Movement of Acoustic Tagged Largemouth Bass in Relation to Lake Level and Water Quality at Lake Mattamuskeet and Surrounding Canals

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Abstract. Largemouth Bass *Micropterus salmoides* are popular sport fish at Lake Mattamuskeet, a 16,299-ha shallow (mean depth < 1.0 m), naturally formed lake surrounded by a system of canals at the Mattamuskeet National Wildlife Refuge in Hyde County, North Carolina. This study tested the hypothesis that Largemouth Bass use of lake and canal habitats is triggered by fluctuating water levels in the main lake. Between March and June 2017, a total of 18 VEMCO VR2W receivers were strategically placed at canal connections to the lake. During May–June 2017, a total of 42 Largemouth Bass were surgically implanted with VEMCO V9 acoustic tags and released near collection sites. Thirteen additional receivers were deployed at lake and canal sites between June and October 2017. Receiver downloads between July 1, 2017 (end of tag probation period) and March 15, 2019 (extent of transmitter battery life) revealed more than 609,000 detections of 32 acoustic-tagged Largemouth Bass within the passive acoustic receiver array. Analysis of detections of Largemouth Bass from the west side of the lake characterized the utilization of the lake and canal interface on the west side of the lake. Largemouth Bass collected from the east lake displayed use of the east lake habitat and movement to the west lake habitat during a relative increase in water level. This study supports the need for fisheries managers to routinely sample both lake and canal habitats to characterize the Largemouth Bass population at Lake Mattamuskeet. Future habitat use studies by Largemouth Bass are warranted when SAV habitat improves in the lake and water depths in the canal are sufficiently maintained.

Connectivity of aquatic systems may be of natural origin or artificial creation. Man-made canals are often associated with natural water bodies for many reasons, including drainage of agricultural land and providing access for commercial and recreational use. Canals that are connected to lakes and reservoirs may provide suitable habitat for fish and aquatic organisms. The utilization of these available habitats by sport fish, such as Largemouth Bass *Micropterus salmoides*, is of interest to fisheries managers and anglers alike (Bisping and Thompson 2017).

Water level fluctuations are primary influences on ecosystem services within most aquatic environments (Gownaris et al. 2018). At Lake Mattamuskeet, water levels fluctuate regularly due to environmental conditions including rainfall, prevailing wind direction, evaporation, or anthropogenic actions like pumping and draining through canals or water control structures. These fluctuating water levels may alter available shoreline and lake habitats for Largemouth Bass and other aquatic organisms, whereas connecting canals are generally considered to be relatively deeper due to regular maintenance dredging and may provide alternative habitat when lake habitat is reduced.

Fishing is a popular activity at Lake Mattamuskeet National Wildlife Refuge (Refuge). Vogelsong (2006) identified fishing as the primary activity reported by 71.1% of the visitors surveyed at the Refuge from October 2004 to October 2005. The North Carolina Wildlife Resources Commission (NCWRC) coordinates with the Refuge for fisheries management and research projects. Regulations pertaining to recreational angling at Lake Mattamuskeet are under the jurisdiction of the NCWRC, including general licensing requirements as well as length and creel limits for the lake's freshwater sport fish species. Important recreational fisheries for Largemouth Bass, Black Crappie *Pomoxis nigromaculatus*, Channel Catfish *Ictalurus punctatus*, sunfish *Lepomis* sp., and White Perch *Morone americana* exist in Lake Mattamuskeet and associated canals (McCargo et al. 2011; Potoka et al. 2014).

Anglers exercised an estimated 200,000 hours of fishing effort at Lake Mattamuskeet in 2014, although angler effort and catch rates of Largemouth Bass ranked fifth for species sought (Dockendorf et al. 2015). In turn, anglers at Lake Mattamuskeet indicated a concern that the Largemouth Bass population seemed less robust than in previous years. Potoka et al. (2014) conducted routine electrofishing surveys and identified a difference in relative abundance of Largemouth Bass at Lake Mattamuskeet between lake and canal habitats. This acoustic telemetry study on the utilization of canal and lake habitats by Largemouth Bass was conducted to: 1) determine the spatial and temporal distribution of Largemouth Bass at Lake Mattamuskeet, 2) document movements of Largemouth Bass within and between main lake and canal habitats, and 3) relate those movement patterns to environmental factors, such as seasonal water levels.

Methods

Study site. Lake Mattamuskeet is a 16,299 ha (USFWS 2018) hypereutrophic lake in Hyde County, North Carolina. While Lake Mattamuskeet is the largest naturally formed lake in North Carolina, extensive hydrologic modifications have occurred over the past 200 years that significantly altered its original footprint (North Carolina Coastal Federation 2018). Between 1915 and 1932, three separate attempts were made to drain the lake to allow for farming the rich land beneath (Waters 2010). Ultimately, these drainage projects failed, and the property was sold to the federal government to be converted into a national wildlife refuge (Carson 1947). The drainage attempts reduced the original lake surface acreage from 48,650 ha to 16,750 ha.

Lake Mattamuskeet is about 29 km long and 11 km wide and average water depths range 0.6–0.9 m (1.9–2.9 ft). Lake Mattamuskeet is the central component of the U.S. Fish and Wildlife Service Mattamuskeet National Wildlife Refuge and is a primary winter migration stop for waterfowl along the Atlantic Flyway. The lake is bisected by a north-south causeway, NC 94 highway (Hwy 94), constructed in 1941–1942 (Cahoon 1953), dividing the lake into an east and west side. Along this causeway, there are five culverts which allow water movement between the east and west sides of the lake depending on wind speed and direction.

Lake Mattamuskeet is 1.0 m above mean sea level and is located 11.2 km north of Pamlico Sound. Lake Mattamuskeet is connected to the Pamlico Sound via four manmade canals: Rose Bay Canal extending from the west lake, and Outfall, Lake Landing, and Waupoppin canals extending from the east lake (Godwin 2004). Each canal is equipped with a water control structure administered and maintained by the Refuge. These water control structures are designed to allow drainage of the lake via head pressure, and directly impact canal water levels via drainage or water intrusion during times when gates are not operating as designed. With proximity to Pamlico Sound, canal habitats have the potential for saltwater intrusion to effect habitat suitability if canals are manually opened or lodged open with debris.

Acoustic receivers. An array of passive acoustic receivers (VEMCO VR2W 69 Hz; Vemco Division, AMIRIX Systems, Inc., Nova Scotia, Canada) were deployed in Lake Mattamuskeet and its associated canals to characterize Largemouth Bass habitat use. A range test was conducted in January–February 2017 in canals of Lake Mattamuskeet to confirm receiver and transmitter communication in this environment and to inform our receiver gate distances. Following the range test, VR2W receivers were deployed at select locations during the study (Figure 1). Eighteen VR2W receivers were placed at lake-canal interfaces at select locations March–May 2017 and labeled as either a lake or canal receiver. Five VR2W receivers were placed near the five culverts in June 2017, three receivers were set in select locations on the west lake in September 2017, and five receivers were deployed in select locations in east lake in October 2017. The receivers were moored on polyvinyl chloride (PVC) tubing. Each receiver was attached to a 50.8-mm PVC stake and then placed over a 38.1-mm PVC pole driven into the substrate (A. Ferguson, Louisiana Department of Wildlife Resources, personal communication).

