RESEARCH & DEVELOPMENT

Distribution, Roosting and Foraging Ecology, and Migration Pathways for Gray Bats in Western North Carolina

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NCDOT Project 2018-36

FHWA/NC/2018-36

October 2020

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Report to North Carolina Department of Transportation

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1. Report No.
FHWA/NC/2018-36

2. Government Accession No.
...leave blank...

3. Recipient's Catalog No.
...leave blank...

4. Title and Subtitle

Distribution, Roosting and Foraging Ecology, and Migration Pathways for Gray Bats in Western North Carolina

5. Report Date
30 October 2020

6. Performing Organization Code
...leave blank...

7. Author(s)
Joey Weber[1], Joy O'Keefe[1], Brianne Walters[1],

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8. Performing Organization Report No.
...leave blank...

9. Performing Organization Name and Address
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10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
North Carolina Department of Transportation

Research and Development Unit

104 Fayetteville Street

Raleigh, North Carolina 27601

13. Type of Report and Period Covered
Final Report

February 1, 2018–October 31, 2020

14. Sponsoring Agency Code

Supplementary Notes:

...leave blank...

16. Abstract
We conducted a two-year study to assess the distribution, roosting and foraging ecology, migratory movements, and winter habits of gray bats (Myotis grisescens) in the French Broad River Basin of western North Carolina. By August 2020, we knew of 37 roosts in the basin. Gray bats actively forage across the basin, but activity is highest north and west of Asheville. Gray bats are active in the basin from March to November each year. We recommend maintaining a current list of bridges, culverts, and buildings used by gray bat roosts in this region to inform project planning and maintenance. Both culverts and bridges are suitable structures for use during at least part of the year. Gray bats are present along streams in the French Broad River Basin and other parts of western NC; more distribution surveys are needed.

17. Key Words
Bridges, culverts, Myotis grisescens, foraging, roosting, migration, rivers, roads

18. Distribution Statement
...leave blank...

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
101

22. Price
...leave blank...

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

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Acknowledgements

We thank many technicians and volunteers who aided with this project. We also received field assistance and logistical support from NCDOT, NV5 Engineers and Consultants, National Park Service, North Carolina Wildlife Resources Commission, US Fish and Wildlife Service, Indiana State University, and UNC-Asheville.

Executive Summary

We conducted a two-year study to assess the distribution, roosting and foraging ecology, migratory movements, and winter habits of gray bats (*Myotis grisescens*) in the French Broad River Basin of western North Carolina. The results of this study will inform the North Carolina Department of Transportation (NCDOT) and US Fish and Wildlife Service (USFWS) on how gray bats may be affected by multiple large scale projects and a range of smaller projects and maintenance activities in NCDOT Divisions 13 and 14. We captured bats, mainly at known roost sites, used various radio telemetry techniques to track bats, searched structures (bridges and culverts), measured roost temperatures, conducted winter surveys in NC, and used acoustics to listen for bats year round. We captured 485 gray bats in 2018 and 374 in 2019; adult males were 73–82% of captures and adult females were 13–23%. By August 2020, we knew of 37 gray bat roosts in the NC portion of the French Broad River Basin; most were bridges, with some culverts, buildings, and live trees. Gray bats showed intra- and interannual fidelity to four primary roosts and to some secondary roosts. Bridges used by gray bats were warmer than ambient conditions. Bats of any species were more likely to occupy long bridges with crevices in the deck, in areas with less urban/suburban landcover. While capable of long-distance flight, gray bats tended to be active < 4 km from primary roosts. Telemetry towers and active telemetry efforts showed gray bats tend to fly along waterways, especially close to roosts in Asheville, Canton, and Marshall, and along the downstream portion of the French Broad River in the basin. We did not detect gray bats in NC during winter, but they arrive by mid-March and depart September–November. Acoustic data showed gray bats active all over the French Broad River basin but most active close to two maternal caves in TN: RC and CCC. We recommend an annual update to the list of known gray bat roosts in this region and delineating a stepwise process for evaluating structures and projects that would allow for certain project activities to occur based on time of year, likelihood of bat presence, and structure checks. Our temperature measurements showed that both culverts and bridges could be suitable roosts during summer and that large culverts are potentially suitable as winter habitat. Gray bat presence should be considered for projects close to large streams in the French Broad River basin and possibly other parts of western NC; more distribution surveys are needed.

Table of Contents

List of Figures

List of Tables

List of Appendices

Introduction

The gray bat (*Myotis grisescens*) is the largest member of the genus *Myotis,* with forearms typically >40 mm in length (Miller and Allen 1928) and body mass of 10–12 g. The gray bat occurs across the eastern United States from western North Carolina (NC) to eastern Kansas and southeastern Indiana to northern Florida (Decher and Choate 1995). The first known gray bat in NC was recorded near Asheville on 1 October 1968 (Tuttle and Robertson 1969); the next records were two submissions to the state rabies lab in 2000 and 2001 (Webster 2005). Gray bats were listed as federally endangered in 1976. Gray bats live in very large numbers in few caves across their range, thus making them more susceptible to disturbance (e.g., flooding, cave commercialization or alteration, vandalism). Tuttle (1979) noted a strong association between gray bat decline and human disturbance, with some colonies completely dispersing from 1968–1976, and they recommended immediate protection of the most important caves used by gray bats in summer and winter.

Gray bats can migrate long distances (Tuttle and Robertson 1969, Whitaker and Hamilton 1998). They generally forage over water and nearby riparian vegetation, from treetop height down to two meters above ground (LaVal et al. 1977). Rivers serve as the main foraging and commuting areas, but gray bats also use lakes, streams, and ponds (Moore et al. 2017). Gray bats opportunistically feed on Coleoptera, Diptera, Lepidoptera, Plecoptera, and Trichoptera (Lacki et al. 1995; Best et al. 1997; Brack and LaVal 2006). Female gray bats typically have a single pup each year, which is born in an altricial state, but capable of independence at three weeks post-parturition (Whitaker and Hamilton 1998). Guthrie (1933b) notes that there must be considerable variation in the timing of parturition, as 29 young of the year examined on 21 June ranged from 27–40 mm in length. Most pups are flying by 20–25 June, but Tuttle (1976a) posited that low roost temperature and other factors slowed growth such that young were not volant until 15 July for one colony. Gray bats predominantly roost in caves year-round (e.g., Guthrie 1933a; Tuttle 1976a; Saugey 1978; Harvey 1994; Harvey et al. 2005). They have also been found roosting in storm drains (Hays and Bingman 1964; Timmerman and McDaniel 1992), culverts (Powers et al. 2016), a barn (Gunier and Elder 1971), a limestone quarry (Brack et al. 1984), and under bridges (Johnson et al. 2002; Cervone et al. 2016; Powers et al. 2016; Sasse 2019).

Gray bat populations show a tendency to aggregate in the winter and disperse into smaller groups in the summer (Hall and Wilson 1966). Guthrie (1933a) noted segregation of sexes in gray bats, where lactating and pregnant bats would roost together, while males and most of the non-reproductive females roosted together in a different location. Male gray bats often form large bachelor colonies. For example, Powers et al. (2016) reported large bachelor colonies ranging from 40–4,000 males in southwestern Virginia. Tuttle (1976b) determined that adult females would occupy a single maternity cave, while adult males and yearlings occupied other caves. However, at the colony level, Tuttle (1976b) noted that the colonies he studied seemed to prefer certain caves and used other caves less often; it is possible gray bats switch between “primary” and “secondary” roosts, akin to the behavior exhibited by tree-roosting bats (Callahan et al. 1997). Gray bats emerge from and return to hibernation in the following order: adult females emerge in early April and return in early September, young of the year of both sexes are next, and adult males are last to emerge in spring and last to return in fall (Tuttle 1976b). Colonies in caves can be quite large; Tuttle (1976b) estimated population sizes in caves in Alabama, Tennessee (TN), and Virginia to be 5,000–1,500,000 gray bats. During the winter of 2018–2019, biologists estimated the total wintering population of gray bats in four TN caves to be 1,513,991 bats; 250,689 bats were counted in RC, which is near the NC border and the confluence of the French Broad and Pigeon Rivers (TWRA 2019). Clusters of gray bats in summer caves contained an average 1,828 bats/m^2 (range of 999–2,575 bats/m^2; Tuttle, 1976b). Elder & Gunier (1981) concluded that gray bat survival rate for the nine years they sampled at Marvel Cave in Missouri was 69.5% per year for males and 73.1% for females.

Until recently, gray bats were thought to be uncommon in western NC. However, 2016–2017 survey work by the NC Wildlife Resources Commission (NCWRC) and others has shown that large gray bat colonies are using manmade structures in the French Broad River Basin in Buncombe and Madison counties, NC, including bridges and a culvert. Prior to the initiation of our study in 2018, gray bats were known from capture, roost, and historical records scattered around the French Broad River Basin (Figure 1). The presence of gray bats in structures constructed and maintained by the North Carolina Department of Transportation (NCDOT) and the foraging and roosting habits of the bat has the potential to affect multiple large scale projects and a range of smaller projects and maintenance activities in NCDOT Divisions 13 and 14.

