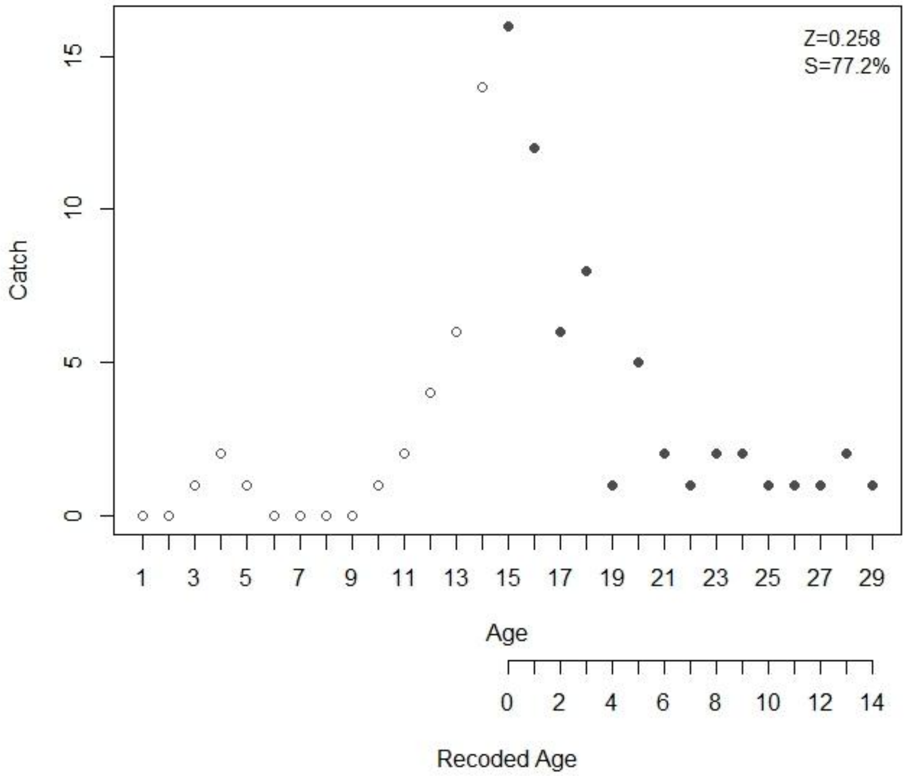

Figure 19. Results of catch curve from aged fish caught during electrofishing surveys in 2024.

A von Bertalanffy growth curve was fit to the observed length-at-age data. Estimated growth parameters were an asymptotic length ($L\infty$) of 21.01" (95% CI, 20.78" – 21.24"), a Brody growth coefficient (K) of 0.98 (95% CI, 0.79 – 1.22), and a theoretical age at length zero ($t0$) of 0.60 (95% CI, 0.38 – 0.74) (Figure 20). These values did not differ much from those estimated by Lamb (2020) ($L\infty$=21.27", K=0.68, $t0$=0.52).

As with the observed lengths, predicted total length increases rapidly up to age-3, however, slows drastically in older carp. A 20" individual may be of a wide range of ages, from age-4 to age-27. Variation among length-at-age was greatest among these individuals.

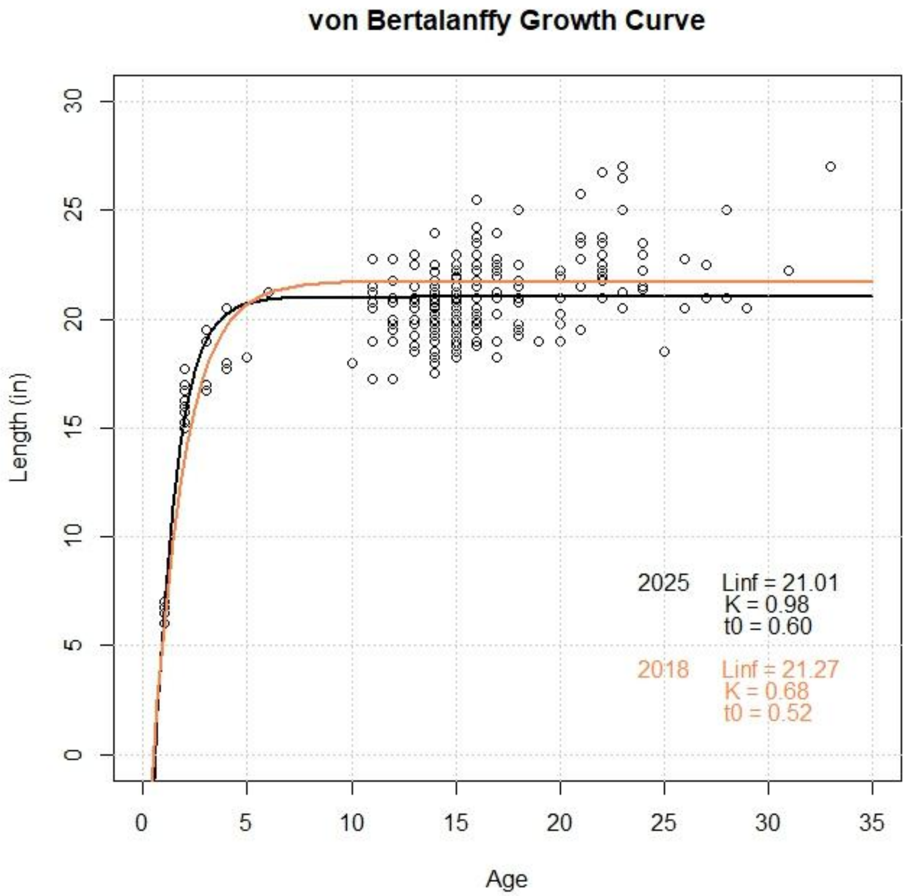

Figure 19. Visualization of von Bertalanffy growth curves from 2018 (brown) and 2025 (black) fit to 2025 length-at-age data from fish captured in a nearby impoundment and the main lake.

Mean relative weight (*Wr*) for the main lake fish was 84.71 (SE, 0.48). Main lake *Wr* values ranged from 44.0 to 144.07 (Figure 21). Although sample size was much smaller for the impoundment fish, mean *Wr* was higher (91.39; SE,1.95) and would be considered healthy unlike those from the main lake which would be considered close to severely thin. These values ranged from 72.13 to 114.17.

It's possible that a large amount of the exceedingly high *Wr* values in the main lake were from gravid females, as we did not subset by season and not all carp length and weights had corresponding sex data. The difference in the extent of the range of values for the two groups is also interesting. A large proportion of the main lake fish were severely thin, less so for the impoundment. However, if sample size in the impoundment was larger, a similar pattern may emerge.

Results of the ANOVA showed that carp from the impoundment had statistically significant higher *Wr* values than those from the main lake F(1, 998)=5.903, p=0.0153). As cautioned above, sample size was highly unbalanced.

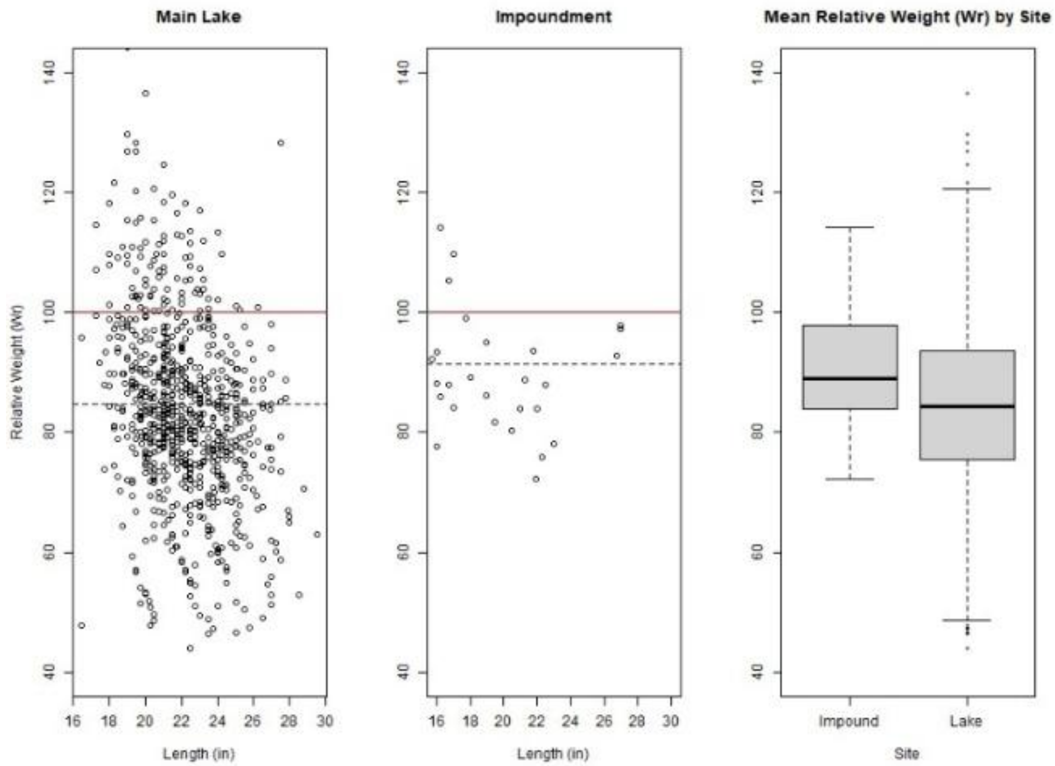

Figure 21. Relative Weight (Wr) of common carp captured in Lake Mattamuskeet and a nearby impoundment. Red line represents normal, "healthy" condition and dashed black line is the mean Wr of each site. Box plot shows mean Wr for each site.

Fish Community and Bycatch

While no analyses were conducted with the fish bycatch data collected during carp monitoring and removal, species totals across gear types and associated species-frequency graphs were produced in the case it is of interest in the future (Figures 22 – 27).

Bluegill and other centrarchids may affect carp recruitment through localized predation pressure in nearshore habitats, potentially reducing survival of carp eggs and larvae (Poole and Bajer 2019). This may be the case for opportunistic omnivores like Channel Catfish and young White Perch also. Anecdotally, we observed decreased carp abundance following two strong years of channel catfish recruitment in a Nebraska lake. It is possible that juvenile channel catfish were preying on carp eggs as bluegill are known to do.