Acoustic transmitters. The first set of 30 VEMCO V9-2L acoustic coded transmitters was programmed to broadcast a unique signal every 90 seconds on a frequency of 69 kHz with an estimated battery life of 651 days. A second set of 12 VEMCO V9-2L acoustic coded transmitters was available from an earlier NCWRC project (Rundle and Cartabiano 2016) and was programmed to broadcast an unique signal every 80 seconds on a frequency of 69 kHz with an estimated battery life of 596 days. Each transmitter weighed 6.3 g in air (3.5 g in water) and was no more than 2% of the weight (2% rule; Brownscombe et al. 2019) of the Largemouth Bass to be tagged (i.e., Largemouth Bass needed to weigh ≥ 315 g.)

Largemouth Bass tagging. Mock surgeries were conducted to implant dummy tags and practice surgical knots in euthanized Largemouth Bass in March 2017 prior to primary live tagging events. In May 2017, fifteen Largemouth Bass from east lake and 15 Largemouth Bass from west lake were collected using boat mounted electrofishing for a total of 30 Largemouth

Bass tagged with the first set of acoustic transmitters. In June 2017, six Largemouth Bass were collected from each canal complex for a total of 12 fish tagged with the second set of transmitters within canal habitats.

Each Largemouth Bass was anesthetized to surgically implant a passive information transponder (PIT tag; Oregon RFID) and a VEMCO V9-2L acoustic transmitter. PIT tags were inserted to identify tagged Largemouth Bass in ongoing sampling surveys. No external tags were utilized. Each Largemouth Bass was anesthetized using a 10–20 mg/L ppm AQUI-S solution (AquaTactics Fish Health, Kirkland, WA) following methods in an approved Aquatic Animal Drug Approval Partnership Program (AADAP; Study # 11-741-17-088F). Each Largemouth Bass was measured (TL, mm) and weighed (g). Anesthetized Largemouth Bass were placed ventral side up in a U-shaped PVC surgery trough, and a small aerator was used to circulate fresh water over the gills while in the surgery trough. All surgical tools, PIT tags, and acoustic transmitters were sanitized in Ovadine® (Buffered PVP Iodine; Western Chemical, Ferndale, WA) solution and rinsed with sterile saline prior to surgery. Surgical implantation generally followed these guidelines: a 2-cm incision was made using a sterile stainless-steel blade approximately 3-cm posterior of the pelvic fins. The tags were inserted, and the incision was closed with one suture of monofilament with a circular cutting needle. Largemouth Bass were placed in an individual holding basket, submerged in an oxygenated live well, and allowed to recover before release.

Largemouth Bass surgically tagged in May 2017 were held overnight in a live car and checked the following morning for survival and intact sutures before being released in the lake near capture locations. Largemouth Bass surgically tagged in June 2017 recovered in a nearby holding tank and were then released into the canal where captured. Largemouth Bass were categorized into four tagging suites based on release locations (East Canal, East Lake, West Canal, West Lake).

Largemouth Bass detections and tracking. Acoustic-tagged Largemouth Bass were detected when within range of an acoustic receiver (Figure 2). Passive acoustic receivers were visited regularly by NCWRC staff to download acoustic transmitter data onto a field computer in the VEMCO User Environment (VUE) software, confirm receiver position, and perform maintenance. Active tracking with VEMCO VR100 was conducted October 2017, December 2017, March 2018, May 2018, and June 2018. Passive tracking concluded in March 2019 when transmitter battery life end was expected. Receivers and mooring stations were removed from the lake in March 2019, except one was lost during the winter bomb cyclone event in January 2018.

Data analysis. VEMCO detections stored on the VUE platform were downloaded and imported to an alternative data management platform as recommended by Webber (2009; pg. 14). All VEMCO data were analyzed with the R programming language (R Core Team 2020) in RStudio (RStudio 2019). Acoustic receiver data were cleansed to remove test tag and false positive detections. A post-tagging probationary period was implemented following surgery to allow for tagged Largemouth Bass to normalize patterns for analysis. The probationary period ended June 30, 2017, and all Largemouth Bass passive receiver detections between July 1, 2017 and March 12, 2019 were included. An acoustic tagged Largemouth Bass was determined to have used the lake when detected on the lake receiver or any receiver in the lake or near the culverts. An acoustic tagged Largemouth Bass was determined to have used the canal when detected on the canal receiver or on any receiver within the canal. Analyses of lake detections and canal detections by Largemouth Bass tagging suite were conducted with a paired Wilcoxon rank sum test. Values were considered significant at $\alpha < 0.05$.

Lake level, water temperature (°C), dissolved oxygen (mg/L) and salinity (ppt) were collected from the two USGS gages, one on each side of the lake, and downloaded via dataRetrieval package available for R (Hirsch and De Cicco 2015). Water quality measurements were also taken at receiver station visits; water depth, water temperature, dissolved oxygen and salinity were taken with a YSI ProPlus 2030 multimeter, water transparency was measured with a secchi disk, and pH with a Hach kit. Water quality data at receiver stations were separated by lake and canal environments. All information collected during receiver visits was recorded on field data sheets, entered into a Qualtrics spreadsheet, and imported into R via the qualtRics package (Silge and Ginn 2019). Monthly means for each variable at each USGS gage were calculated from available daily values. A Mann-Kendall Trend test was performed to assess trends in the environmental data. Values were considered significant at $\alpha < 0.05$.

Results

Acoustic receiver range test. Range tests identified a listening distance of up to 100 m could detect a VEMCO tag at 90% of the expected detections, whereas a VEMCO tag was detected at 0% of expected detections at a listening distance ≥ 150 m. Receivers were separated by 250 m between gates at the interface of the lake and canal to ensure no overlap of detections at interface gates within the receiver array.

Largemouth Bass tagging. A total of 42 Largemouth Bass (Table 1) were implanted with acoustic tags between May 2017 (n = 30) and June 2017 (n = 12). Total length of all tagged Largemouth Bass ranged 294–569 (mean = 382.6 mm, SD = 52.8) and total weight ranged 327–2870 (mean = 885.2 g, SD = 444.2). Twenty-four-hour survival was 100% for Largemouth Bass held in the live car prior to release back to lake collection locations in May 2017. Largemouth Bass acoustic-tagged in June 2017 were released at each canal site after recovery.