To address NCDOT research needs, we conducted a three-year (2018–2020) study with five major objectives (see below). The work began in March 2018 and we present some data collected through July 2020. This was an expansive effort that involved intensive field work by a crew of personnel dedicated to this project, partners from NCDOT, UNC-Asheville, NCWRC, NPS, USFWS, NV5 Engineers and Consultants, Inc. (formerly CALYX Engineers and Consultants, Inc.), and volunteers. Herein we report data on the distribution, roosting and foraging ecology, migratory behavior, and winter ecology of gray bats in the French Broad River Basin of western NC.

Results of Literature Review

Our review of the primary and secondary literature revealed that there is ample support for some of the general knowledge about gray bats—natural caves typically serve as winter and maternity roost sites, water is the preferred foraging habitat, and gray bats can range over long distances during nightly foraging bouts. However, we discovered a surprising dearth of information on gray bats' use of anthropogenic structures and little knowledge of the species' distribution in the Appalachian Mountains. Relevant to our work, Powers et al. (2016) reported on gray bat colonies in southwestern Virginia, where a culvert in Bristol, TN-VA houses up to 9,000 gray bats and a bridge on the Clinch River holds ~1,500 gray bats. Papers we reviewed are summarized in Appendix A.

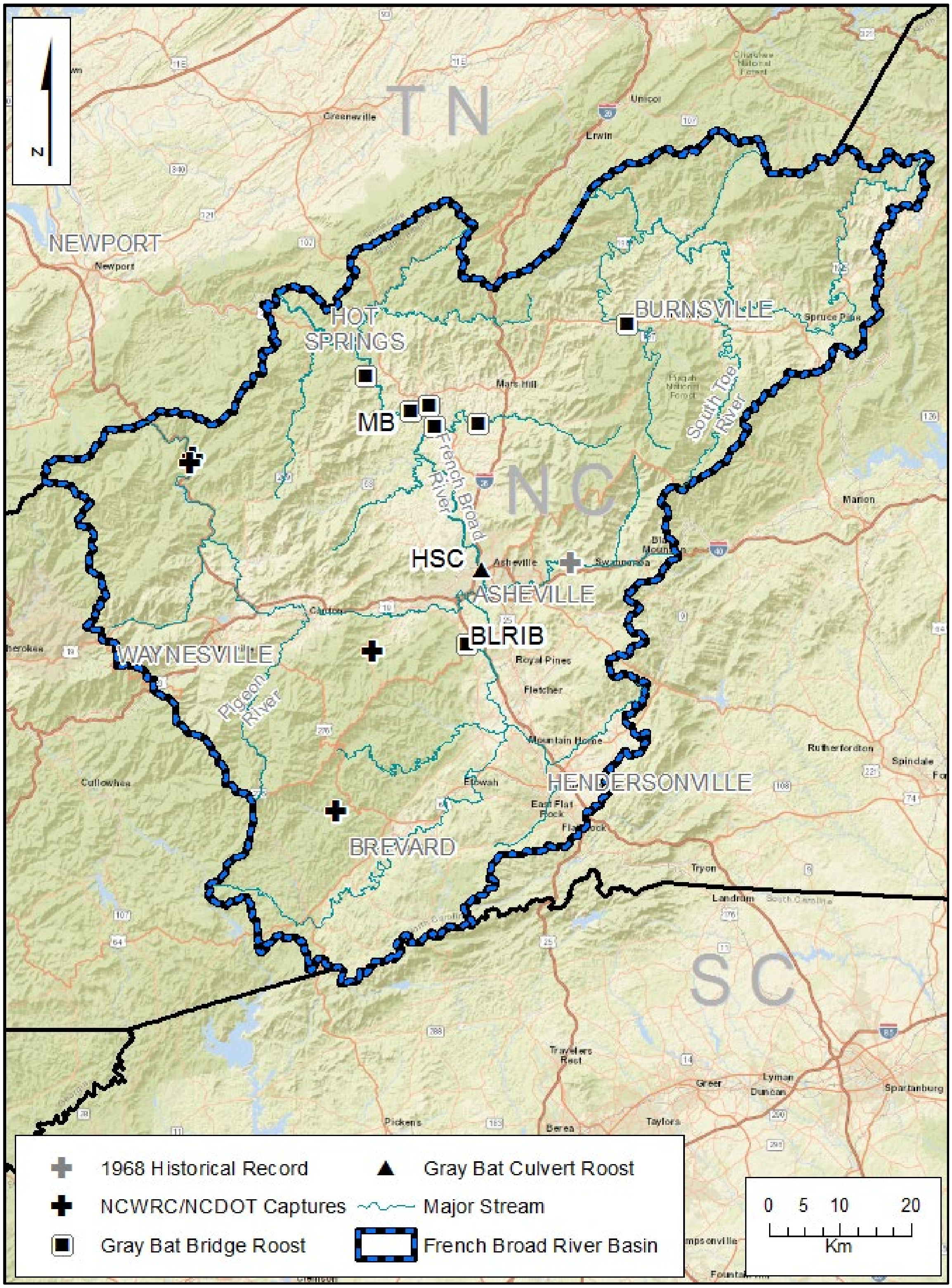


Figure 1. Known French Broad River Basin gray bat roosts, capture sites, and a 1968 historical record. Two gray bat rabies submissions from Buncombe County in the years 2000 and 2001 are not on the map (we have no specific location). Major roosts are labeled (BLRIB, HSC, MB).

Objectives

Our first objective was to review existing literature on gray bats, including peer-reviewed journal articles and whitepapers on their distribution, roosting and foraging habitat requirements, migration patterns, and use of anthropogenic structures. These papers are summarized in reverse chronological order in Appendix A and the articles are presented as a data folder.

Our second objective was to describe the distribution of gray bats in the NC portion of the French Broad River Basin. To achieve this objective, we used a combination of radio telemetry, bridge and culvert surveys, acoustic monitoring, and winter survey. We coordinated with biologists in NC and TN to learn of the whereabouts of gray bats during winter.

Our third objective was to learn the relative importance of roost sites used by gray bats, to describe roost sites, and to locate additional roosts beyond those known when the study began. We conducted habitat assessments at used and unused bridges and modeled these data to understand factors important to bats or gray bats using bridges. These assessment data can be merged with existing NCDOT data from 1996–2017. We present a manual for assessing bridges for bat use in Appendix B. By regular exit counts and spotlight checks of important roosts, we were able to characterize the relative importance of roosts over time. We also assessed temperatures of bats at roost as a surrogate method for measuring the temperatures in inaccessible crevices in bridge roosts. We used datalogging temperature sensors to assess temperatures in culverts, as gray bats were known to use culverts during this study.

Our fourth objective was to identify important foraging areas and routes for gray bats, using a combination of passive and active radio telemetry. With 16 fixed telemetry towers, we recorded the movements of bats along the major waterways in the French Broad River Basin. With ground and aerial telemetry, we identified some areas where bats foraged.

Our final objective was to identify the migratory pathways used by gray bats in western NC. To do this, we relied on data from fixed telemetry towers and ground or aerial telemetry.

Methods

Captures

From April to October 2018 and 2019 we used mist nets and a harp trap to capture bats at four known roosts (three bridges and one culvert) and at four additional net sites (three rivers and one pond; Appendix C, Table C1). The BLRIB, MB, and HSC were known to be important roost locations prior to this study (Figure 1). We determined that the CB was a roost in fall 2018 and, thus, devoted more nights to surveying this structure in 2019. On one occasion, we attempted to capture bats at a bridge just south of CB because the water was less turbulent under this bridge than at the CB structure. We netted the Davidson River and Sandy Bottom sites in conjunction with NCWRC, anticipating correctly that we might capture gray bats at both sites. We decided to survey the Swannanoa River site near Warren Wilson College because we often recorded gray bat calls on the acoustic detector station there in 2018 and 2019.

After removing bats from the net, we placed them into cloth holding bags prior to processing; we released free-tailed bats near the net, however. For each gray bat, we recorded sex, age, mass, forearm length, and white-nose syndrome wing damage score as per Reichard and Kunz (2009) (Figure 2; Appendix C, Table C2). We banded >97% of gray bats we handled and usually did not band other species. Both female and male bats that weighed ≥ 8.5 g and that appeared to be in good health were radio-tagged with standard beeper transmitters (PicoPip Ag317; Lotek Wireless, Inc., Newmarket, Ontario or LB-2X; Holohil Systems Ltd., Carp, Ontario; henceforth, beeper tags), digitally encoded radio transmitters (NTQB-2; Lotek Wireless, Inc.; henceforth, coded tags), or temperature-sensitive beeper transmitters (LB-2XT; Holohil Systems Ltd.). Transmitters weighed 0.30–0.44 g (≤ 4.9% of body weight). We attached radio tags to 189 bats (131 females and 58 males; 94 coded tags, 64 standard beeper tags, and 31 temperature-sensitive beeper tags). Coded tags worked with our datalogging telemetry towers, whereas both types of beeper tags facilitated active tracking by vehicle or airplane. We collected guano from 186 gray bats to facilitate a diet analysis, which is on hold until we gain access to a faster computer processor. We released all bats at the capture site. When handling bats or entering known roost sites, we followed the guidelines of the American Society of Mammalogists for the use of wild mammals in research (Sikes et al. 2016; ISU IACUC protocol 1203485-2), and national white-nose syndrome decontamination protocols (USFWS 2016) to reduce the potential for transmitting or spreading white nose syndrome. Fieldwork was conducted under permits held by J. O'Keefe: USFWS federal recovery permit TE206872, NC permits 18-SC00266 and 18- ES00261, TN permit 1480, and National Park Service Permit BLRI-2018-SCI-0018.