Considering the rapid growth carp display over their first two years, overall predation pressure from top-down predator species, like Largemouth Bass, is likely relegated to age-0 and age-1 carp. Juvenile Bighead Carp were documented to be a preferred forage item over native forage by White Bass, Black Crappie, and Shortnose Gar in the Illinois River. This was the case even as juvenile bighead carp became less readily available than other prey species (Anderson et al. 2021). Although black crappie is the only species of these found in Lake Mattamuskeet, White Perch and Longnose Gar are classified in the same genera as the other two listed above. White perch have been shown to become more piscivorous with increased age and size and appear to be relatively abundant in the lake; however, habitat overlap between young carp and adult white perch may be the limiting factor in terms of substantial predation and carp suppression. Both crappie and gar demonstrate high levels of piscivory, therefore are possible predators of young carp also. However, the relationships and interactions between these native species and invasive carp remain largely unexplored.

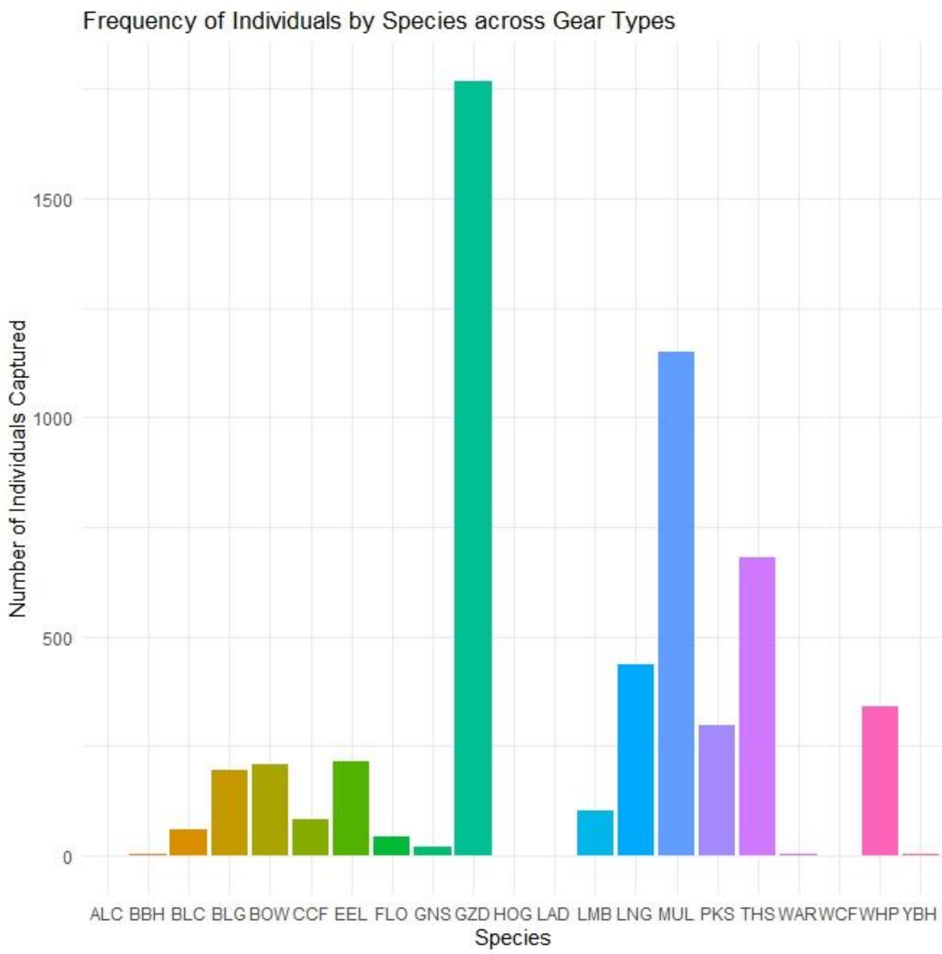

Figure 22. Number of individuals, other than common carp, captured for each species across all gear types in Lake Mattamuskeet and its associated canals and impoundments. ALC=Atlantic Croaker (1), BBH=Brown Bullhead (4), BLC=Black Crappie (59), BLG=Bluegill (196), BOW=Bowfin (210), CCF=Channel Catfish (83), EEL=American Eel (215), FLO=Flounder (44), GNS=Golden Shiner (19), GZD=Gizzard Shad (1767), HOG=Hogchoker (1), LAD=Ladyfish (1), LMB=Largemouth Bass (104), LNG= Longnose Gar (438), MUL= Mullet (1149), PKS=Pumpkinseed (299), THS=Threadfin Shad (679), WAR=Warmouth (3), WCF=White Catfish (1), WHP=White Perch (339), YBH=Yellow Bullhead (5).

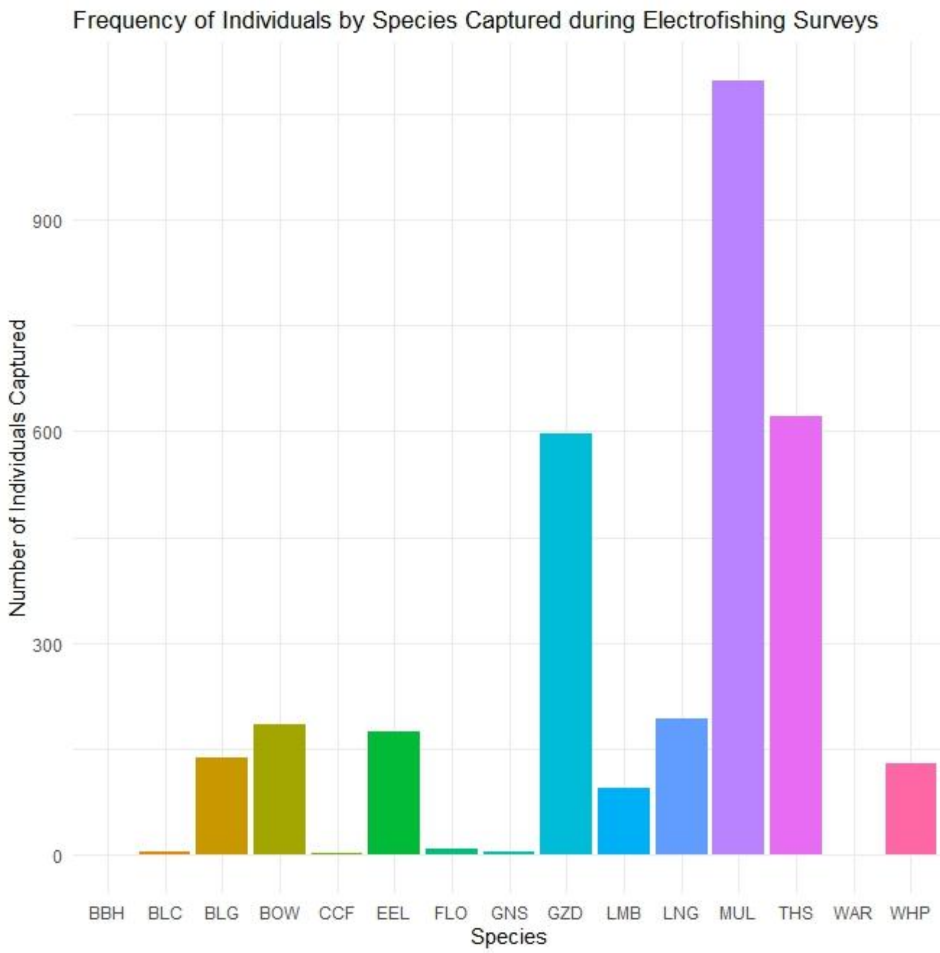

Figure 23. Number of individuals, other than common carp, captured/observed for each species during electrofishing surveys at Lake Mattamuskeet and its associated canals. BBH=Brown Bullhead (1), BLC=Black Crappie (4), BLG=Bluegill (138), BOW=Bowfin (184), CCF=Channel Catfish (3), EEL=American Eel (174), FLO=Flounder spp. (9), GNS=Golden Shiner (4), GZD=Gizzard Shad (596), LMB=Largemouth Bass (94), LNG=Longnose Gar (149), MUL=Mullet spp. (1097), THS=Threadfin Shad (621), WAR=Warmouth (1), WHP=White Perch (129).

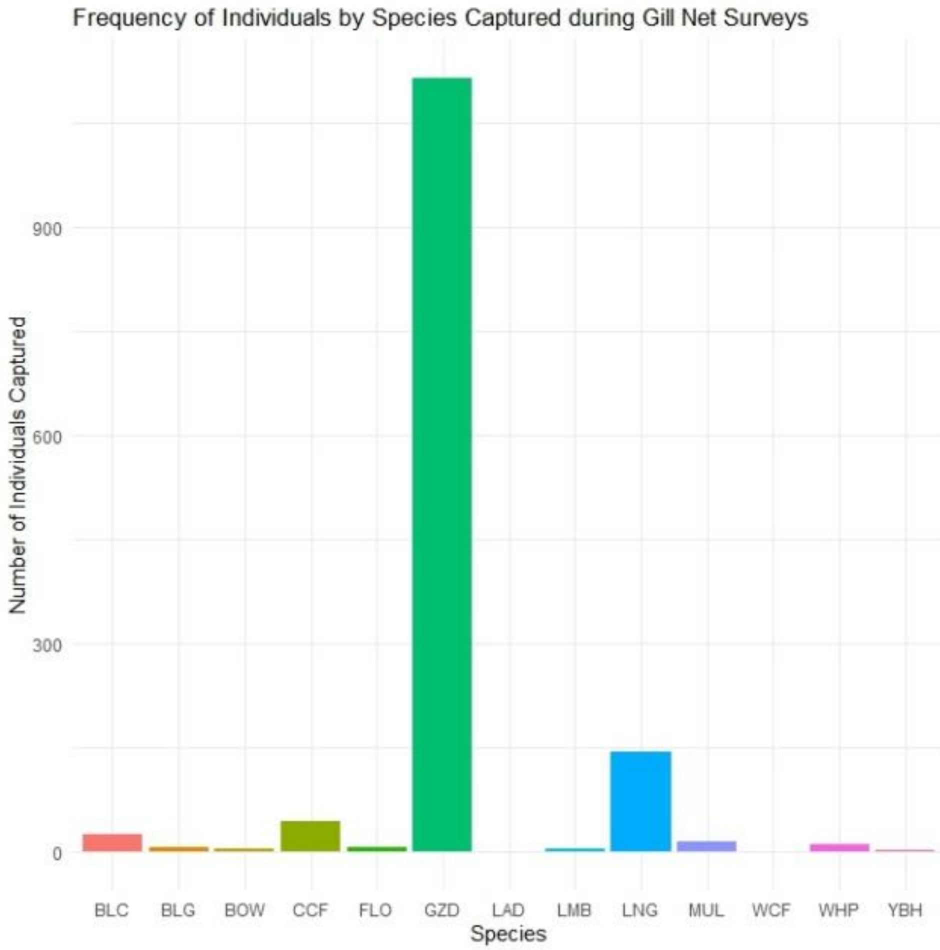

Figure 24. Number of individuals, other than common carp, captured for each species during gill net surveys on Lake Mattamuskeet. BLC=Black Crappie (126), BLG=Bluegill (7), BOW=Bowfin (5), CCF=Channel Catfish (45), FLO=Flounder spp. (6), GZD=Gizzard Shad (1114), LAD=Ladyfish (1), LMB=Largemouth Bass (5), LNG=Longnose Gar (145), MUL=Mullet spp. (15), WCF=White Catfish (1), WHP=White Perch (11), YBH=Yellow Bullhead (2).