Largemouth Bass detections. A total of 32 Largemouth Bass remained following the probationary period and were included in the detection and habitat use analyses (Figure 3). Thirteen of the 15 Largemouth Bass released in East Lake and seven of 15 Largemouth Bass released in West Lake were detected after the probationary period. All 12 Largemouth Bass released in the canals, six in West Canal and six in East Canal, were detected following the probationary period. The remaining 10 acoustic-tagged Largemouth Bass were assumed to have either died, experienced tag loss or tag failure, were harvested by anglers, or went otherwise undetected during the probationary period.

Largemouth Bass detected after the probationary period and at any receiver in the array contributed to a total of 609,875 overall detections. Acoustic detections at the lake-canal interface accounted for 543,752, or 90% of the total detections. Acoustic-tagged Largemouth Bass were grouped by tagging suite (Table 2). Acoustic-tagged Largemouth Bass collected from East Lake accounted for 16,130 detections on lake receivers and 8,022 detections on canal receivers. Acoustic-tagged Largemouth Bass collected from East Canal accounted for 10,123 detections on lake receivers and 455,538 detections on canal receivers. Largemouth Bass collected from West Lake accounted for 6,485 detections on lake receivers and 3,271 detections on canal receivers. Acoustic-tagged Largemouth Bass collected from West Canal accounted for 7,108 detections on lake receivers and 37,075 detections on canal receivers. Detections of acoustic-tagged Largemouth Bass from the East Canal tagging suite were significantly greater on the canal receivers than the lake receivers ($W = 34$; $p = 0.008$); remaining acoustic-tagging suites of Largemouth Bass exhibited no differences between lake and canal detections (Table 2).

Detections for all Largemouth Bass of the East Canal and West Canal tagging suites ceased during fall 2018. Eight acoustic-tagged Largemouth Bass from East Lake and West Lake were heard within 30 days of the end of the study period, or about 40% of the 20 acoustic-tagged Largemouth Bass available from the two lake tagging suites. Twelve (60%) acoustic-tagged Largemouth Bass were not detected within the last 30 days.

Acoustic-tagged Largemouth Bass of the West Lake and West Canal tagging suites were detected at canal and lake receivers (Figure 4). Largemouth Bass of the East Lake tagging suite were more often detected at the lake receivers than canal receivers. East Lake Largemouth Bass were also detected on east and west sides of the lake. Largemouth Bass collected from the canals tended to use the canals, especially East Canal Largemouth Bass. West Canal Largemouth Bass were detected in the lake near the causeway on the west side of the lake (Figure 5).

Largemouth Bass movement was based on linear swim distance between detection points following the probationary period. Mean (SD) swim distance of 32 acoustic-tagged Largemouth Bass was 203.7 km and individual swim distances ranged from 0.8 km to 1,081.6 km. Mean swim distances by tagging suite was 77.5 (40.4) km for West Lake, 103.7 (151.0) km for East Canal, 280.9 (306.0) km for East Lake, and 289.9 (266.0) km for West Canal. There were no significant differences in swim distances by tagging suite (Table 2).

Lake level and water quality. USGS gage data (Figure 7) for lake level, water temperature and dissolved oxygen were not statistically different for the study period and were combined for trend analysis. Salinity measurements were statistically different and were not combined.

Discussion

Acoustic-tagged Largemouth Bass revealed general habitat use patterns at Lake Mattamuskeet. Largemouth Bass exhibited a tendency to use the habitat of initial collection and release; Largemouth Bass from lake tagging suites predominantly used the lake habitat, and Largemouth Bass from canal tagging suites were most often detected in canal habitats. However, with two notable exceptions within East Canal, each individual fish tagged during the project exhibited frequent movement between the lake and canal habitat types. Fish 18319 which was originally tagged and released in East Canal was not detected on any lake receivers during the 203 days that this fish was at large. Similarly, fish 18320 spent over 441 days at large and was detected 141,443 times within East Canal but only twice on lake receivers. Movement and relative abundance of Largemouth Bass in lake and canal habitats is thought to vary based on prevailing habitat and water quality conditions between the two habitat types.

Acoustic-tagged Largemouth Bass from East Lake tagging suite were detected more often on lake receivers than canal receivers. Largemouth Bass from the East Lake tagging suite were detected throughout the lake including the east side, west side, and all five culvert receivers. Largemouth Bass from the West Lake tagging suite used both lake and canal habitats on the west side of the lake, yet were not detected in lake or canal habitat on the east side of the lake.

Largemouth Bass movements in the upper Chesapeake Bay were suspected to be different depending on habitat preferences (Heft and Richardson-Heft 2002). Differences in movement patterns between the Lake Mattamuskeet tagging suites may be related to relative habitat dynamics of Lake Mattamuskeet; however, these differences might also be attributed to the larger sample size of acoustic-tagged bass within the East Lake tagging suite, specific ecological niches related to spawning and foraging, or some combination of these factors.

Some acoustic-tagged Largemouth Bass were detected on the receivers near the culverts under the Highway 94 causeway and indicated Largemouth Bass used these causeway culvert areas. Largemouth Bass were likely attracted to the causeway culverts due to relatively deeper water, variable water flow, forage fish availability, and proximity to rip-rap habitat. The Highway 94 causeway is easily accessible by shoreline anglers and is open to fishing throughout the year as compared to the annual lake closure to boating anglers from November to February. Normally, harvest rates of Largemouth Bass are often quite low (Allen et al. 2008, Myers et al. 2008). However, the estimated harvest rate for Largemouth Bass was higher (34%) at Lake Mattamuskeet in 2014 than rates observed from most other coastal systems (Dockendorf et al. 2015). Fates of acoustic-tagged Largemouth Bass not detected on the receiver array were generally unknown; angler harvest was suspected, especially when an acoustic-tagged Largemouth Bass was last heard near a culvert receiver.

Lake levels tended to rise during the study period likely due to extensive rainfall associated with Hurricane Florence in September 2018. Hurricane Florence may have contributed to the fate of Largemouth Bass tagged and released in the canals. After Hurricane Florence, very few detections of Largemouth Bass tagged and released in the canals occurred at any receiver despite numerous detections prior to the storm, especially in East Canal. Brown et al. (2015) found Largemouth Bass exhibited avoidance behavior when dissolved oxygen concentrations were below 1.8 mg/L in coastal rivers of North Carolina. Largemouth Bass habitat use patterns of the Mattamuskeet canals may have been influenced by hurricane-induced hypoxia events following Hurricane Florence as dissolved oxygen levels were less than 0.9 mg/L on September 25, 2018. Although the fates of the tagged Largemouth Bass were unknown, it is possible that fish may have succumbed or rapidly left the canals in response to the hypoxic conditions.