We removed bats from our sample if no data were recorded for the bat other than species (e.g., if the bat escaped from the net or the hand before being worked up); this led us to drop three individuals that were counted in the 2018 total in our February 2019 report. We calculated the relative proportions of adult male, adult female, and juvenile gray bats using data for first time captures. We discuss recaptures for bats banded during this study or for bats banded by NCWRC prior to 2018.

Figure 2. A gray bat in the hand after capture (left); inspecting a gray bat's wing for damage (center); applying a radio transmitter (right).

Roosts

We used homing telemetry to track bats to roosts during the day. However, due to the large area gray bats used, we mainly used active radio telemetry to confirm radio-tagged bats' use of structures already known to us when the project began or discovered via radio telemetry and opportunistic searches during this project. We used radio telemetry receivers (R410 model, Advanced Telemetry Systems, Isanti, Minnesota; and SRX800, Lotek Wireless, Inc.) and 3- or 5-element Yagi antennae to track bats to daytime roosts. We searched for each bat for the expected transmitter battery life, as feasible (45 days for Lotek coded tags, 35 days for Lotek beeper tags, or 21 days for Holohil beeper tags). Upon finding a roost, we circled the roost to confirm the bats presence, then we listened to transmitter signals from different angles to confirm the crevice in which the bat was roosting. For buildings and one culvert, we entered the roost once to confirm the radio-tagged bat's location. When feasible, we conducted ≥ 1 emergence count or visual survey on roosts that might have held > 1 bat. In 2019, we used datalogging receivers (SRX-DL1, Lotek Wireless, Inc.) and a 3-element or 5-element Yagi antennae at bridge roosts to record data from temperature-sensitive transmitters. We set the dataloggers to record pulses at 30 ± 6 beats per minute (bpm). We also visited and set datalogging receivers at two cave roosts in TN known as gray bat maternity roosts prior to this study: RC near Newport and CCC near Houston Valley.

We checked known roosts as often as possible to assess the presence of gray bats and population sizes. We divided roosts into "primary" and "secondary" based on the numbers of gray bats observed and frequency of use. The distinction between primary and secondary roosts could be different for gray bats than for tree-dwelling bats. One reason for the difference is the tendency for cave-dwelling bats to roost in extremely large colonies and for bats in general to show strong fidelity to more permanent structures (Lewis 1995). It is important to consider that the two TN caves mentioned above are likely the most important and traditional primary roosts for the population of gray bats that we studied. As we describe in the Results (see *Estimates of the roosting population*), gray bats moved from NC back to those two TN caves during the summer season. When we describe roosts as primary or secondary in this report, we are describing the relative importance of the roosts we found in NC to each other, not to the TN caves. Important roosts in NC may have fewer bats than caves in TN due to limitations on space. Aside from population size, other roosting behaviors that describe roost importance include repeated use by individuals or the population (i.e., roost fidelity) and connectivity to other roosts in the area (i.e., is the roost a "hub" that many bats pass through). We surveyed perceived primary roosts more intensively than perceived secondary roosts; with greater scrutiny, we might find that some secondary roosts were more important to the colony. Further, we note that for a few roosts it was difficult to count the number of gray bats and to discern the numbers of different species in multi-species roosts.

We knew of three major roosts, suspected to be "primary" when the study began (Figure 1) and located another during this study (see *Results* section, *Roosts: Types of roosts*). We conducted simultaneous, coordinated exit counts at known roosts on seven occasions (four times in 2018, three in 2019). When feasible, on the same day and prior to the coordinated exit counts (in the daytime) we counted the number of bats at other secondary roosts with spotlights. We also conducted additional exit counts and spotlight checks on primary roosts, secondary roosts, and suspected roosts (e.g., bridges with visual and auditory evidence of bats present). For example, we returned to several potential roosts to do exit counts after structure checks indicated bats were present. We often recorded bat calls with Anabat SD2 bat detectors (Titley Scientific, Inc., USA) during these exit counts and visually examined recorded files to look for probable gray bat calls.

When river levels were low enough, we used a 1,000-lumen spotlight and binoculars to count bats in MB, giving us a good estimate of the population size. Sometimes river levels were too high to spotlight all crevices in the bridge (or any other roost for that matter) and these counts were considered underestimates. To count bats at MB, we counted and estimated the number of bats in various crevices and added those counts at the end without rounding any numbers.

Measuring skin temperatures of bats at roost

For the bats carrying temperature-sensitive radio transmitters, we vetted records from the Lotek datalogger to verify bat presence/absence at roosts and to discern skin temperatures. The datalogger recorded the rate of pulses from each bat's transmitter (bpm) and the strength of the signal (a unitless measurement ranging from 0 to 255) as perceived by the receiver and dependent upon the receiver's gain setting; gain settings varied depending upon our ability to detect bats at the structure. We used signal strength as a measure of pulse quality when vetting the data (see below). Pulse rate provides a measure of the temperature of the skin at the point where the radio transmitter is attached to the bat; this skin temperature is often used as a proxy for body temperature, but we also inferred within-roost temperature from these data. We used this method to assess the temperatures in otherwise inaccessible crevices in the large bridges that served as primary roosts for the gray bat population.

Gray bats are heterothermic endotherms, meaning that while they exert control over their body temperatures they also use short (e.g., a few hours) or extended (e.g., a few days) bouts of torpor in which they drop their body temperature to save energy. During the summer, a typical thermoregulatory pattern for a bat at roost is that body temperature is highest right before evening emergence. When the bat returns to its roost during the night or at dawn, the roost is at its coldest and the bat allows its body temperature to drop to be closer to the roost temperature (i.e., thermoconforms), thereby invoking torpor. As the roost gradually warms throughout the day, a bat will also warm, eventually arousing from torpor closer to the time of evening emergence. If the bat has chosen a roost that is cooler due to shade or small size, the bat may stay torpid for almost the entire day and use metabolic energy to arouse. Alternately, a bat in a warm, solar-exposed roost may achieve a higher body temperature earlier in the day by passive transfer of heat from the roost to its body and may not need to use metabolic reserves to achieve an active body temperature. Reproductively active female bats (i.e., pregnant or lactating) tend to selectively roost in warm, solar-exposed roosts because this allows them to stay warm enough to facilitate fetal growth and milk production while consuming less of their own metabolic energy.

One challenge with using radio-transmitters to quantify temperature is false-positive detections, which occurred commonly over the sampling period. The first step in analysis is minimizing false positive readings, which can be identified by variable and inconsistent intervals of time between readings, bpm rates that are randomly spread between 23–37 bpm (the range detected by the datalogger), and power readings that are lower than true hits. To eliminate false positive readings, we deleted all recordings where power was <50. After applying this power threshold, we considered a recording as coming from a radio-tagged bat when at least four consecutive hits varying by <1 bpm were recorded within a 10 second interval. Once this pattern was identified, data coming from that transmitter were considered as true results until there was evidence for a loss of the signal (e.g., increased variability of readings, prolonged spacing between readings, or significant reduction of signal power). See Appendix E, Figure E1 for visual of vetting process.

Table 1 summarizes the results of this vetting process and provides descriptive information on the reproductive condition of the bats that were analyzed. From the 385,920 hits that were originally recorded, we distilled 318,475 observations from 19 individuals for inclusion in the final analysis. Ultimately, each of the three primary bridge roosts (BLRIB, CB, MB) had readings from 2–4 individuals.

To simplify the data and minimize noise that survived the initial vetting process, data were averaged over one-hour intervals, and the average values for each hour were used in subsequent analysis. Data were converted to temperatures (°C) by using specific calibration curves provided by the manufacturer of the transmitters (Holohil Systems, Inc.).

For analysis, the data collected from each bridge were grouped into three seasons: spring (April-May), summer (July-August), and fall (September-October). Specific dates on which data were recorded in each season can be seen in Table 1. Additionally, for some analyses, the data were also broken into four categories (‘morning’ = 6:00–8:00; ‘noon’ = 11:00–13:00; ‘afternoon’ = 15:00–17:00’; ‘evening’ = 17:00–19:00). For bats where consistent and reliable signals were obtained, we noted the time of departure from a roost in the evening and time of return. We used non-parametric tests to compare means. We note that there is a great deal of pseudoreplication in the data, with the same individuals being sampled multiple times on consecutive days. Results from these analyses should be understood as trends representing a small number of samples, not strongly supported by large sample sizes.

Ambient temperature readings and weather conditions were obtained from climatological records recorded by the weather station at the Asheville Airport (AVL; www.timeanddate.com), which is the closest weather station to the three bridges from which data could be obtained. Local conditions at each of the bridges certainly varied somewhat from the AVL records, so these numbers are used only as an approximation of the local conditions.

Table 1. Individual gray bats that were included in this 2019 study following the vetting process. A * indicates a gray bat that was detected at multiple bridges. N is the number of true readings (i.e., not false positives) from each transmitter that were detected over the time period indicated.