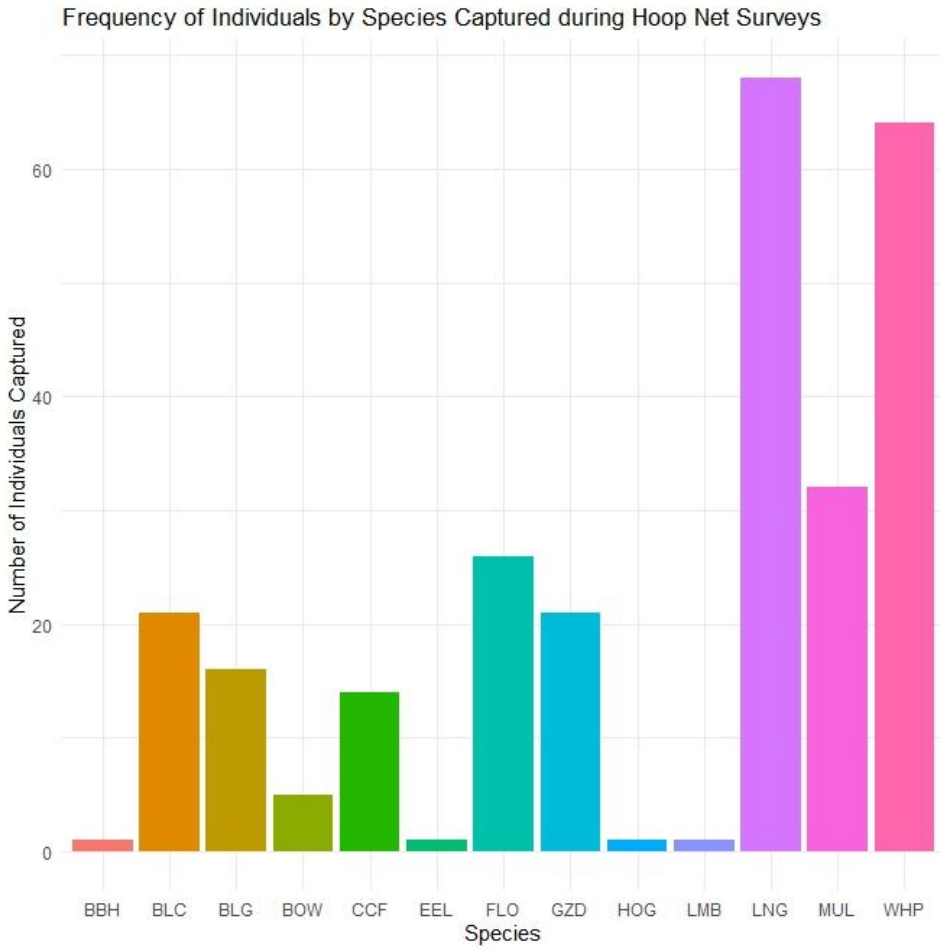

Figure 25. Number of individuals for each species, other than common carp, captured during the hoop net surveys at Lake Mattamuskeet. BBH=Brown Bullhead (1), BLC=Black Crappie (21), BLG=Bluegill (16), BOW=Bowfin (5), CCF=Channel Catfish (14), EEL=American Eel (1), FLO=Flounder spp. (26), GZD=Gizzard Shad (21), HOG=Hogchoker (1), LMB=Largemouth Bass (1), LNG=Longnose Gar (68), MUL=Mullet spp. (32), WHP=White Perch (64).

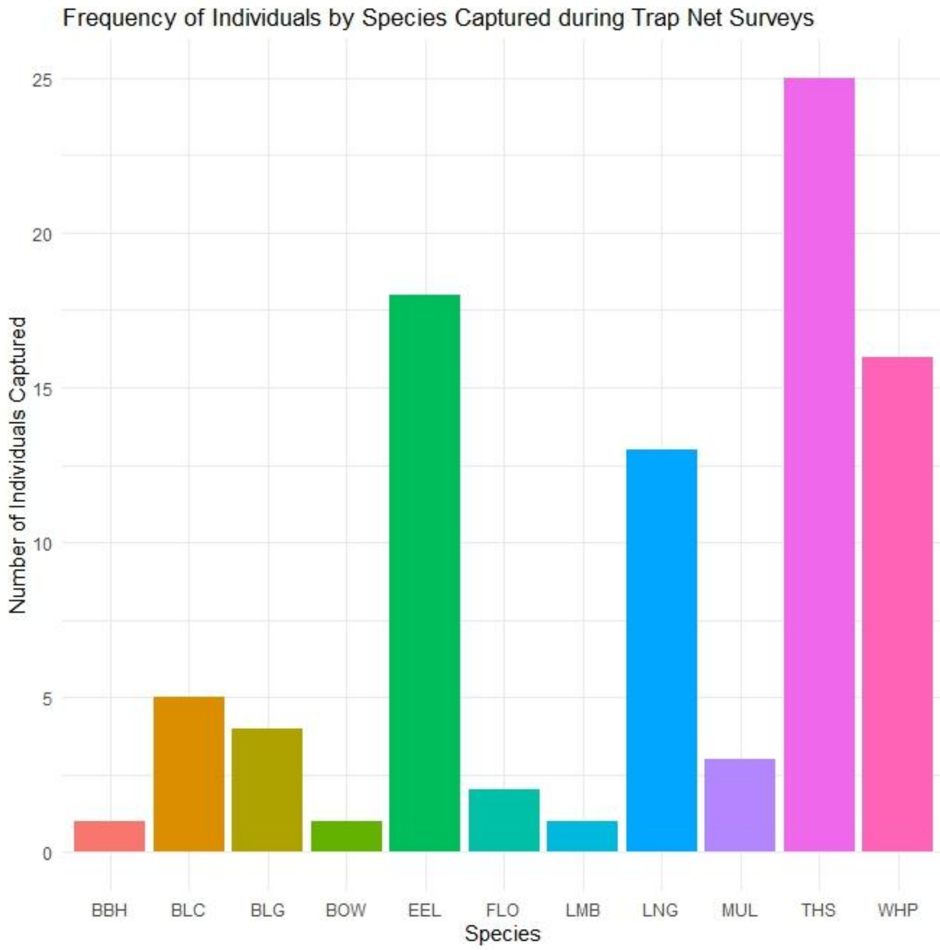

Figure 26. Number of individuals for each species, other than common carp, captured during the trap net surveys at Lake Mattamuskeet. BBH=Brown Bullhead (1), BLC=Black Crappie (5), BLG=Bluegill (4), BOW=Bowfin (1), EEL=American Eel (18), FLO=Flounder spp. (2), LMB=Largemouth Bass (1), LNG=Longnose Gar (13), MUL=Mullet spp. (3), THS=Threadfin Shad (25), WHP=White Perch (16).

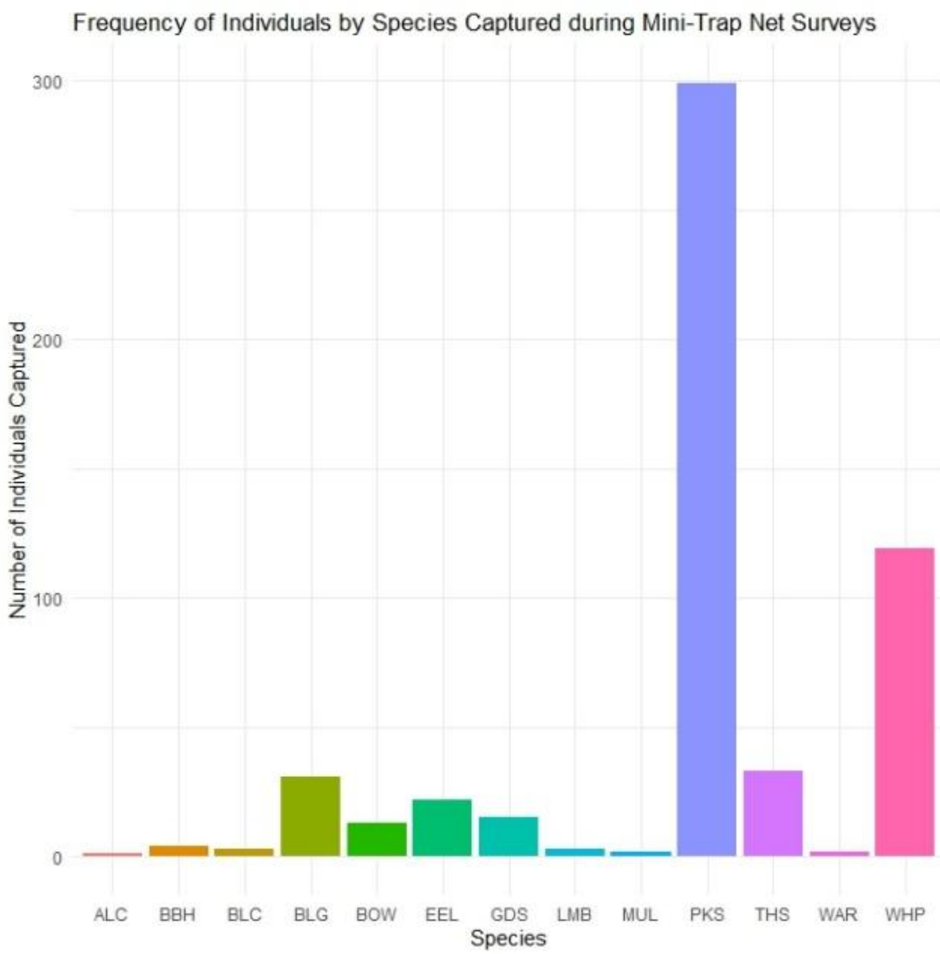

Figure 27. Number of individuals for each species, other than common carp, captured in mini-trap nets at Lake Mattamuskeet and its associated impoundments. ALC=Atlantic Croaker (1), BBH=Brown Bullhead (3), BLC=Black Crappie (3), BLG=Bluegill (31), BOW=Bowfin (13), EEL=American Eel (22), GDS= Golden Shiner (15), LMB=Largemouth Bass (3), MUL=Mullet spp. (2), PKS=Pumpkinseed (299), THS=Threadfin Shad (33), WAR=Warmouth (2), WHP=White Perch (119).