Water control structures at Lake Mattamuskeet are designed to allow water to flow from the lake to the sound and prevent sound water from entering the lake (Rulifson and Wall 2006). While elevated salinity levels at Lake Mattamuskeet are expected within the complex of canals connected to the Pamlico Sound, a spike in salinity levels measured on the USGS gage in the East Lake was likely result of a storm surge from Hurricane Florence. This elevated salinity level, albeit temporary and below survival thresholds of freshwater fish, may have triggered a flight response in Largemouth Bass on the east side and canal systems to move away from this rapid change in water quality.

In October 2018, NCWRC fisheries biologists collected a PIT-tagged Largemouth Bass during a routine electrofishing survey that identified the fish as an acoustic-tagged Largemouth Bass from East Canal. This encounter was evidence that this individual Largemouth Bass was alive despite the absence of detection on the receiver array following Hurricane Florence. While dissolved oxygen conditions may have been inadequate for Largemouth Bass habitat use, it is also possible that the batch of acoustic transmitters acquired from an earlier NCWRC project had a shorter battery life than anticipated and stopped transmitting in fall 2018. Utilization of that specific batch of transmitters for Largemouth Bass tagged in canals provided additional detections to inform short-term habitat use; however, questions regarding the transmitter battery life confounded the ability to observe movements that may have been associated with hurricane-induced water quality degradation.

Secchi depth and pH measurements during this study were indicative of intensive algal blooms. Multiple years of algal blooms and increased suspended sediments are thought to have caused reductions in submerged aquatic vegetation (SAV). During this survey, SAV coverage was <5% (Moorman et al. 2017; Refuge, unpublished data). Lack of SAV at Lake Mattamuskeet may have influenced habitat utilization of Largemouth Bass during this study. Colle et al. (1989) described Lake Baldwin, Florida, as devoid of SAV during their survey and determined home ranges of Largemouth Bass to be extensive as compared to aquatic habitats with abundant SAV. Fish 618 which was originally tagged in East Lake exhibited the furthest linear swim distance, traveling over 1000 km during the 532 days at large. Largemouth Bass at Lake Mattamuskeet may have utilized alternative habitats and expanded their home ranges as a function of low (nearly absent) SAV densities during the study period. Although linear movement between suites was not statistically different, Largemouth Bass within the West Lake suite had the smallest home ranges based on mean linear swim distances. Continued efforts to improve SAV abundance through nutrient reductions, supplemental SAV plantings, and Common Carp *Cyprinus carpio* removal programs are warranted for an improved aquatic ecosystem at Lake Mattamuskeet.

The extensive canals at Lake Mattamuskeet are part of a historic infrastructure to drain water from the lake to the Pamlico Sound. These canals coupled with functioning water control structures are intended to allow for water level management. Canal depths during the study period were less than original canal depths (Figure 8; R. Etheridge, East Carolina University, unpublished data). Along with the water flow, sediment from wind tides and shoreline erosion settle in these canals and effectively create sediment plugs when water flows stagnate. On many occasions throughout the study period, navigation between the lake and canal interface was challenging, especially at Lake Landing Canal, Central Canal, and behind the historic Mattamuskeet Lodge (Figure 9). These sediment plugs are not only navigational hazards for agency staff and boating anglers, but they may impede ability for Largemouth Bass and other fish to effectively access and use the two habitat types or avoid poor water quality conditions. The extent of sediment plugs may require further dredging and shoreline stabilization to circumvent this situation.

Management Recommendations

1. Continue periodic sampling of both lake and canal sites to assess variability in Largemouth Bass abundance between the two habitat types.
2. Maintain funding for the two USGS gaging stations at Lake Mattamuskeet.
3. Support Refuge management actions that maintain the integrity of the canal system, especially dredging and shoreline stabilization to ensure sufficient water depths for aquatic connectivity between the lake and the canals.
4. Support research and cooperative programs to restore SAV habitat at Lake Mattamuskeet.

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TABLE 1. Individual Largemouth Bass with acoustic tags at Lake Mattamuskeet, 2017–2019.

Acoustic LMBID	Total weight	Total length	Tag Suite	Detected after Probation
600	629	355	West Lake	No
601	769	379	West Lake	Yes
602	794	370	West Lake	No
603	549	346	West Lake	Yes
604	809	378	West Lake	Yes
605	994	417	West Lake	Yes
606	816	382	West Lake	Yes
607	327	294	West Lake	No
608	513	336	West Lake	Yes
609	420	305	West Lake	Yes
610	1360	450	West Lake	Yes
611	524	339	West Lake	No
612	439	310	West Lake	No
613	1344	446	West Lake	No
614	715	365	West Lake	No
615	1701	458	East Lake	Yes
616	1142	406	East Lake	Yes
617	752	368	East Lake	Yes
618	1110	413	East Lake	Yes
619	971	406	East Lake	Yes
620	875	398	East Lake	Yes
621	1270	428	East Lake	Yes
622	832	376	East Lake	Yes
623	1295	408	East Lake	Yes
624	1048	406	East Lake	No
625	402	303	East Lake	Yes
626	1175	428	East Lake	Yes
627	477	318	East Lake	Yes
628	906	402	East Lake	Yes
629	1199	426	East Lake	No
18283	928	404	West Canal	Yes
18291	1000	420	West Canal	Yes
18292	776	381	West Canal	Yes
18294	571	359	West Canal	Yes
18299	405	302	West Canal	Yes
18317	329	297	West Canal	Yes
18302	905	396	East Canal	Yes
18276	2870	569	East Canal	Yes
18319	782	360	East Canal	Yes
18320	700	375	East Canal	Yes
18323	782	385	East Canal	Yes
18326	974	405	East Canal	Yes

TABLE 2. Acoustic-tagged Largemouth Bass detections at canal and lake locations categorized by tagging suite at Lake Mattamuskeet, 2017–2019. Asterisks (*) denotes significant difference among detection type at P < 0.05.

Acoustic LMBID	Total weight	Total length	Tag Suite	Days at large	Canal detections	Lake detections	Wilcoxon sum test
18276	2870	569	East Canal	373	58631	4180	W = 34 p = 0.008*
18302	905	396	East Canal	458	177066	136	
18319	782	360	East Canal	203	1009	0	
18320	700	375	East Canal	441	141443	2	
18323	782	385	East Canal	431	18704	5381	
18326	974	405	East Canal	441	58685	424	
615	1701	458	East Lake	600	264	410	W = 50 p = 0.214
616	1142	406	East Lake	619	73	299	
617	752	368	East Lake	94	510	1124	
618	1110	413	East Lake	532	24	306	
619	971	406	East Lake	316	122	160	
620	875	398	East Lake	118	417	686	
621	1270	428	East Lake	585	32	135	
622	832	376	East Lake	571	23	160	
623	1295	408	East Lake	69	81	31	
625	402	303	East Lake	587	5301	10859	
626	1175	428	East Lake	586	258	1717	
627	477	318	East Lake	595	917	243	
18283	928	404	West Canal	19	6002	2743	W = 25 p = 0.309
18291	1000	420	West Canal	415	8478	2344	
18292	776	381	West Canal	333	25300	3806	
18294	571	359	West Canal	24	1064	286	
18299	405	302	West Canal	32	93	39	
18317	329	297	West Canal	68	2140	633	
601	769	379	West Lake	587	1328	2144	W = 15 p = 0.699
603	549	346	West Lake	54	492	454	
604	809	378	West Lake	573	455	585	
608	513	336	West Lake	225	810	2887	
610	1360	450	West Lake	371	29	150	
614	715	365	West Lake	601	157	265	