Period	Bridge	Frequency	Sex	Condition[1]	Dates	N
Spring						
	CB	151.261*	M	NR	19–20 May	754
	CB	151.299	F	NR	19–28 Apr	6263
	CB	151.342	M	NR	23 Apr–13 May	59675
	CB	151.380	F	NR	27 Apr–4 May	20708
	BLRIB	151.261*			8–14 May	19458
	BLRIB	151.940	M	S	8–13 May	18724
Summer						
	CB	151.701	F	PL	29–30 July	19
	CB	151.819	F	PL	28–30 July	906
	CB	151.782	F	PL	29–30 July	36
	BLRIB	151.581	F	NR	17–31 July	22416
	BLRIB	151.617*	F	NR	17–18 July	6729
	BLRIB	151.659	F	PL	24 July–2 Aug	1739
	MB	151.617*			25–27 July	9585
	MB	151.862	F	PL	30 July–5 Aug	13669
	MB	151.900	F	PL	15–17 Aug	18048
Fall						
	CB	151.139	F	NR	24–30 Sept	53
	CB	151.060	F	NR	24–30 Sept	100
	CB	151.179	F	PL	23–26 Sept	83
	BLRIB	151.219	M	NR	28 Sept–7 Oct	50725
	BLRIB	151.458	M	S	27–29 Sept	13585
	BLRIB	151.540	M	NR	27 Sept–3 Oct	55200

[1] NR = non-reproductive, PL = post-lactating, S = scrotal

Structures

We conducted checks at 250 bridges in the French Broad River Basin (Figure 3). We randomly selected the 250 bridges (101 in 2018 and 149 in 2019) from 457 bridges located within 400 m of major streams in the French Broad River Basin (NCDOT shapefile 'NCDOTStructureLocations'). At each bridge we performed a thorough survey for bats and evidence of use by bats (see Appendix B), and then recorded information on the bridge characteristics. We recorded data according to NCDOT's standard operating procedures for bat habitat assessments (NDCOT 2014), with some modifications (see Appendix F, Figure F1 for our datasheet). We also recorded these same measurements at every bridge roost at which we detected gray bats. We also opportunistically surveyed and recorded presence/absence data for 23 bridges but did not record descriptive information for the structure unless we found gray bats using the bridge.

Noting that gray bats used the HSC during this study and that gray bats have used culverts in other areas (e.g., Powers et al. 2016), we conducted a brief survey of potentially suitable culverts in the French Broad River Basin. In total, we surveyed 31 culverts for the presence of bats, including HSC and the A Avenue Culvert in Asheville to which we radio-tracked a bat in 2019 (Appendix F, Table F1). We used a newly created datasheet (see Appendix F, Figure F2) to record measurements on culverts.

Spatial/GIS Data

We used ArcGIS 10.5 and 10.8 (ESRI, Redlands, CA, USA) along with environmental layers to create detailed maps of the study area, roosts, and bat foraging data. We used the ArcGIS "Near" analysis tool to measure the distance between focal points (e.g., surveyed bridges, known roosts, foraging points, acoustic stations, known TN gray bat caves) and the nearest waterway, roadway (primary and secondary), and transportation improvement project (TIP).

We received locations of gray bat caves in TN as X, Y coordinates from the Tennessee Cave Survey, a volunteer-led organization that maintains records on caves in TN (http://www.subworks.com/tcs/). We obtained waterway vector data from the NC Department of Environment and Natural Resources Division of Water Quality, dated 11 November 2012 (http://portal.ncdenr.org/web/wq). These vector data include surface water classifications for streams, rivers, and lakes. For roadways in NC, we used vector data from NCDOT on state-maintained roads (Interstate, US Highway, NC Highway, Secondary Routes, and Ramps), current through March 2020. We classified roadways of Route Class 1–3, 80, and 81 as primary roads and roadways of Route Class 4–7 and 9 as secondary roads. For TIPs, we used September 2019 NCDOT State TIP data given to us by Melissa Miller (NCDOT) on 14 April 2020. The data consisted of point and line features in a GIS geodatabase (2020_2029_STIP_September2019.gdb). We were also given the TIP subnumbers 14SP.20881.1 (TRAN 45) and 17BP.14.R.183 (TRAN 63), two bridge replacement projects in NCDOT Division 14, Transylvania County. We address these bridge replacement projects separately. For roadways in TN (only used to calculate foraging distances for bats with locations in TN), we used vector data from the 2020 USGS National Transportation Dataset (NTD) for Tennessee 20200518 State or Territory Shapefile (https://www.sciencebase.gov/catalog/item/5a61c93de4b06e28e9c3bdbb) and the U.S. Census Bureau (2015; https://www2.census.gov/geo/tiger/TIGER2015/PRISECROADS/). In TN, we classified roadways with MAF/TIGER Feature Class Codes (MTFCC_CODE) of S1100 and S1200 as primary roads and any other codes as secondary roads. Where we report distance to roads, TIPs, or other features, we note that there will be less accuracy (or more fuzziness) in GIS measurements due to the fact that structures like culverts and bridges are represented as point features even though the structures may cover distances of tens or hundreds of meters.

We obtained 2016 land cover raster data from the National Land Cover Database (NLCD; https://www.mrlc.gov/data?f%5B0%5D=category%3Aland%20cover). The NLCD raster contained land cover data at a 30-m resolution, with 21 land cover classes. We grouped the 21 land cover classes into four land cover categories recognized by NCDOT (Urban, Suburban, Natural, and Agricultural) using the Reclassify tool in ArcMap. Urban included developed areas from low to high intensity of development, while the Suburban category included developed, open spaces. We placed the pasture/hay and cultivated crops land cover classes into the Agricultural category. We included all remaining land cover classes in the Natural category.

To determine the percent of each land cover category within a 1-mile (1.6-km) buffer of surveyed bridge locations, we used the *sp* (*v1.3-2*; Pebesma and Bivand 2005), *rgdal* (*v1.4-8*; Bivand et al. 2019), *raster* (*v3.1-5*; Hijmans 2020), and *maptools* (*v0.9-8*; Bivand and Lewin-Koh 2019) packages in R statistical software (R Statistical Environment, Vienna, Australia). First, we imported the NLCD land cover raster and 1-mile bridge buffer shapefile into R and used the *extract* function to extract raster values from the buffer zones. Next, we tabulated the values for each buffer zone polygon with the *sapply* function, which provided the output in a matrix table. Lastly, we saved the tabulated values as a .csv file and calculated the percent of each land cover category within individual buffer zones. We repeated this method to determine the percent of each land cover category within a 500-meter buffer of acoustic stations and telemetry towers (Appendix I, Tables I1 and I2).

Model assessing selection for bridge characteristics

We used multiple logistic regression to assess the effects of landscape and bridge characteristics on differentiating bridges used by any bat (if we detected ≥1 live or dead bats at the bridge; we did not count bridges as used if we only saw guano) and bridges that were not used by bats. While we recorded data on many facets of the bridges, not all data were used in the modeling process; we dropped variables that were potentially unreliable due to different interpretations of how to measure those bridge features (e.g., presence of horizontal or shelf-like crevices in the underside of the deck near the end wall, or degree of disturbance under the bridge). Due to the high degree of correlation between certain variable pairs (Spearman's $r > 0.75$), we did not use percent area of natural, bridge height, or guardrail type in the model. For the same reason, percent area of urban was merged with percent area of suburban into a single variable (percent area of urban/suburban). We recoded deck gap size, parallel gap size, and perpendicular gap size values as available (gap size > 1 cm) or not available (gap size ≤ 1 cm). Guardrail gaps often host smaller bats, so guardrail gap size was recoded as available (gap size > 0 cm) or not available (no gap).The model included the following predictors: distance to nearest primary road (m), distance to nearest secondary road (m), distance to nearest waterway (m), distance to nearest major waterway (m), the percent area of each of landscape types (urban/suburban, agricultural) within one mile, bridge length (m), bridge width (m), guardrail gap size (available or not), deck type (concrete or not), deck gap size (available or not), bridge azimuth (North/South or East/West), under type (concrete or not), beam type (concrete or not), parallel gap size (available or not), and perpendicular gap size (available or not). Additionally, we attempted to use logistic regression to assess the effects of landscape and bridge characteristics on differentiating bridges that were used by gray bats and bridges used by other bat species. This model performed poorly, with overinflated parameter estimates and standard errors, and no significant effects. We attribute this poor performance to our small sample size (23 gray bat bridges and 15 bridges used only by other bats). In addition, the fact that some of the bridges used by gray bats were also used by other species would make it difficult to tease out the bridge-related factors important only to gray bats. We present means and standard errors for variables used in the model described above, and separate means for bridges used by gray bats versus other bats.