Discussion and Recommendations

Common carp abundance in Lake Mattamuskeet appears to be substantially lower than previously thought. Multiple findings from the current project indicate that the current population is likely characterized by limited recruitment, poor individual condition, and an annual mortality rate in range of that normally associated with carp, resulting in a population structure primarily comprised of old individuals.

The apparent absence of successful recruitment may be a key factor explaining low observed abundance. A total of five young-of-year carp were sampled near the Lake Landing canal tide gates, apart from those very few individuals under the age of 10 were observed. This suggests that, at least currently, in the lake's unvegetated state, spawning either fails to produce viable offspring or that early life stages experience high mortality. It's possible that the routine bluegill stocking conducted by North Carolina Wildlife Resources Commission is also further promoting this recruitment bottleneck.

While not exceptionally high, the estimated annual mortality rate of 22.8%, in the absence of compensatory recruitment, is sufficient to drive the population decline (Table 4). Poor relative weights and poor individual health, according to USFWS fish health analysis, provide additional support for this. This seems to be due to a lack of food availability, rather than density dependence as CPUE across gear types was low.

Implementing carp barriers may have also contributed to the reduction in abundance by interrupting important aspects of Lake Mattamuskeet carp life history. In the absence of suitable spawning habitat within the lake due to the decline in submerged aquatic vegetation, carp may have used habitat toward the Pamlico Sound and other areas adjacent to the main lake for spawning and foraging. The barriers may have restricted access to these traditionally used habitats and disrupted seasonal movements that were critical for successful reproduction. Over time, these structures could prove to be one of the most viable, in terms of efficiency and cost effectiveness, in managing and suppressing carp abundance in the lake.

These findings, when compared to previous information, highlight the importance of repeated abundance estimates and YOY carp monitoring in the future.

Table 1. Number of individuals remaining in 2025, assuming annual mortality rate of 22.8% and no successful recruitment since 2018 population estimate.

Year	Number of Individuals	Number of Individuals Lost
2018	971,220	221,438
2019	749,781	170,950
2020	578,831	131,973
2021	446,858	101,883
2022	344,974	78,654
2023	266,320	60,721
2024	205,599	46,876
2025	158,722	-

Given the apparent low recruitment and poor condition of carp in Lake Mattamuskeet, management actions should focus on promoting native fish communities, continued suppression of carp recruitment, SAV recovery trials and research, carp population monitoring, and sustained removals at whatever level deemed feasible.

Continued bluegill stocking is recommended as a recruitment control strategy, as sunfish predation on carp eggs and larvae may be important to limiting the carp population over the long term. Monitoring and assessments of the bluegill population would be desirable. Currently, there seem to be adequate levels of stocked adult bluegill with a number of large stocked, adult “coppernose” bluegill observed over the course of sampling.

Further exploration in establishing refugia sites or protective enclosures for SAV is also recommended. These areas may promote habitat recovery, improve water clarity, reduce wind and wave erosion, and support native fish assemblages while limiting carp access to sensitive habitats as they develop. Establishing a series of “smaller” sites that are protected from herbivory and uprooting by carp is one alternative as it may take multiple years to establish vegetation across the lake.

These enclosures could be constructed from fencing similar to what was used in the Rose Bay abundance estimate or be constructed of semipermeable membrane to reduce water exchange between the inside and outside of the enclosure to potentially improve water clarity which may increase the amount of light penetration within the enclosure and lead to increased vegetative growth. These smaller areas could be scaled up to increase distribution across the lake. Limited success has been had in the past establishing SAV within enclosures over the long term at Lake Mattamuskeet, so continued experimentation may be necessary.

Routine updates to carp abundance estimates should be continued to track population trends and detect any changes in density or age structure. Considering funding and staffing limitations, the best monitoring practice for adult carp may be to establish survey sites that are sampled annually. This could be via continuing a subset (or all) of the electrofishing transects established by NCWRC for their sportfish surveys or gill netting various sites in the lake. It may be prudent to establish winter (December – February) gill net sites in the deep water near the USGS gauges on either side of the lake and, perhaps, additional causeway sites near the flow of the causeway culverts during the spring and/or summer. This would allow for CPUE values to be compared across years while also continuing removal of adult carp annually.

In addition, annual monitoring for young-of-year carp is strongly recommended as an early warning indicator of renewed recruitment. Detection of consistent YOY cohorts would signal a shift in population dynamics and warrant reconsideration of management strategies. This would likely be conducted most efficiently with mini-trap nets or a similar passive gear type set near any suspected spawning habitat in the lake or connected waterbodies. Similar to the adult monitoring outlined above, CPUE values could be used to monitor YOY or juvenile adult populations, in lieu of abundance estimation, until it is deemed necessary.

Unfortunately, reestablishing SAV in Lake Mattamuskeet, assuming it's eventual success, could bring about concomitant increase in carp abundance over time, following the return of potential spawning habitat. Again, highlighting the importance of routine monitoring, if possible. Given that many of the fish species that predate upon carp rely heavily on vision during foraging, increased water clarity following an increase in SAV coverage may increase their foraging efficiency and, in turn, maintain carp abundance at manageable levels into the future (M. Wicker; personal communication). For further details, refer to accompanying document: Lake Mattamuskeet Common Carp Integrated Pest Management Plan.

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Appendix A

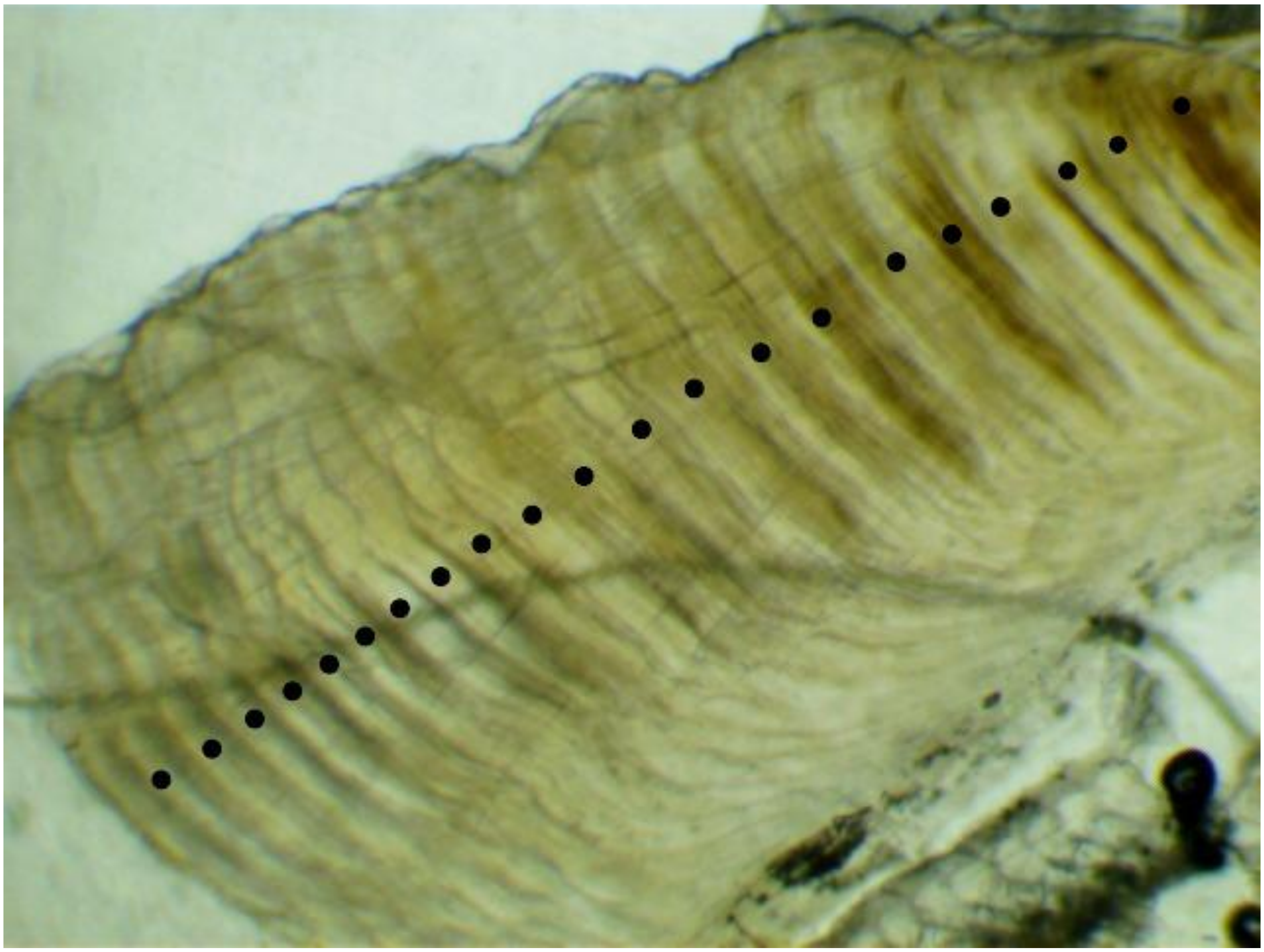

Figure 28. Example of otolith cross section from a Lake Mattamuskeet common carp. This image does not include all annuli due to sample being too large to fit in microscope camera frame.