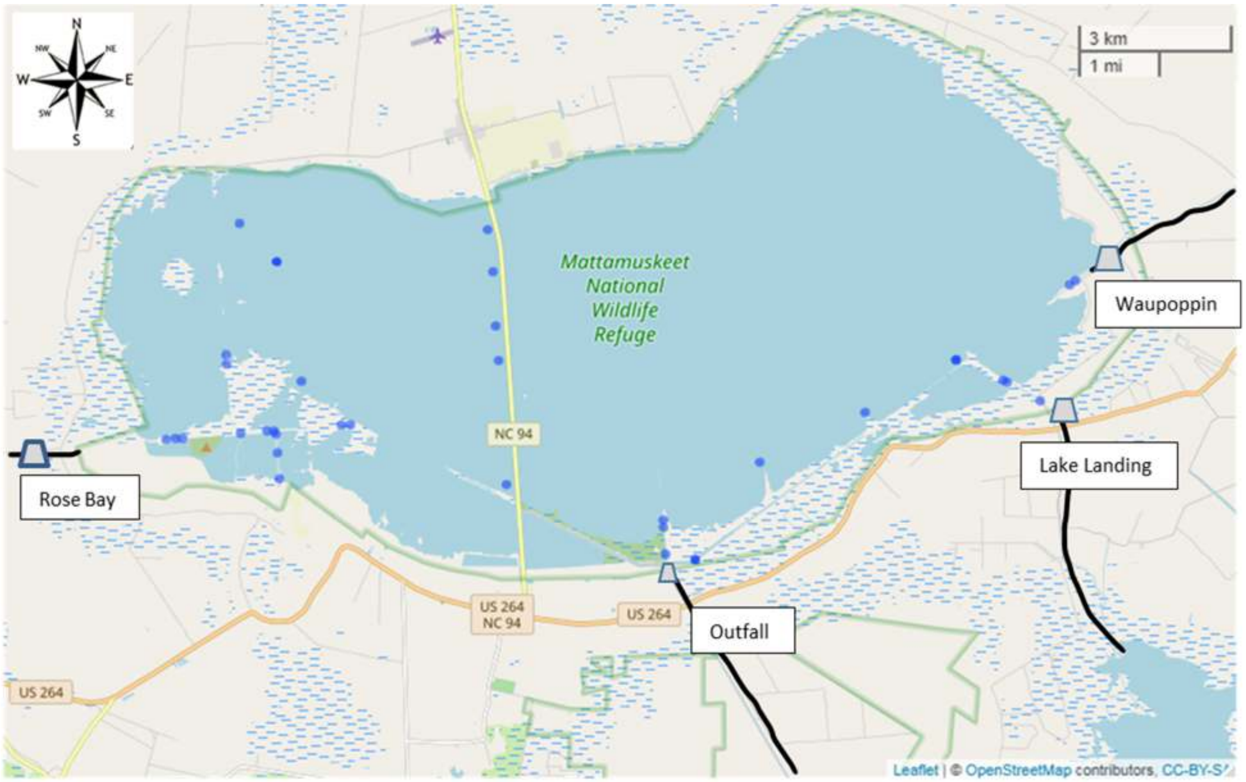

FIGURE 1. Lake Mattamuskeet with acoustic receiver locations for tracking Largemouth Bass, 2017–2019. The four primary canals and associated water control structures are noted.

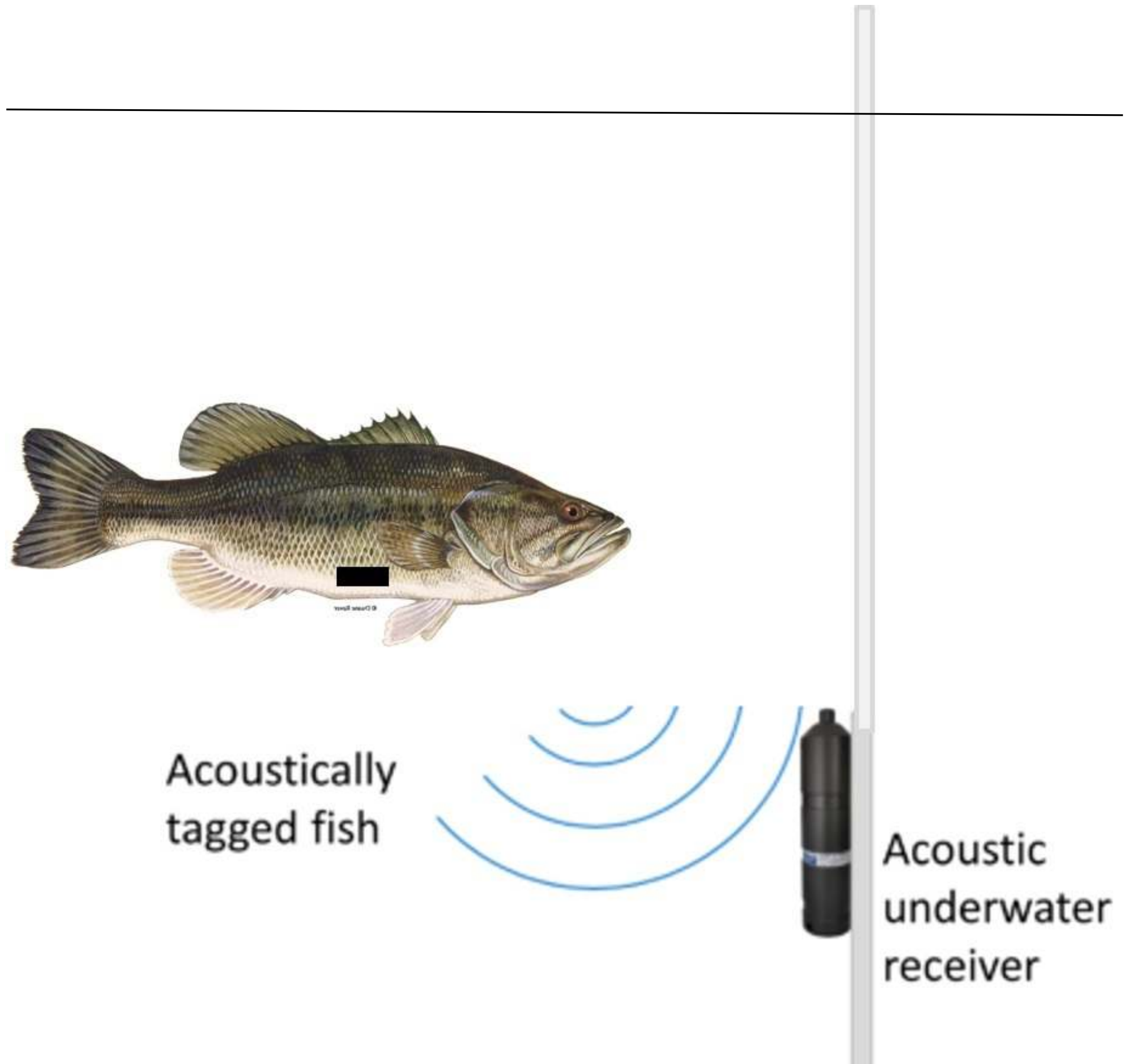

FIGURE 2. Illustration of acoustically tagged Largemouth Bass detected at an underwater passive acoustic receiver station at Lake Mattamuskeet. Illustration is not to scale.