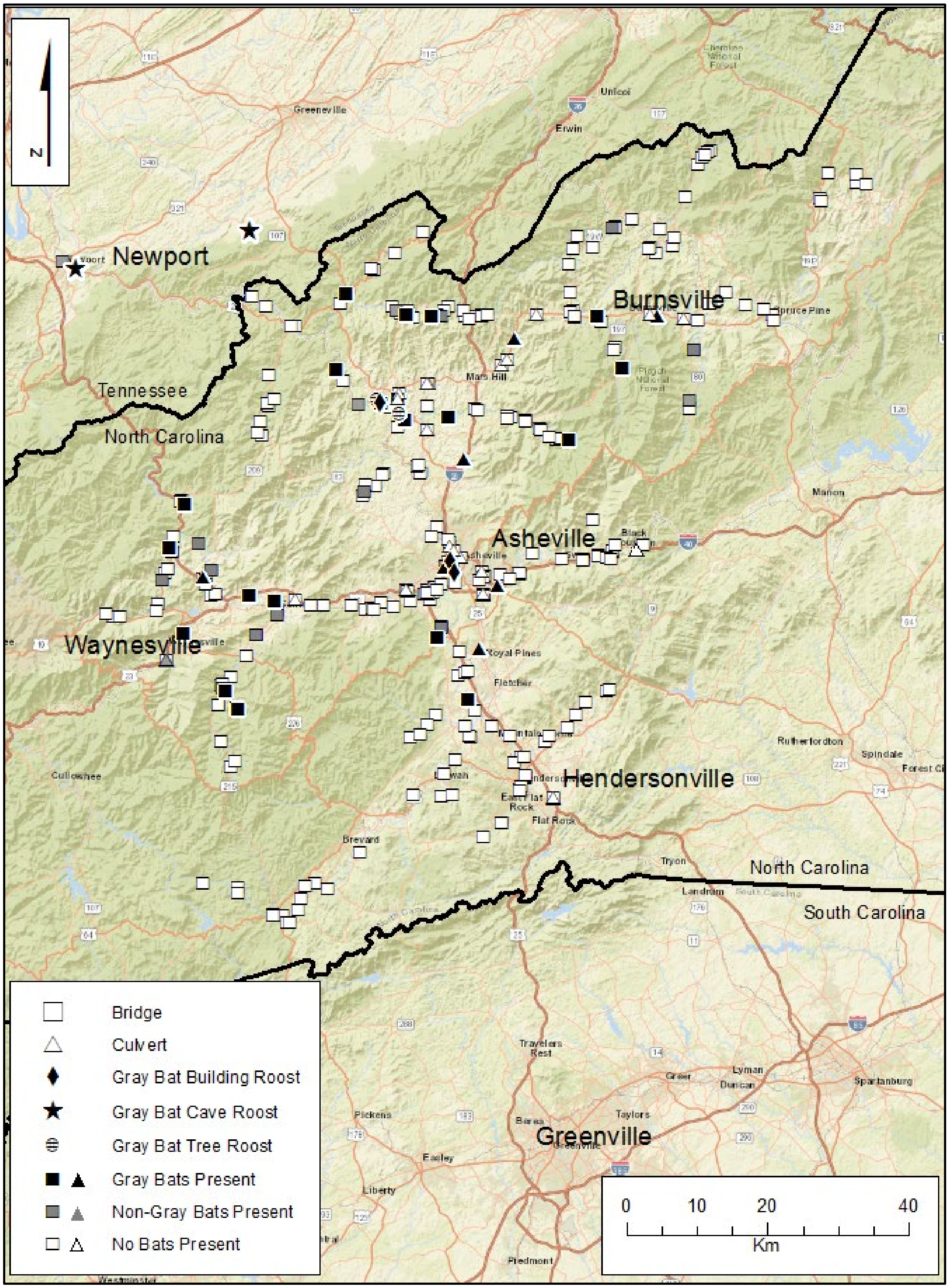


Figure 3: Structures where we searched for or detected gray bats in the French Broad River Basin, North Carolina and Tennessee, March 2018–April 2020.

Foraging

Ground-based nighttime telemetry

In 2018 and 2019 we collected foraging data for 16 bats (10 female, 6 male) captured at the CB, BLRIB, MB, HSC, and at the Sandy Bottom capture site near the BLRIB. For ground-based foraging telemetry and aerial foraging telemetry (below) standard beeper or temperature-sensitive beeper tags (see Captures Methods, page 15) work best due to quick (2-second) signal pulses and unique frequencies for each bat, however, we also listened for coded tags at night. To identify foraging areas, we followed 1–3 bats per night, as feasible. From immediately after emergence time (around 20:00 EDT) until as late as 02:06, we recorded a series of simultaneous multi-azimuth (2–5) triangulations/biangulations at 5–6-minute intervals to obtain location estimates for foraging bats. We stationed personnel at various points on the landscape around a focal bat's foraging area (Figure 4), with each person recording an azimuth or bearing for the focal bat at set time intervals. Azimuths were recorded on a 5-minute cycle when a single bat was being tracked or a 3-minute cycle when multiple bats were being tracked; thus, when tracking two bats, personnel recorded azimuths for each bat every six minutes. We converted foraging telemetry triangulations/biangulations to point location estimates using the program Locate III, Version 3.34 (Nams 2006). When estimating point locations, we excluded biangulations that differed by < 15 degrees, and triangulations or biangulations with lines that did not cross. Ground-based telemetry error for location estimates should be similar to error measured in a previous study on foraging bats (148.3 ± 24.6 m) in western NC (Weber et al. 2016). However, gray bats move faster during flight, so the error may be greater in the present study.

We recorded areas where we tracked foraging bats at night even if we were not able to obtain triangulations/biangulations. Much of our nighttime foraging telemetry effort consisted of driving along waterways and adjacent areas searching for radio-signals from foraging bats. Once a foraging bat was located, in many cases we had a difficult time maintaining a signal on the bat due to the extensive amount of area the bats would cover, speed at which the bats moved, lack of access to private property, the lack of roads near major waterways north of Asheville, and the limited distance a radio-tag transmitted a signal.

Figure 4. Temporary listening station for nighttime, ground-based foraging telemetry near a highway crossing of the French Broad River south of Asheville, NC.

Aerial nighttime telemetry

We contracted Copperhead Consulting to conduct aerial searches for bats in 2018 and 2019. Using fixed wing aircraft with two strut-mounted, 4-element, directional Yagi, the pilot and another biologist circled or crossed over flying bats and marked approximate locations via GPS and mapping software (DeLorme Topo North America 9.0, Yarmouth, ME). Aerial telemetry allowed for multiple bats to be located each night over long distances. Locations for each bat were collected ≥ 1 minute apart. Copperhead Consulting flew the nights of 12–19 October in 2018, and 27–30 April, 14–16 August, 24–25 September, and 1–3 October in 2019. They collected foraging data for 33 bats (24 females, 8 males, 1 unknown) captured at the CB, BLRIB, MB, HSC, and another capture site near CB. We present, without correction or modification, Copperhead Consulting's aerially collected foraging locations in Appendix G and H. In some cases, we collected foraging locations for the same individual bat using both aerial and ground-based foraging telemetry.

Fixed tower nighttime telemetry

We positioned 16 fixed telemetry towers at regular intervals along 4 radii extending from a centerpoint in Asheville, which was the midpoint between the confluences of Hominy Creek and Swannanoa Rivers with the French Broad River (Figure 5; Appendix I, Table I2). Towers E1, S1, W1, and N1 were 2.8–3.9 km from the center; E2, S2, W2, and N2 were 8.9–10.7 km from center; E3, S3, W3, and N3 were 18–20 km from the center; and E4, S4, W4, and N4 were 26.8–28.9 km from the center. Tower sites were along the French Broad River, Pigeon River, Hominy Creek, Swannanoa River, and at Lake Julian. Each fixed telemetry tower consisted of a SRX-DL1 or SRX800-D datalogging telemetry receiver (Lotek Wireless, Inc.) powered by a 12V battery, two 9-element Yagi antennae, and one antenna mast (approximately 5–6 m elevation for antennae). One antenna pointed upstream and the other downstream (Figure 6).

We began recording with fixed telemetry towers starting April 2018, and 15 of 16 stations were operational by July 2018. One telemetry tower (W4 on the Pigeon River) erected in 2018 was not recording correctly due to technical issues; thus, we are unable to tell if any radio-tagged bats flew near the tower in 2018. The W4 tower was operating properly the entire 2019 field season. In 2018, we maintained all telemetry towers through 6 November and kept the four towers north of Asheville (along the French Broad River) active through 15 November. In 2019, we maintained all telemetry towers from 14 April to 8 December. We checked or changed batteries regularly, but at times the towers were not operational because of discharged batteries, other technical issues, or flooding. Due to numerous flood events in 2018 and 2019, we were forced to periodically pull equipment from the field to prevent damage from flooding.

The dataloggers were able to simultaneously monitor ≤ 15 coded tags with the same frequency and digitally encoded unique IDs. We used test transmitters, not attached to a bat, to define legitimate detections (i.e., detections from the presence of a radio-tagged bat vs. false positives) and establish data vetting criteria. Coded tags transmitted a signal every 5 seconds. We considered signals to be detections if they were at 5-second intervals and there were ≥ 3 detections within one minute of each other; thus, if there were only two signals at a 5-second interval within one minute of each other, we did not consider this a detection. Based on a previous study using these types of telemetry towers in western NC (Weber et al. 2016), we expect that the towers in this study recorded radio-tagged bats at distances ≤ 3.1 km away.