Figure 29. Photo taken in March during spawning season. Gravid female on top demonstrating traits of egg resorption, which was commonly observed among female carp captured during spawning seasons.

Appendix B

Radio Tagged Carp Movement Discussion and Maps

Movement maps display detections during telemetry surveys over time in sequential order of when a unique frequency was heard. The numbered points start at #1 which is the individual fish's release location after tagging. Numbered points will continue to show where the individual was detected in chronological order. Lines connect the points to create a visual track to aid in understanding the movement patterns of each tagged carp.

Carp from tagging location 1, east of the most southern canal on the causeway, utilized their home range almost exclusively. Two individuals can be seen moving away from the tagging location at certain points, but overall movement was centered around the canal structures on the south end of the causeway.

Carp from tagging location 2 moved extensively throughout the system. Multiple tagged fish trekked across the lake to both the east and west basins. Other fish can be observed moving to multiple causeway locations.

Carp from tagging location 3 stayed relatively close to the original tagging location and did not traverse away from the southern east basin.

Only one carp was a part of tagging location 4, this fish had a small detection rate and was found in the same area of the lake that it was released in,

Carp in tagging location 5 had the most movement of all groups. Fish from this group were seen in both east and west basins and at the causeway. A few fish were not located again after release.

One fish from tagging group 6 was seen moving from their original location to the most southern part of the causeway then back to their original range after some time away. It is eventually heard back in the release site.

Finally, the carp in tagging location group 7 stayed in the northwestern part of the lake where it was originally found.

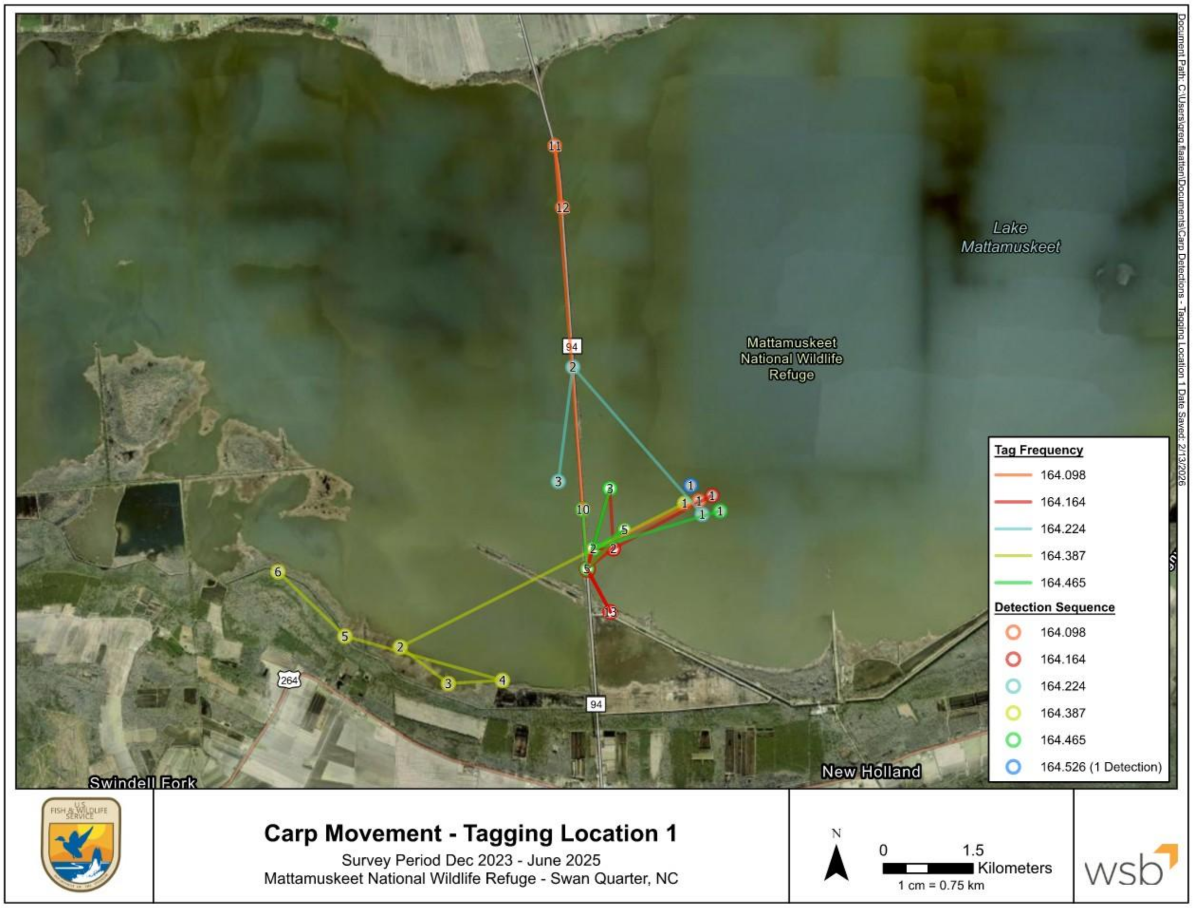

Figure 1. Individual movements of tagged carp from tagging location 1.

Table 5. Summary of tagged carp movement distance (km) for tag location 1. Date columns correspond to telemetry survey dates. Distance (km) is the length between listening points where the tag was heard, not necessarily distance an individual fish moved. Some tags were heard from multiple listening points during the same survey.

Tag Frequency	From	To	Distance (km)
164.098	12/13/2023	9/11/2024	1.6
164.098	9/11/2024	10/24/2024	0.0
164.098	10/24/2024	12/10/2024	0.3
164.098	12/10/2024	12/12/2024	0.7
164.098	12/12/2024	12/14/2024	0.7
164.098	12/14/2024	1/7/2025	0.0
164.098	1/7/2025	1/15/2025	0.0
164.098	1/15/2025	4/1/2025	0.0
164.098	4/1/2025	5/2/2025	0.8
164.098	5/2/2025	6/11/2025	4.9
Total Distance			**9.1**

164.164	12/13/2023	9/11/2024	1.5
164.164	9/11/2024	9/12/2024	0.8
164.164	9/12/2024	9/24/2024	0.3
164.164	9/24/2024	9/28/2024	0.0
164.164	9/28/2024	10/24/2024	1.1
164.164	10/24/2024	12/10/2024	0.5
164.164	12/10/2024	12/12/2024	0.7
164.164	12/12/2024	12/14/2024	0.7
164.164	12/14/2024	1/1/2025	0.7
164.164	1/1/2025	1/7/2025	0.7
164.164	1/7/2025	1/14/2025	0.7
164.164	1/14/2025	1/15/2025	0.7
164.164	1/15/2025	1/21/2025	0.0
164.164	1/21/2025	1/24/2025	0.0
164.164	1/24/2025	1/26/2025	0.0
164.164	1/26/2025	1/27/2025	0.0
164.164	1/27/2025	2/24/2025	0.0
164.164	2/24/2025	4/1/2025	0.0
164.164	4/1/2025	4/15/2025	0.0
164.164	4/15/2025	4/15/2025	0.0
164.164	4/15/2025	4/16/2025	0.0
164.164	4/16/2025	4/16/2025	0.0
164.164	4/16/2025	4/17/2025	0.0
164.164	4/17/2025	4/21/2025	0.0
164.164	4/21/2025	5/2/2025	0.0
Total Distance			**8.5**
164.224	12/13/2023	9/24/2024	2.7
164.224	9/24/2024	10/9/2024	1.6
Total Distance			**4.2**
164.387	12/13/2023	10/7/2024	4.3
164.387	10/7/2024	1/15/2025	2.2
164.387	1/15/2025	1/15/2025	1.3
Total Distance			**7.8**
164.465	12/13/2023	9/11/2024	1.8
164.465	9/11/2024	10/24/2024	0.0
164.465	10/24/2024	12/12/2024	0.5
164.465	12/12/2024	12/14/2024	0.7
164.465	12/14/2024	5/2/2025	0.8
Total Distance			**3.9**