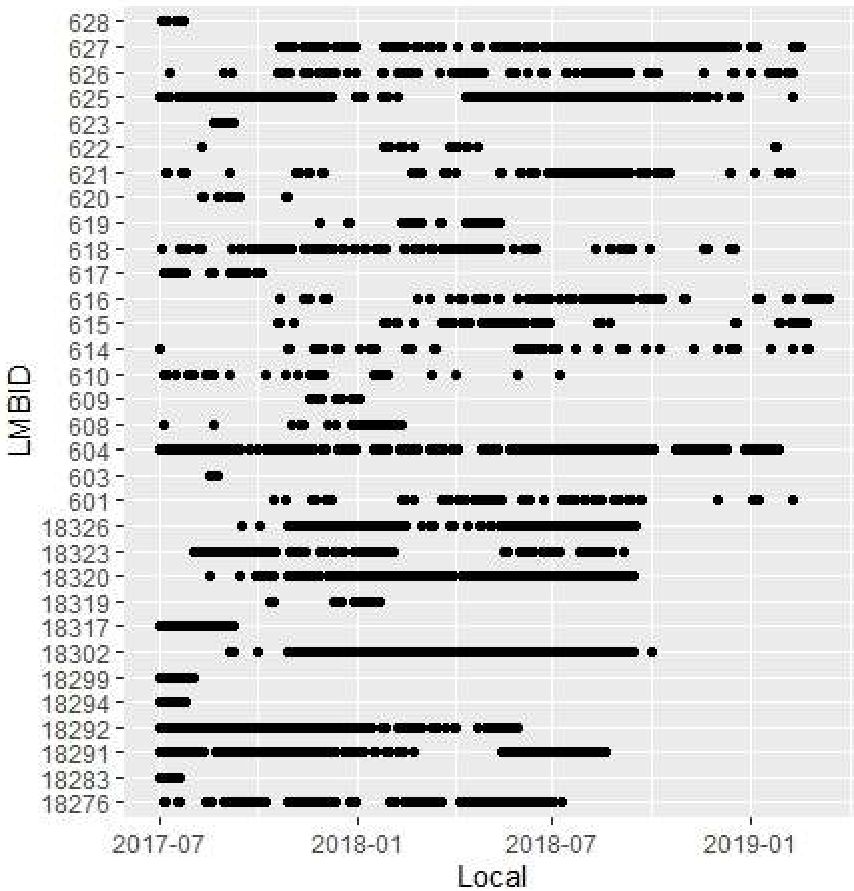

FIGURE 3. Detections of acoustic-tagged Largemouth Bass downloaded from VUE software.

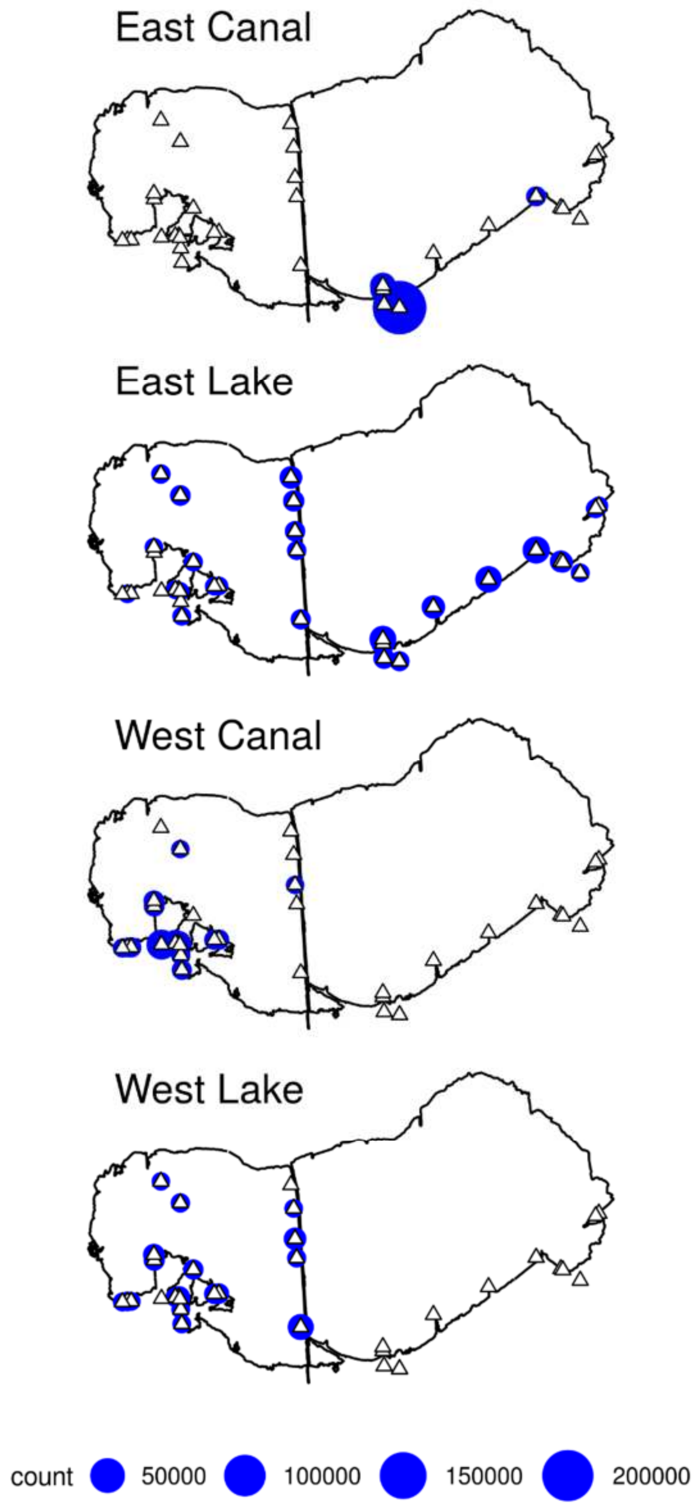

FIGURE 4. Acoustic detections of Largemouth Bass by tagging suite at Lake Mattamuskeet, July 2017–March 2019.