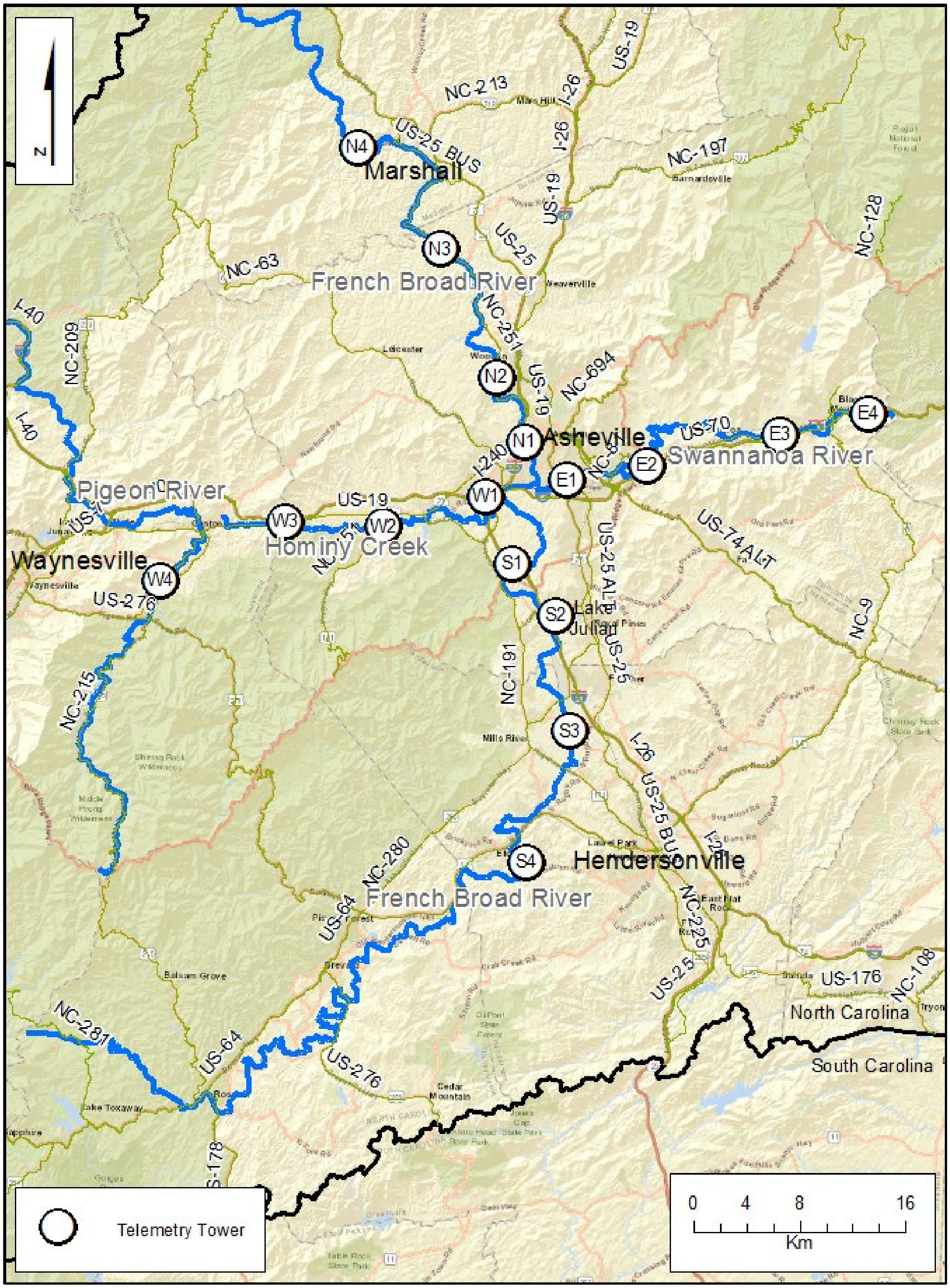


Figure 5. Locations of 16 radio-telemetry towers used to detect foraging gray bats between April and October 2018 and 2019. The towers were positioned along the French Broad River, Hominy Creek, Swannanoa River, Pigeon River, and Lake Julian.

Figure 6. Fixed telemetry tower (N1) alongside the French Broad River in Asheville, North Carolina. One 9-element antenna points downstream and one points upstream. The antennae are connected to a datalogging receiver stored in a watertight case and powered by rechargeable batteries, sometimes in conjunction with a solar panel.

Migration

Dataloggers deployed at or near hibernation sites

In addition to the 16 fixed telemetry towers centered on Asheville, we deployed one additional beeper datalogger at the N4 tower to record beeper transmitters from 31 October–19 November 2018; however, we did not record any valid bat detections on this receiver. We also deployed dataloggers at the entrance to RC (a known gray bat hibernaculum) near Newport, TN; RC is ~0.4 km from the Pigeon River and < 3 km from the French Broad River. We deployed 1–3 beeper dataloggers and one coded datalogger at this cave from 3 October–19 November 2018 and we deployed 1–2 beeper dataloggers from 23 September–26 October 2019. Beeper tags transmitted a signal approximately every 2 seconds. As with coded transmitters, we used test beeper transmitters, not attached to a bat, to identify legitimate detections (i.e., detections from the presence of a radio-tagged bat vs. false positives) at expected intervals. For beeper transmitters, when analyzing data from the datalogging receivers, we considered signals to be detections if they were at 2-second intervals and there were four consecutive detections within eight seconds; if there were ≤ 3 consecutive signals at a 2-second interval, we did not consider this a detection. We discarded records if the signals varied by >1 bpm. We positioned dataloggers at Pearson Cave (three hours north of Asheville) and at the confluence of the French Broad River and the Pigeon River in TN from early to late October 2018 but did not have any detections.

Winter Surveys

We inquired with NCWRC, Tennessee Wildlife Resources Agency (TWRA), and University of Tennessee Knoxville (UTK) about winter occurrences of gray bats from western North Carolina. In 2003, a NCDOT contractor (BHE Environmental, Inc.) banded one gray bat on S. Hominy Creek in Buncombe County. From 2005–2018, NCWRC has banded 39 of 41 gray bats captured at foraging sites on the Pigeon River in Haywood County; from 2014–2019, NCWRC also banded gray bats at the Davidson River in Transylvania County (5 bats) and at four sites in Buncombe County: BLRIB (24 bats), Cold Knob/FS 479H (2 bats), HSC (1 bat), and Sandy Bottoms (1 bat). NCWRC had banded 40 gray bats in NC prior to the beginning of our study in March 2018. However, prior to March 2018, during surveys of winter hibernacula in TN, Tennessee Wildlife Resources Agency (TWRA) had not detected any of the gray bats banded in NC. We joined NCWRC for four hibernacula/potential hibernacula surveys in January–March 2019 and 2020.

Temperatures in culverts

Gray bats were known to use HSC prior to the start of this study and, thus, we searched and studied this and other culverts during this study (Figure 3). We entered HSC on 14 December 2018 and 22 March 2019 to search for bats and for placement of datalogging and telemetry equipment. We entered HSC three times in Winter 2019–2020 (16 December 2019, 1 March 2020, and 23 March 2020). From 22 March 2019 through 23 March 2020 we recorded the internal temperature at HSC using a HOBO temperature datalogger (HOBO Pro Series RH Temperature Data Logger; Onset Computer Corporation, Bourne, Massachusetts). We mounted the HOBO datalogger onto the concrete wall close to the ceiling near where we saw gray bats roosting and set the datalogger to record temperature every 30 minutes, 24 hours per day. We present daily minimum, maximum, and mean temperature in the Results section and note when bats were observed inside the culvert. We compared datalogger recorded values to temperature data collected outside at a nearby NOAA weather station (USW00013872; 35.5954°, -82.5568°).

Noting that there are no known hibernacula for gray bats in western NC, we wanted to investigate the potential suitability of culverts as hibernacula. Therefore, we conducted a brief study of culvert microclimate in winter. From 19 December 2019 through 9 March 2020, we recorded internal temperatures at 12 culverts (including HSC; Table 2) within the French Broad River Basin using iButton temperature loggers (iButton model DS1921G-F5 Temperature Logger, 0.5˚C increments at ± 1.0 ˚C accuracy, range −40 to 85˚C). We used aerial photographs and a '20190910CulvertData' file from NCDOT to select 14 box culverts in the French Broad River Basin to survey for hibernating bats and record temperatures (see below); we only surveyed culverts >100 m long because longer culverts should be better able to buffer cold outside air temperatures and thus are more likely to be suitable as hibernacula. We searched for bats in all 14 culverts; two of the culverts were too prone to flooding to leave iButtons inside. For temperature measurements, we surveyed the single portal that carried most of the culvert's water flow. We mounted the iButtons to 6.4-mm thick wood blocks glued to the concrete wall close to the ceiling, where gray bats commonly roost inside culverts (Figure 7). Each culvert had 3–14 iButtons positioned ≤ 5 m from each of two main entrances and spread ~50m apart throughout the full length of the culvert (and in a few junction boxes in offshoots from the main culvert at the HSC and culvert NCDOT #100469). The iButtons were set to record temperature every 60 minutes, 24 hours per day. As noted earlier, we recorded culvert characteristics (Table 2) on a simple datasheet (Appendix F). Culvert length, width, and number of vents can affect airflow through the culvert and, hence, temperature stability and the deviation in culvert temperature when compared to outside air temperature.

Table 2. Twelve culverts in the French Broad River Basin, North Carolina in which we recorded temperatures during winter 2019–2020. We note if gray bats were detected in the culvert during checks in mid-March or Sept.–Oct. 2019 (active season). We measured the length, width, and entrance height for the portal carrying most of the water flow. Entrance names have no spatial reference, but were names based on how we first entered the culvert. All vents noted below were inlets >0.2 m across that could drain water into the culvert. Each culvert was also checked at least twice for the presence of bats.