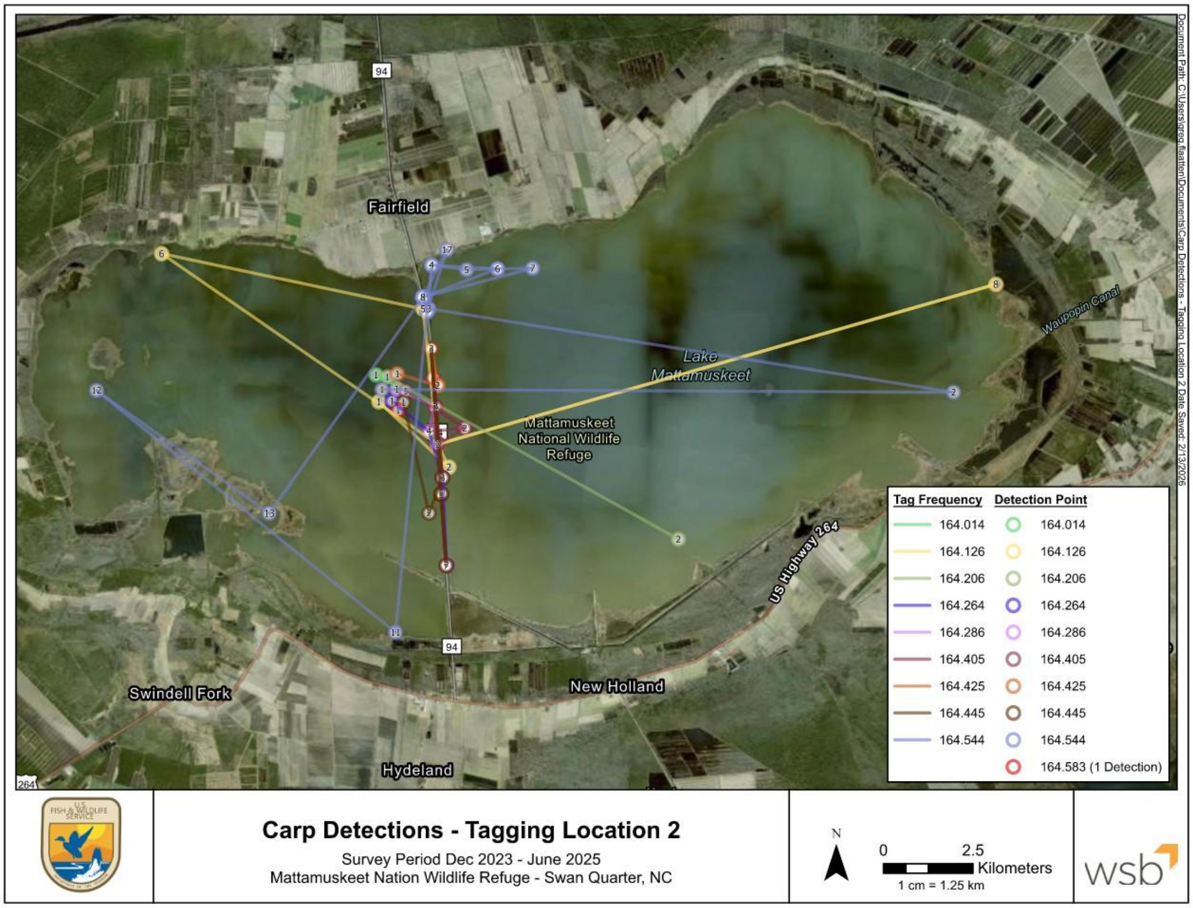

Figure 2. Individual movements of tagged carp from tagging location 2.

Table 6. Summary of tagged carp movement distance (km) for tagging location 2. Date columns correspond to telemetry survey dates. Distance (km) is the length between listening points where the tag was heard, not necessarily distance an individual fish moved. Some tags were heard from multiple listening points during the same survey.

Tag Frequency	From	To	Distance (km)
164.014	12/13/2023	9/24/2024	1.5
164.014	9/24/2024	9/28/2024	0.0
164.014	9/28/2024	10/9/2024	0.6
164.014	10/9/2024	12/10/2024	0.4
164.014	12/10/2024	12/16/2024	0.0
164.014	12/16/2024	4/15/2025	0.0
Total Distance			**2.5**
164.126	12/13/2023	9/11/2024	2.2
164.126	9/11/2024	9/24/2024	0.6
164.126	9/24/2024	9/28/2024	0.0
164.126	9/28/2024	10/9/2024	3.1

164.126	10/9/2024	10/24/2024	6.1
164.126	10/24/2024	12/10/2024	7.6
164.126	12/10/2024	1/15/2025	13.2
164.126	1/15/2025	4/15/2025	13.2
164.126	4/15/2025	4/15/2025	0.0
164.126	4/15/2025	4/21/2025	2.2
Total Distance			**48.1**
164.206	12/13/2023	2/4/2024	7.6
Total Distance			**7.6**
164.264	12/13/2023	10/9/2024	1.1
164.264	10/9/2024	12/10/2024	1.1
164.264	12/10/2024	6/11/2025	2.0
Total Distance			**4.2**
164.286	12/13/2023	9/24/2024	1.0
164.286	9/24/2024	10/9/2024	0.6
164.286	10/9/2024	4/16/2025	0.6
164.286	4/16/2025	4/16/2025	0.0
164.286	4/16/2025	4/16/2025	0.8
164.286	4/16/2025	4/17/2025	0.8
Total Distance			**3.0**
164.405	12/13/2023	9/11/2024	1.6
164.405	9/11/2024	9/28/2024	0.8
164.405	9/28/2024	10/9/2024	0.6
164.405	10/9/2024	10/24/2024	0.8
164.405	10/24/2024	12/10/2024	0.7
164.405	12/10/2024	12/16/2024	2.7
164.405	12/16/2024	12/16/2024	3.6
164.405	12/16/2024	1/7/2025	0.9
164.405	1/7/2025	1/21/2025	1.5
164.405	1/21/2025	1/21/2025	0.7
164.405	1/21/2025	1/21/2025	1.3
164.405	1/21/2025	1/24/2025	0.7
164.405	1/24/2025	1/24/2025	1.5
164.405	1/24/2025	1/24/2025	0.9
164.405	1/24/2025	1/26/2025	1.3
164.405	1/26/2025	1/27/2025	1.3
164.405	1/27/2025	2/24/2025	1.6
164.405	2/24/2025	4/15/2025	1.6
164.405	4/15/2025	4/15/2025	0.8
164.405	4/15/2025	4/15/2025	0.8
164.405	4/15/2025	4/16/2025	0.0
164.405	4/16/2025	4/16/2025	0.0
164.405	4/16/2025	4/17/2025	0.0

164.405	4/17/2025	4/21/2025	0.0
164.405	4/21/2025	5/2/2025	0.0
164.405	5/2/2025	5/2/2025	0.9
Total Distance			**16.2**
164.425	12/13/2023	9/11/2024	1.0
164.425	9/11/2024	9/28/2024	0.8
164.425	9/28/2024	10/24/2024	0.8
Total Distance			**2.6**
164.445	12/13/2023	10/9/2024	2.6
164.445	10/9/2024	12/10/2024	0.9
164.445	12/10/2024	12/16/2024	2.9
164.445	12/16/2024	1/21/2025	3.3
164.445	1/21/2025	1/24/2025	0.0
164.445	1/24/2025	2/23/2025	1.6
164.445	2/23/2025	5/2/2025	1.6
Total Distance			**12.9**
164.544	2/4/2024	9/11/2024	12.1
164.544	9/11/2024	9/11/2024	1.0
164.544	9/11/2024	9/11/2024	0.8
164.544	9/11/2024	9/11/2024	0.7
164.544	9/11/2024	9/11/2024	0.8
164.544	9/11/2024	9/24/2024	2.6
164.544	9/24/2024	10/24/2024	1.8
164.544	10/24/2024	10/24/2024	1.5
164.544	10/24/2024	10/24/2024	8.3
164.544	10/24/2024	10/24/2024	8.7
164.544	10/24/2024	10/24/2024	4.8
164.544	10/24/2024	12/10/2024	6.0
164.544	12/10/2024	12/16/2024	0.0
164.544	12/16/2024	1/15/2025	0.3
164.544	1/15/2025	1/15/2025	1.5
164.544	1/15/2025	4/16/2025	1.2
164.544	4/16/2025	4/16/2025	0.0
164.544	4/16/2025	4/17/2025	0.0
164.544	4/17/2025	4/21/2025	0.0
164.544	4/21/2025	5/2/2025	0.3
164.544	5/2/2025	5/2/2025	0.3
Total Distance			**24.4**

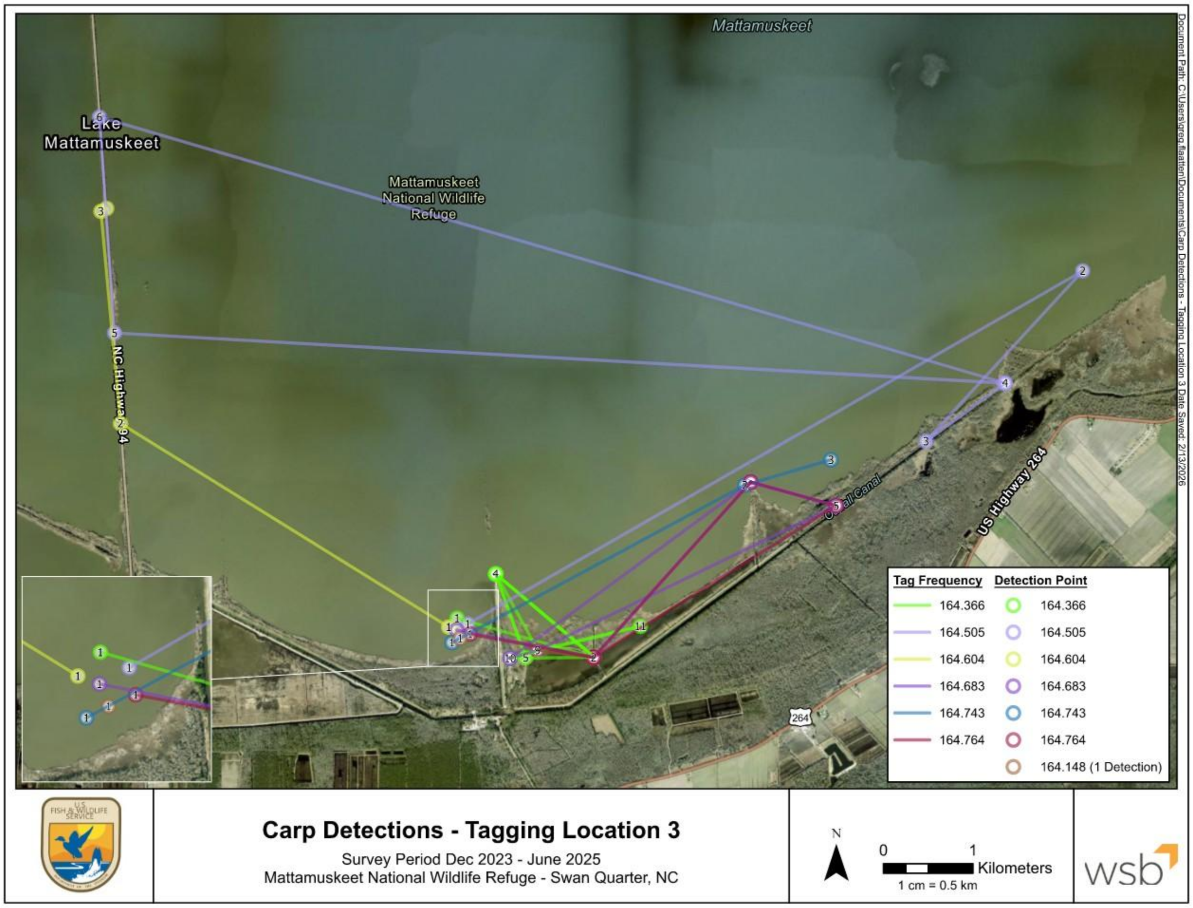

Figure 3. Individual movements of tagged carp from tagging location 3.