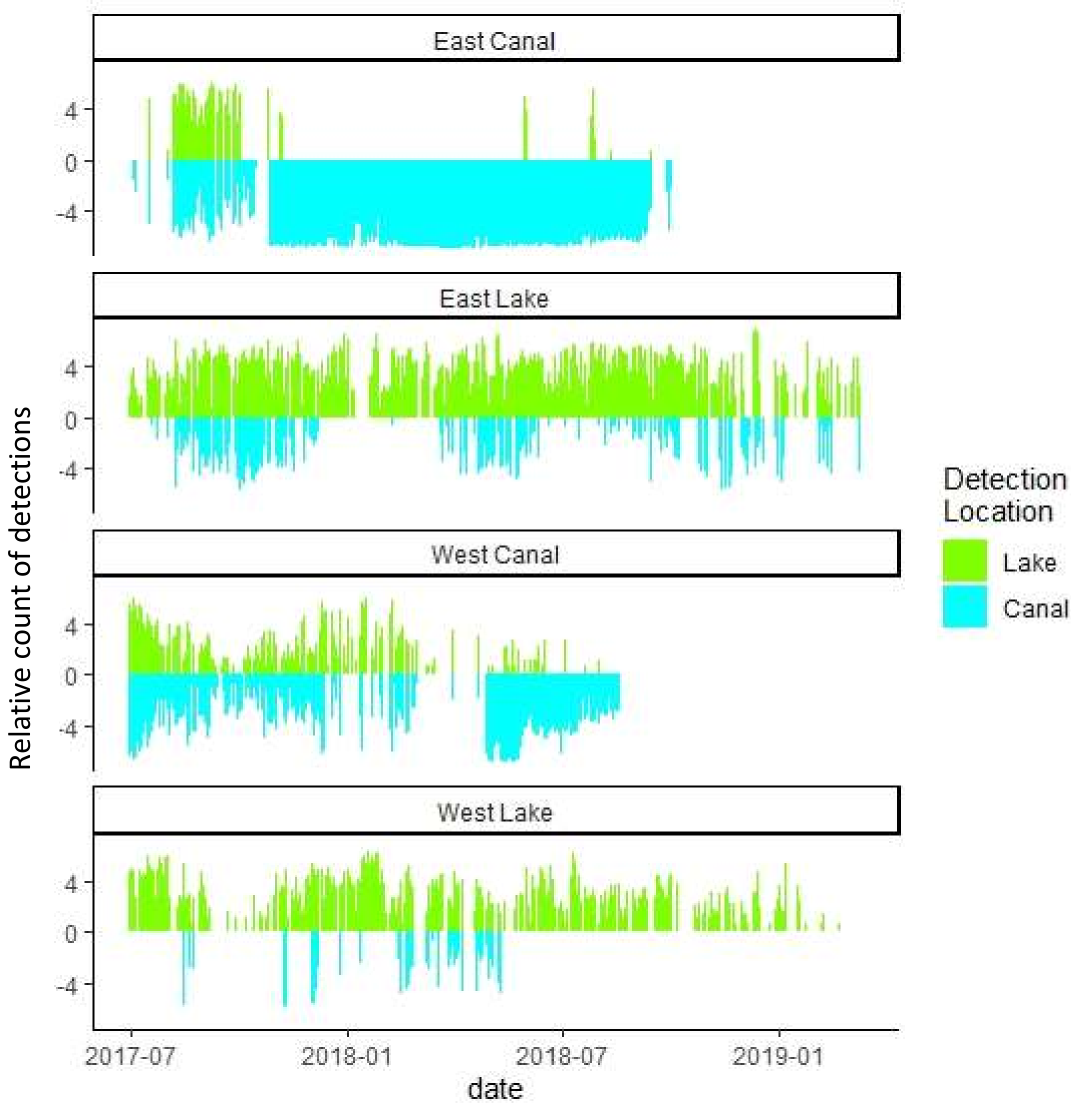

FIGURE 5. Relative count of Largemouth Bass detections at lake and canal receivers by tag suite. Positive values are detections at the lake receivers and negative values are the canal receivers where 0 is the lake-canal interface. Each graph is categorized by tagging suite (release location).

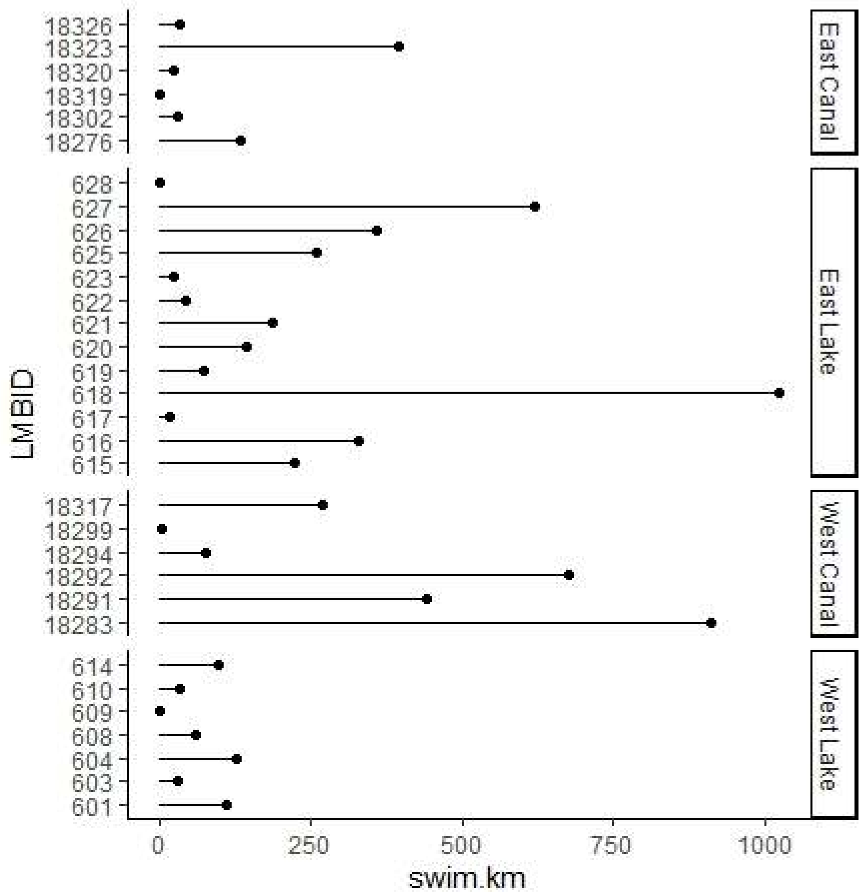

FIGURE 6. Linear swim distances by acoustic-tagged Largemouth Bass by tagging suite at Lake Mattamuskeet, July 2017–March 2019.