Culvert ID	Length (m)	Width (m)	Entrance 1 Height (m)	Entrance 2 Height (m)	Number of Vents	Gray bats detected in active season
100297	142.3	2.1	2.6	1.9	0	no
100409	206.9	2.7	2.3	2.3	1	yes
100442	314.1	3.0	2.4	1.8	3	no
100469	509.8	2.4	2.1	1.3	6	no
100508	570.0	2.7	2.5	2.1	9	yes
100769	252.9	2.7	2.6	1.3	5	yes
430097	138.6	3.0	1.7	1.1	1	no
430252	132.0	2.4	2.6	2.3	0	no
560161	120.8	2.1	1.9	1.7	1	yes
990022	97.8	2.1	2.5	1.6	0	yes
I-40	274.4	2.7	2.2	2.0	3	yes
HSC	328.6	2.4	1.5	N/A	12	yes

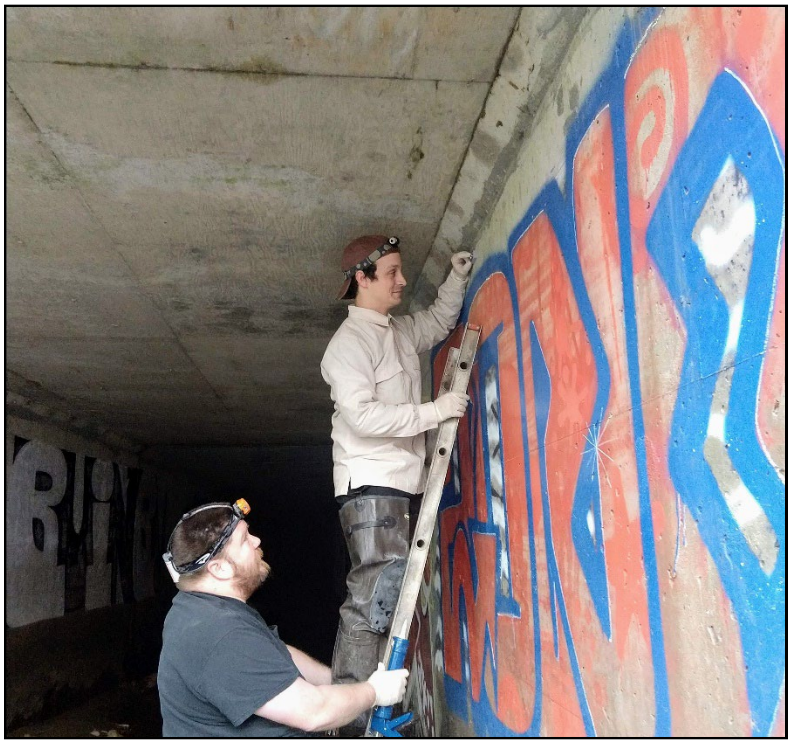


Figure 7. Placing iButton temperature sensor near the ceiling of a culvert to record winter (December–March) temperatures in 12 culverts in the French Broad River Basin of western North Carolina, 2019–2020.

Acoustics

We deployed bat detectors at 15 stations throughout the French Broad River Basin (Figure 8; Appendix I, Table I1). To locate points for detector stations, we selected major streams in the French Broad River Basin from a major hydrography layer (NC Center for Geographic Information and Analysis 2002). For each stream in the layer, we selected a site 0.1–6.6 km from the midpoint. We divided the French Broad River into three sections (North, Middle, South) and created a station near the midpoints of each section. While all stations were on perennial streams, landcover around each station varied; for example, the Spring Creek station was 71% natural and < 12% urban/suburban, while the North Toe River station was only 6.7% natural and 93% urban/suburban (Appendix I, Table I1). We began deploying bat detectors at stations in June 2018; all 15 stations were operational by December 2018. Due to numerous flood events in 2018, 2019, and 2020, we were forced to periodically pull equipment from the field to prevent water damage. We selected a new site for the Turkey Creek station on 1 August 2019 because the original site repeatedly flooded, inundating the detectors and mics.

Each station had two Anabat SD1s or SD2s (Titley Scientific, Inc.), with directional hi-type, weatherproofed microphones (housed inside a 31.75-mm PVC tube with a 40° axis angle) on 10-m cables, powered by a combination of 12V batteries and a solar panel. Data division was set at 8 and sensitivity was set as high as ambient noise would allow (between 3 and 6 depending on water and insect noise). The mics were elevated 1.5–2.5 m above ground level on a pole or extending on a L-bracket away from a tree trunk and oriented so that one recorded upstream and the other downstream (Figure 9). Detector stations were at points where riparian vegetation was minimal, so we expected little interference from vegetation on our recordings. Bat detectors recorded from sunset to sunrise for a total of 12,858 mic nights.

We downloaded calls from compact flash cards and organized data by site, mic direction, and night. We used automated identification software, Bat Call Identification (BCID; v2.7c; Bat Call Identification 2016), to identify bat echolocation calls to species from a list of 13 species that occur in western NC (*Tadarida brasiliensis* is not an option). By default, BCID discards files that have noise or no bat pulses, where a pulse is defined as an individual sound wave that is a part of the larger bat echolocation call sequence; files that pass the filter are identifiable sequences of search phase calls. For species identification, we required call sequences with a 5-pulse minimum within 15 seconds, a 70% species confidence level (at least four pulses identified as one species), and minimum discriminant probability of 0.35. If the minimum discriminant probability was not met, BCID marked the file as unknown.

For this report, we present the number of files identified as gray bats according to the BCID criteria above. A sample gray bat call sequence is presented in Figure 10. We present total gray bat calls by epi-week (there are 52 epi-weeks per year) and gray bat calls per mic per night ("mic-night"), where a mic-night is one detector and its associated microphone active for one entire night (dusk to dawn). On a typical night, there were two mics active and, hence, two mic-nights for each of the 15 acoustic stations. However, due to flooding, equipment malfunction, and battery failure, there was 1 or no mics active on some occasions. We summed the mean gray bat calls/mic per week across all active stations to estimate an overall weekly activity index for gray bats throughout the French Broad River Basin. The number of stations active each week varied from 1–15. In most weeks after early September 2018, there were at least 10 stations active. We also calculated total *Myotis* calls and total bat calls per site based on BCID outputs; these data are contained within an Excel file that will accompany this report to NCDOT.

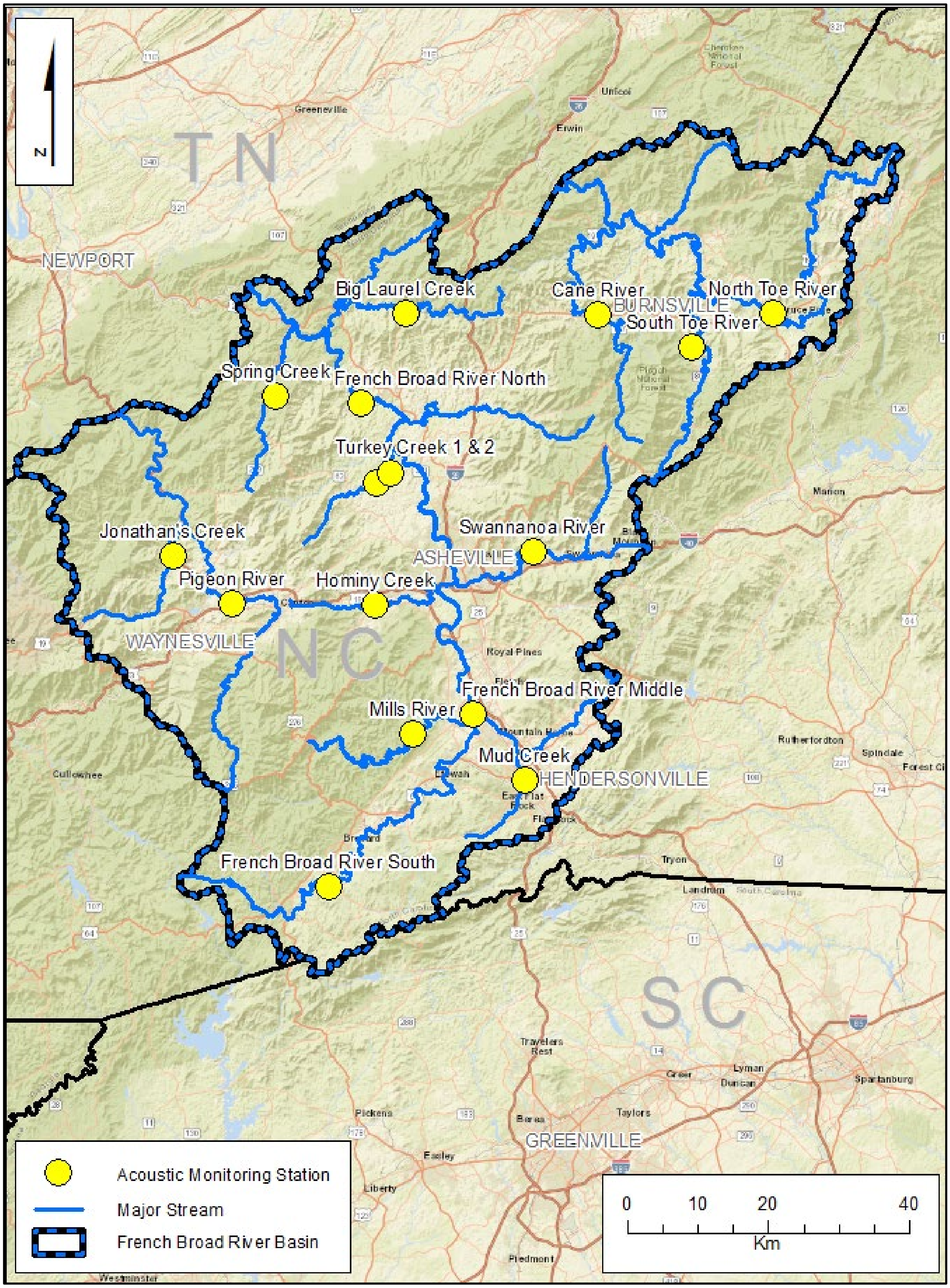


Figure 8. Locations of acoustic monitoring stations in the French Broad River Basin where we deployed Anabat detectors to listen for bat calls between June 2018 and April 2020.