Table 7. Summary of tagged carp movement distance (km) for tagging location 3. Date columns correspond to telemetry survey dates. Distance (km) is the length between listening points where the tag was heard, not necessarily distance an individual fish moved. Some tags were heard from multiple listening points during the same survey.

Tag Frequency	From	To	Distance (km)
164.366	12/13/2023	10/24/2024	1.3
164.366	10/24/2024	10/24/2024	0.0
164.366	10/24/2024	12/10/2024	1.2
164.366	12/10/2024	12/14/2024	0.8
164.366	12/14/2024	12/16/2024	0.8
164.366	12/16/2024	1/8/2025	1.2
164.366	1/8/2025	1/14/2025	1.2
164.366	1/14/2025	5/1/2025	1.0
164.366	5/1/2025	6/11/2025	0.8
Total Distance			**8.1**
164.505	12/13/2023	9/30/2024	6.4

164.505	9/30/2024	1/14/2025	2.1
164.505	1/14/2025	6/11/2025	8.1
Total Distance			**16.7**
164.604	12/13/2023	6/11/2025	3.5
Total Distance			**3.5**
164.683	12/13/2023	10/24/2024	1.3
164.683	10/24/2024	10/24/2024	0.0
164.683	1/14/2025	1/14/2025	0.0
164.683	1/14/2025	5/1/2025	2.7
Total Distance			**4.0**
164.743	12/13/2023	9/30/2024	3.0
164.764	12/13/2023	10/24/2024	1.1
164.764	10/24/2024	10/24/2024	0.0
164.764	10/24/2024	1/14/2025	2.1
164.764	1/14/2025	6/11/2025	2.6
Total Distance			**8.9**

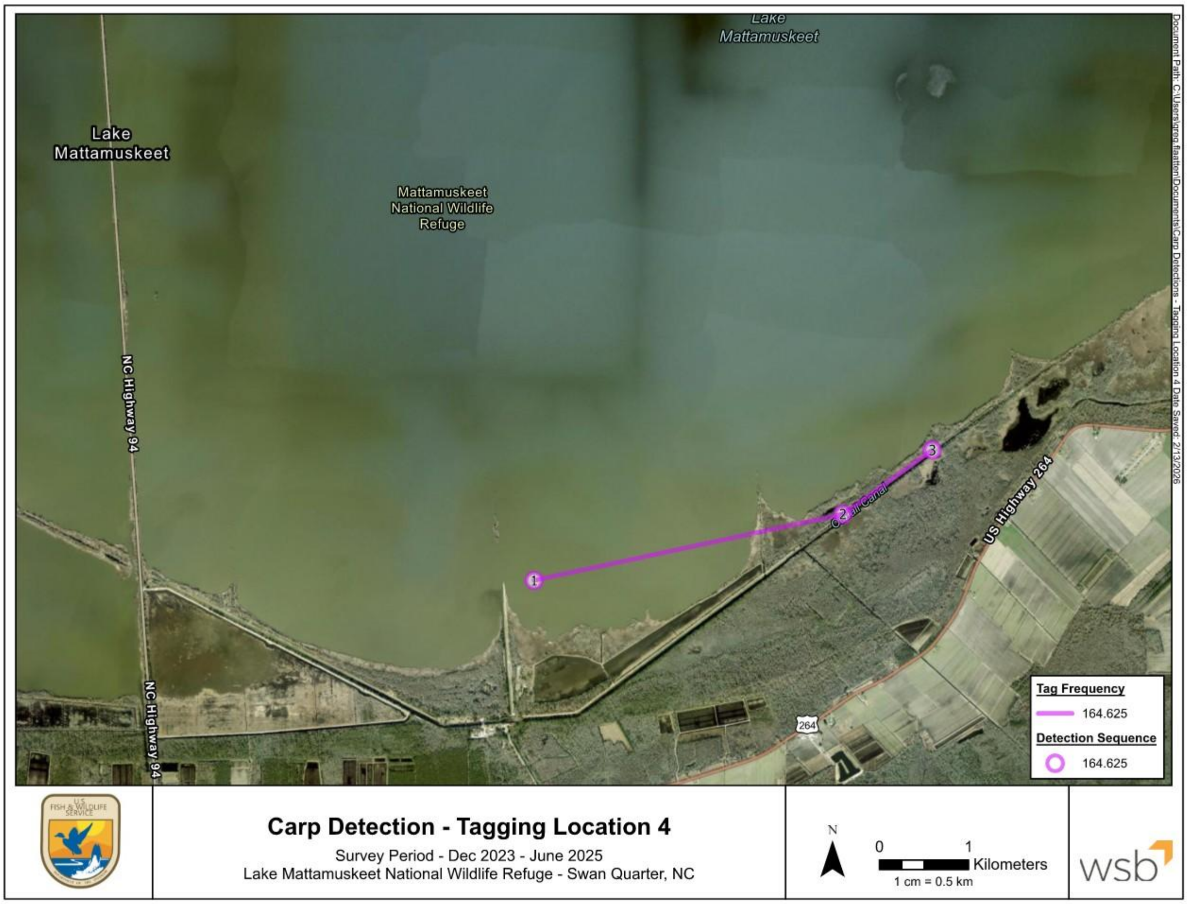

Figure 4. Individual movement of carp from tagging location 4.

Table 8. Summary of tagged carp movement distance (km) for tagging location 4. Date columns correspond to telemetry survey dates. Distance (km) is the length between listening points where the tag was heard, not necessarily distance an individual fish moved. Some tags were heard from multiple listening points during the same survey.

Tag Frequency	From	To	Distance (km)
164.625	12/13/2023	1/14/2025	2.9
164.625	1/14/2025	1/14/2025	1.0
Total Distance			**3.9**

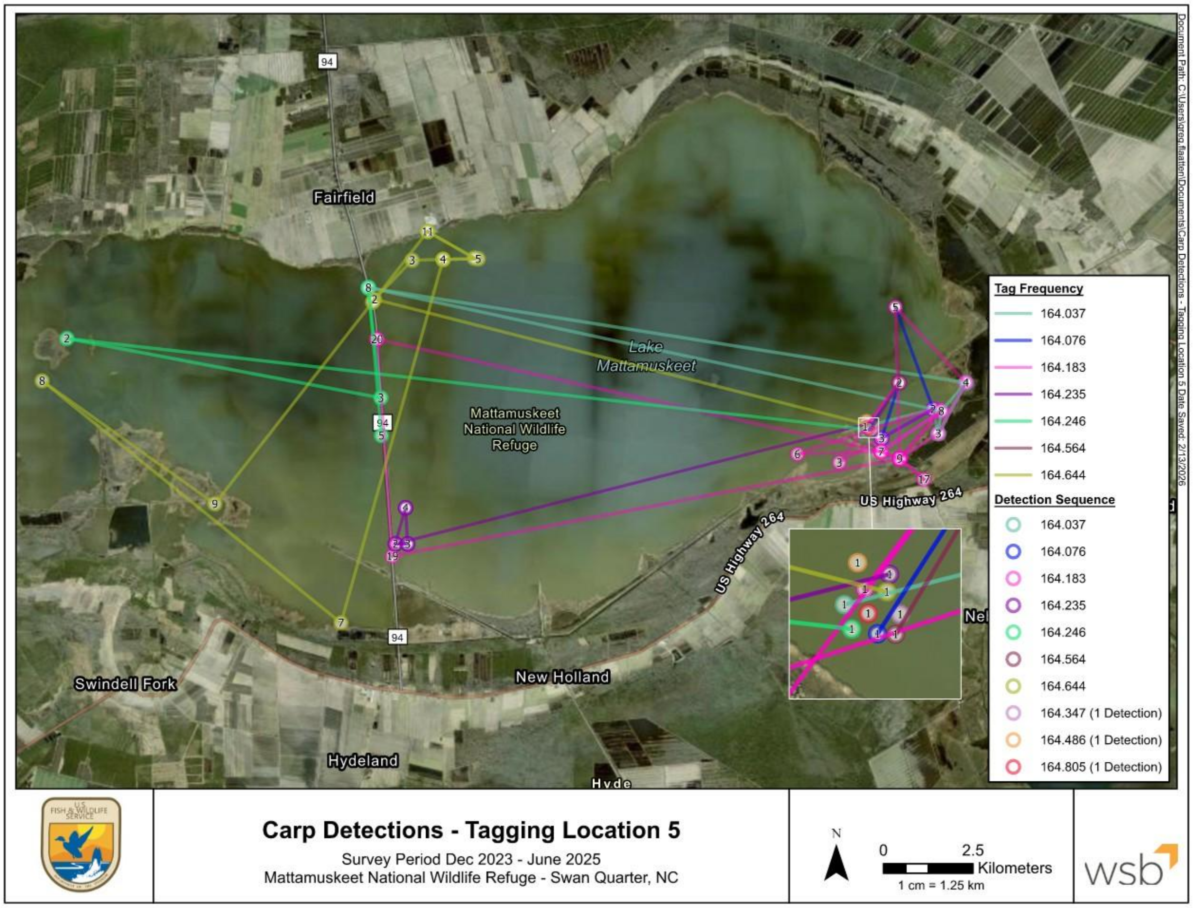

Figure 5. Individual movements of tagged carp from tagging location 5.

Table 9. Summary of tagged carp movement distance (km) for tagging location 5. Date columns correspond to telemetry survey dates. Distance (km) is the length between listening points where the tag was heard, not necessarily distance an individual fish moved. Some tags were heard from multiple listening points during the same survey.