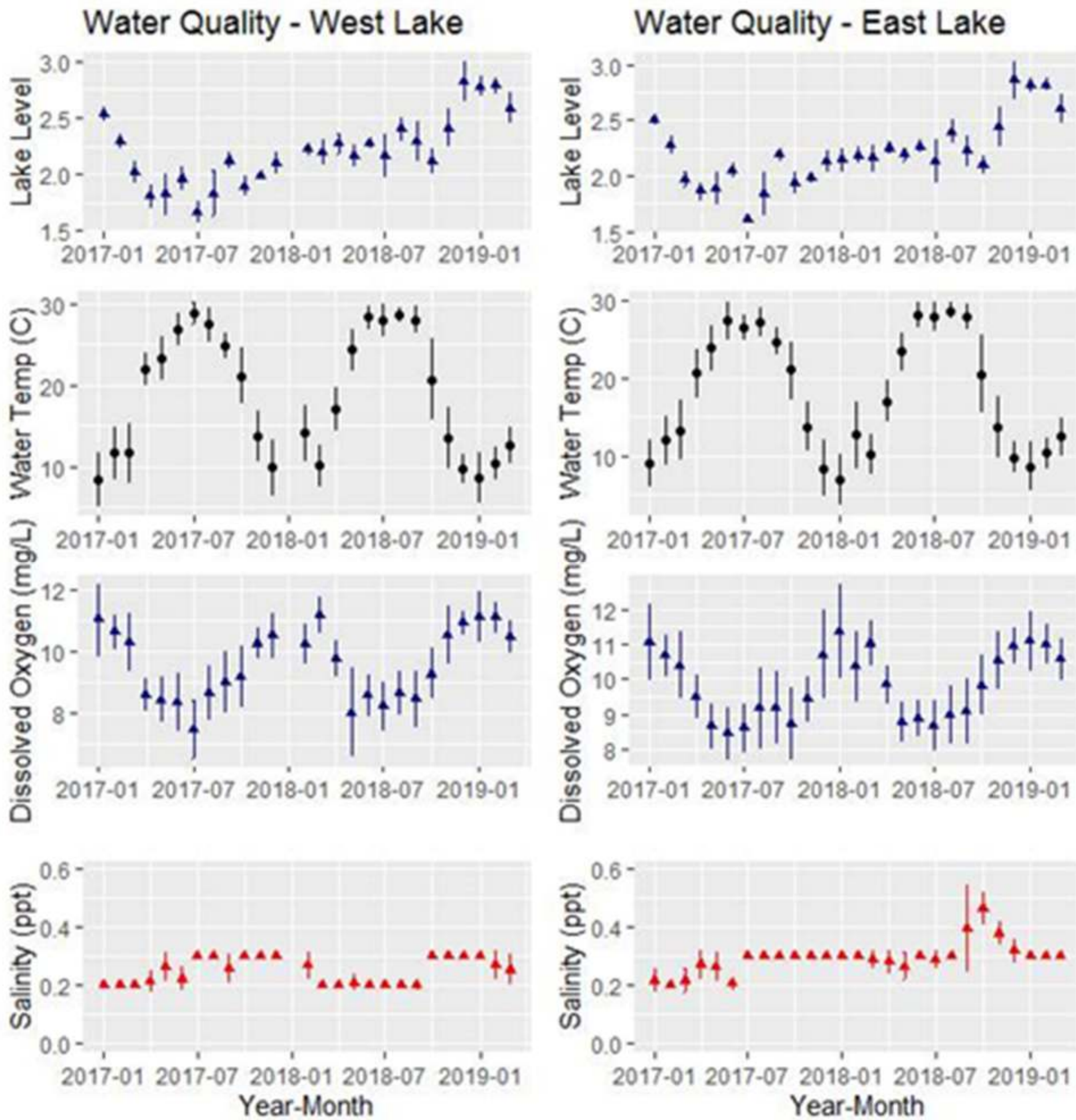

FIGURE 7. Monthly water quality data from two USGS gages at Lake Mattamuskeet, January 2017–March 2019.

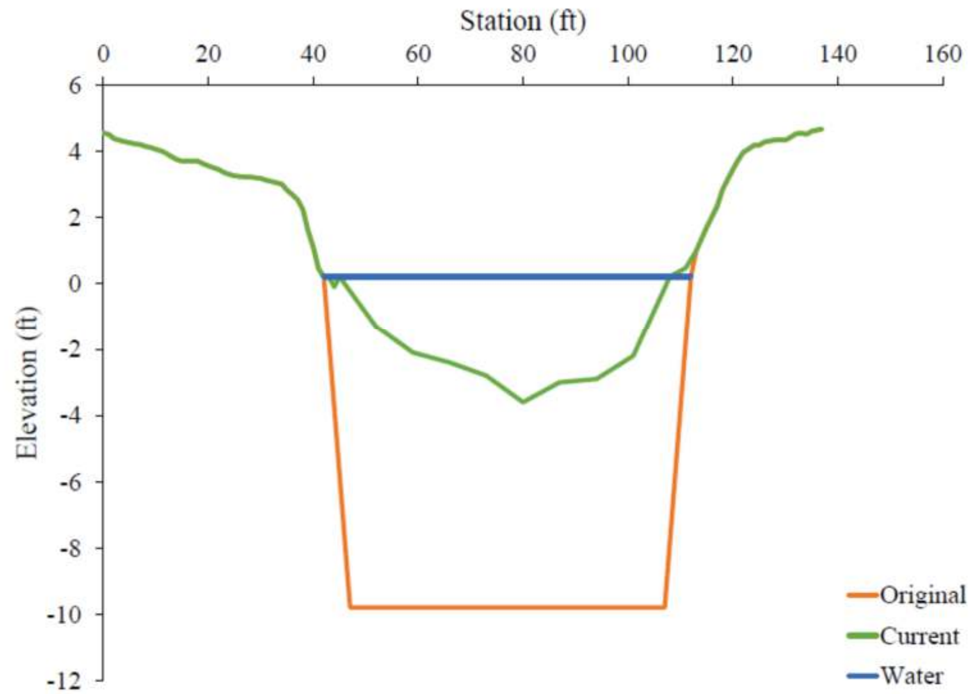

FIGURE 8. Cross-section view of depth measurements of Outfall Canal collected by Dr. Randall Etheridge, East Carolina University. Current canal depth is the green line. Red lines depict the original depths at time of canal excavation. Water level is demonstrated by blue line.

FIGURE 9. Image of excessive sedimentation in Outfall Canal behind Mattamuskeet lodge on May 7, 2021 near the East Canal complex. Photo Credit: Kendall Smith, Refuge Manager, Mattamuskeet Wildlife Refuge.