Tag Frequency	From	To	Distance (km)
164.037	12/15/2023	9/30/2024	1.6
164.037	9/30/2024	1/1/2025	0.6
164.037	1/1/2025	1/14/2025	0.9
164.037	1/14/2025	1/15/2025	13.8
164.037	1/15/2025	5/5/2025	13.3
164.037	5/5/2025	6/13/2025	1.6
Total Distance			**31.7**
164.076	12/15/2023	2/4/2024	1.3
164.076	2/4/2024	9/30/2024	1.3
164.076	9/30/2024	2/8/2025	2.5
Total Distance			**5.0**

164.183	12/15/2023	2/4/2024	1.2
164.183	2/4/2024	9/30/2024	2.3
164.183	9/30/2024	12/17/2024	3.2
164.183	12/17/2024	1/1/2025	1.9
164.183	1/1/2025	1/14/2025	0.5
164.183	1/14/2025	2/8/2025	2.3
164.183	2/8/2025	5/5/2025	3.4
164.183	5/5/2025	5/8/2025	0.7
164.183	5/8/2025	6/11/2025	11.7
164.183	6/11/2025	6/13/2025	11.7
Total Distance			**39.0**
164.235	9/11/2024	9/11/2024	0.3
164.235	9/11/2024	10/24/2024	0.0
Total Distance			**0.3**
164.246	12/15/2023	2/4/2024	18.3
164.246	2/4/2024	1/15/2025	7.3
Total Distance			**25.5**
164.564	12/15/2023	2/4/2024	1.2
164.564	2/4/2024	2/8/2025	1.7
Total Distance			**3.0**
164.644	12/15/2023	9/11/2024	11.6
164.644	9/11/2024	10/24/2024	0.8
164.644	10/24/2024	1/15/2025	5.8
164.644	1/15/2025	1/16/2025	2.0
164.644	1/16/2025	2/6/2025	1.2
164.644	2/6/2025	6/12/2025	1.2
Total Distance			**22.7**

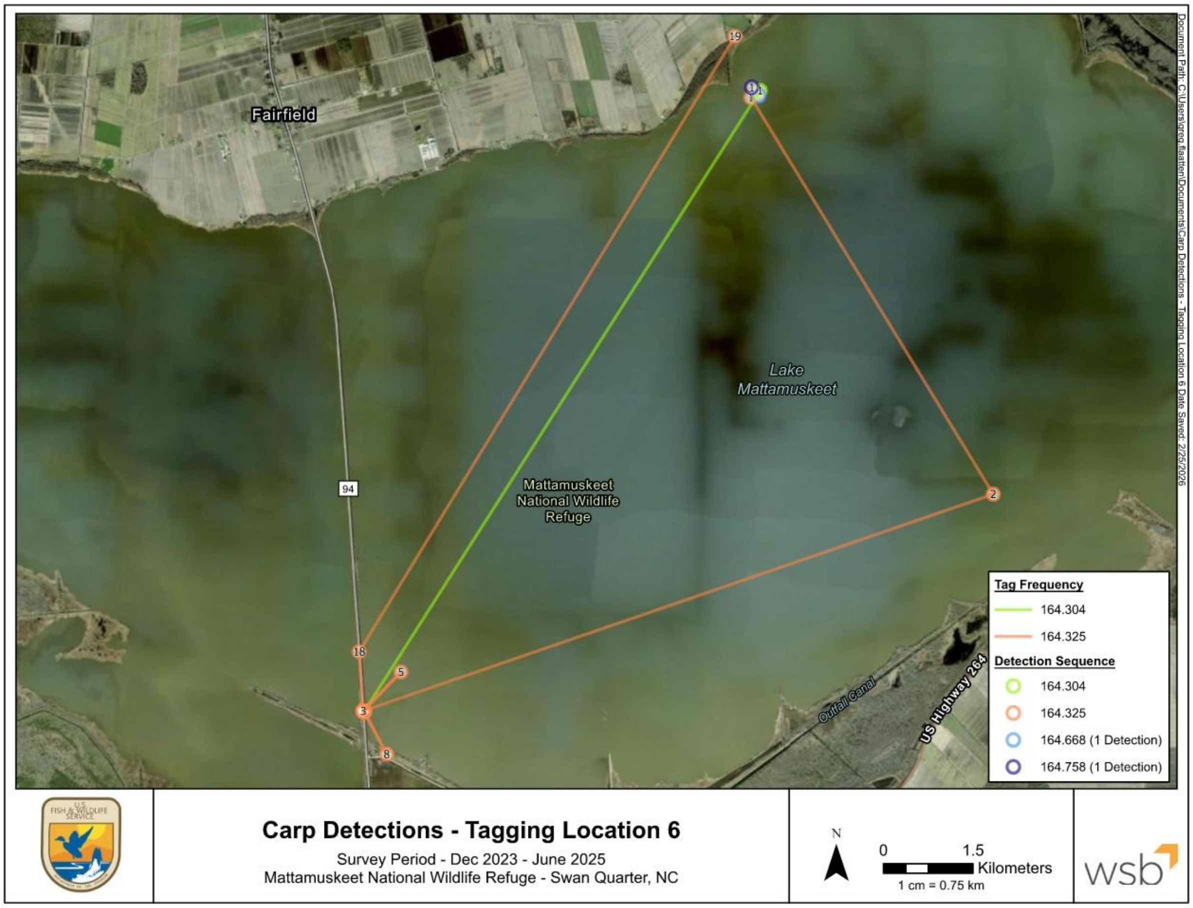

Figure 6. Individual movements of tagged carp from tagging location 6.

Table 10. Summary of tagged carp movement distance (km) for tagging location 6. Date columns correspond to telemetry survey dates. Distance (km) is the length between listening points where the tag was heard, not necessarily distance an individual fish moved. Some tags were heard from multiple listening points during the same survey.

Tag Frequency	From	To	Distance (km)
164.304	12/15/2023	1/15/2025	10.0
Total Distance			**10.0**
164.325	12/15/2023	2/4/2024	6.3
164.325	2/4/2024	9/24/2024	9.1
164.325	9/24/2024	12/10/2024	0.0
164.325	12/10/2024	12/12/2024	0.7
164.325	12/12/2024	12/14/2024	0.7
164.325	12/14/2024	1/7/2025	0.0
164.325	1/7/2025	1/14/2025	0.7
164.325	1/14/2025	1/15/2025	0.7
164.325	1/15/2025	1/21/2025	0.0

164.325	1/21/2025	1/24/2025	0.0
164.325	1/24/2025	1/26/2025	0.0
164.325	1/26/2025	4/1/2025	0.0
164.325	4/1/2025	4/15/2025	0.0
164.325	4/15/2025	4/15/2025	0.0
164.325	4/15/2025	4/17/2025	0.0
164.325	4/17/2025	4/21/2025	0.0
164.325	4/21/2025	5/2/2025	0.8
164.325	5/2/2025	6/12/2025	9.8
Total Distance			**28.9**

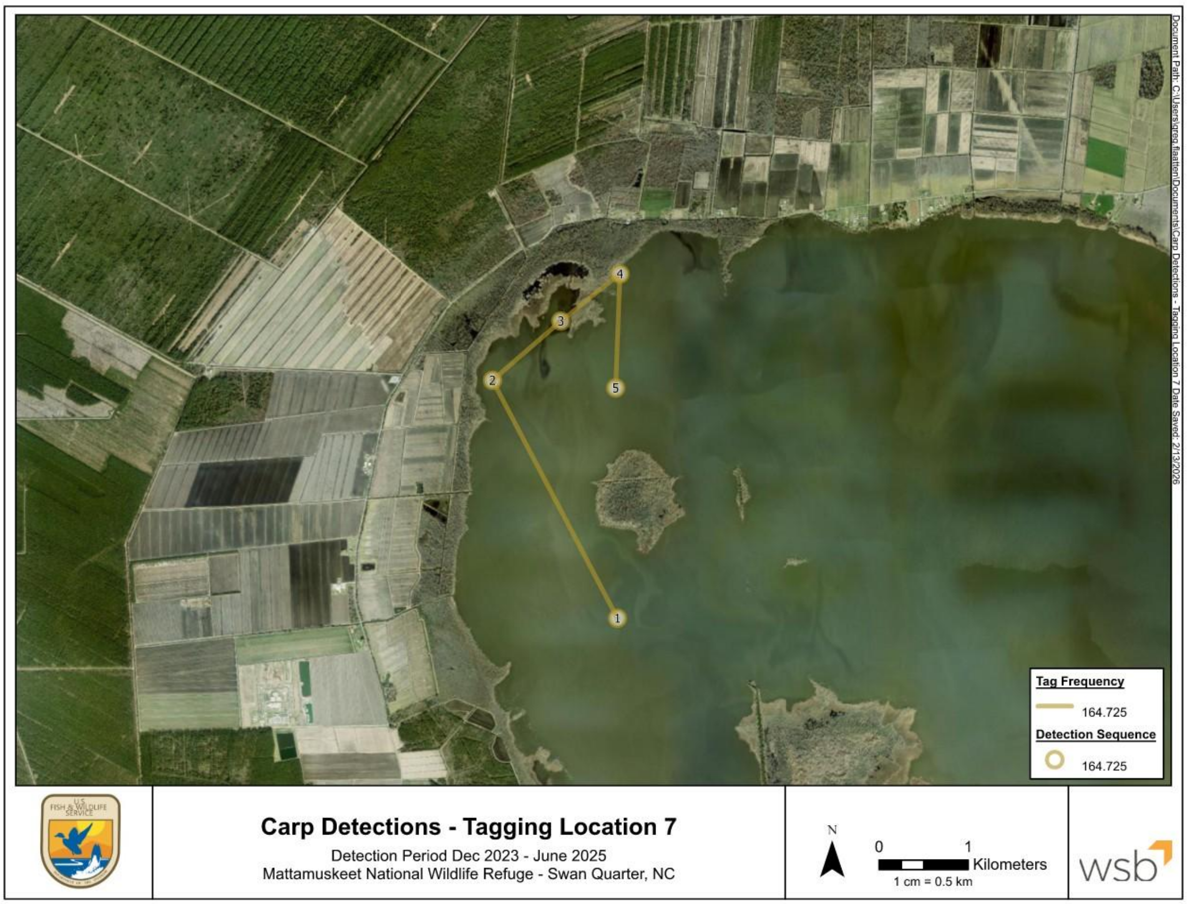

Figure 7. Individual movements of tagged carp from tagging location 7.

Table 11. Summary of tagged carp movement distance (km) for tagging location 7. Date columns correspond to telemetry survey dates. Distance (km) is the length between listening points where the tag was heard, not necessarily distance an individual fish moved. Some tags were heard from multiple listening points during the same survey.

Tag Frequency	From	To	Distance (km)
164.725	12/13/2023	10/2/2024	2.4
Total Distance			**2.4**