Figure 9. Examples of acoustic stations used to survey for foraging gray bats across the French Broad River Basin in western North Carolina. Big Laurel Station at left and Swannanoa River Station at right. Typically, two Anabat SD1 or SD2 units, housed with batteries in a water-tight case, were operational at each station. Microphones, mounted on the same or separate posts, were oriented such that one pointed upstream and the other pointed downstream.

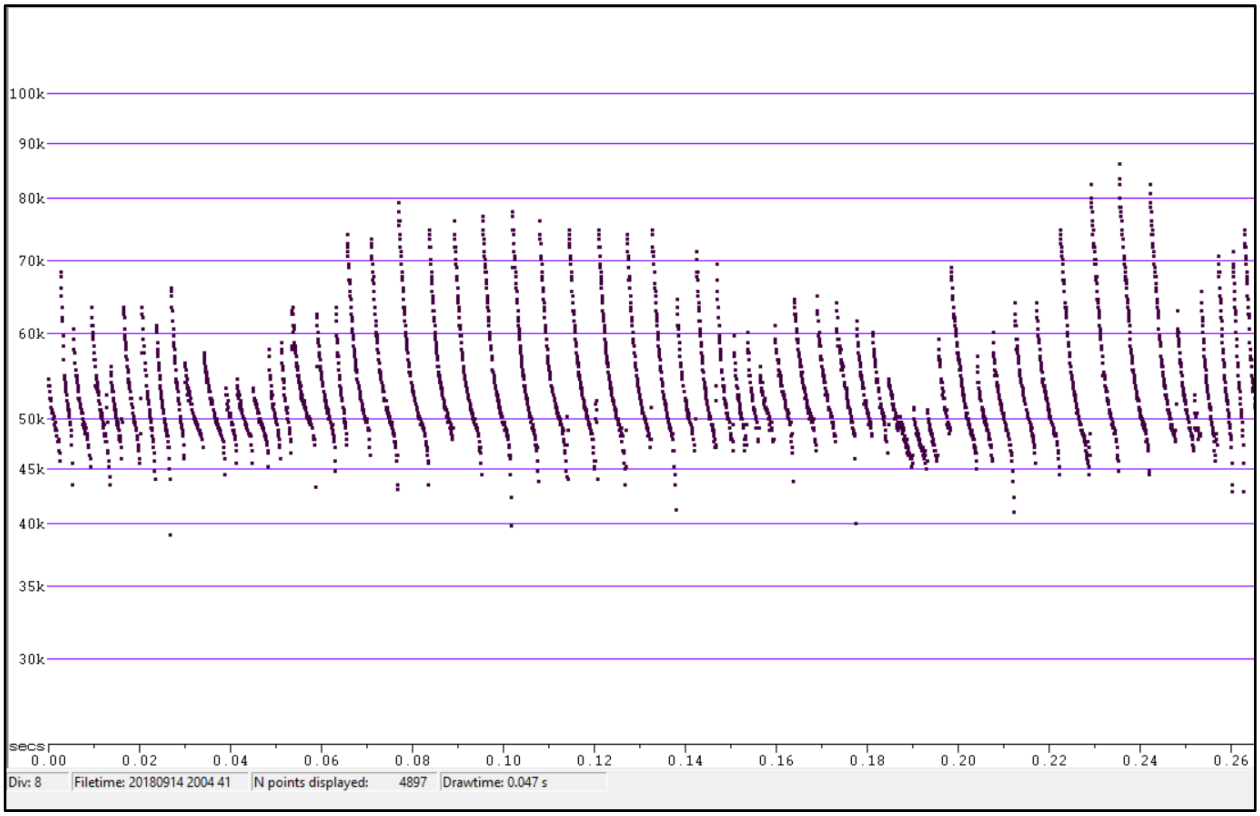


Figure 10. Example gray bat call sequence recorded at CB over the Pigeon River in Canton, NC. Sequence is presented in AnalookW, with a magnification of F7 and with compression of spaces between calls (i.e., not true time). Note the sigmoidal shape of each pulse and relatively long duration compared to other *Myotis*. Characteristic frequency (Fc, the frequency at the flattest portion of the call) is >45 kHz for this sequence.

Results and Discussion

Captures

We captured gray bats at four roost sites in the French Broad River Basin (Table 3). We also surveyed four other net sites, capturing gray bats at all of them. Because we mainly netted at gray bat roost sites, gray bats comprised most of our captures (~58% of all captures in each year, Table 4, Table 5). We captured adult males and females at all four roost sites in both years. Juvenile gray bats were captured at only two sites in 2018, but at all four roost sites in 2019 (Table 3). We also occasionally captured big brown bats (*Eptesicus fuscus*, EPFU) and Mexican free-tailed bats (TABR), especially where the three species roost together in BLRIB. Other species we encountered were eastern red bats (*Lasiurus borealis*, LABO), tri-colored bats (*Perimyotis subflavus*, PESU), silver-haired bats (*Lasionycteris noctivagans*, LANO), eastern small-footed bats (*Myotis leibii*, MYLE), and evening bats (*Nycticeius humeralis*, NYHU).

In 2018, we captured 485 gray bats, recapturing 31 banded gray bats on one or more nights after the original capture. In 2018, adult males comprised 82% of gray bat captures, adult females were 13%, and juveniles were 5% (Table 4).

In 2019, we captured 374 gray bats, recapturing 22 banded gray bats on one or more nights. In 2019, the relative proportions shifted—adult males were 73% of captures, adult females were 23%, and juveniles were 4% (Table 5).

In 2018 and 2019 there were 53 occasions on which we recaptured a gray bat banded in a prior survey. Three bats, all adult males, were captured on three occasions and two of those bats were captured in both 2018 and 2019. One adult male gray bat was captured on four occasions—three times from July–October 2018 and once in October 2019. Twelve bats were captured in both 2018 and 2019, and two bats were captured two years after their first capture. An adult female gray bat first captured by NCWRC at BLRIB in August 2017 was captured there again in July 2019 (post-lactating). An adult male gray bat first captured at a Bent Creek net site in June 2017 was recaptured April 2019 at MB. Recaptures also give an indication of how gray bats moved among roosts. By recaptures, we detected bats moving from BLRIB to CB, and BLRIB to HSC and vice versa.

In 2018 surveys at BLRIB, we recaptured three big brown bats first captured at this structure in 2016.

Table 3. Captures and effort for surveys at roosts and other net sites in the French Broad River Basin, North Carolina, April to October 2018–2019. Gray bat (MYGR) captures are categorized by age (A=adult, Juv=juvenile, U=unknown) and sex (M=male, F=female). Recaptures are indicated after a plus (+). We also present data for big brown bats (EPFU), eastern red bats (LABO), tri-colored bats (PESU), Mexican free-tailed bats (TABR), silver-haired bats (LANO), eastern small-footed bats (MYLE), and evening bats (NYHU). We did not band TABR, so recaptures were not discernible.

2018	Site Name	Nights	Hours	MYGR - AF/UF	MYGR - AM/UM	MYGR - Juv	EPFU	LABO	PESU	TABR
Roosts	CB	1	1.42	4	29	0	0	0	0	0
	BLRB	10	26.02	15 + 1	103 + 7	5	32 + 3	3	0	309
	MB	9	28.62	23	80 + 4	0	0	0	1	7
	HSC	10	33.82	20	167 + 19	17	0	0	0	0
Other Net Sites	South of BC	1	1.3	1	20	0	0	0	0	0
	Sandy Bottom	1	3.98	0	1	0	8	0	0	0
	Grand Total	**32**	**95.16**	**64**	**430**	**22**	**43**	**3**	**1**	**316**

2019	Site Name	Nights	Hours	MYGR - AF	MYGR - AM	MYGR - Juv	EPFU	LABO	PESU	TABR	LANO	MYLE	NYHU
Roosts	CB	7	12.37	35 + 1	112 + 3	3	0	0	1	1	0	0	0
	BLRIB	10	18.35	24 + 1	40 + 4	3	17 + 1	0	0	229	0	0	0
	MB	6	17.77	16	34 + 2	3	0	0	0	13	0	0	0
	HSC	7	26.52	11	82 + 11	6	0	0	0	0	0	0	0
Other Net Sites	Davidson River	1	4.25	0	2	0	0	0	3	0	0	2	0
	Swannanoa River	3	12.33	1	2	0	6	5	0	0	1	0	2
	Grand Total	**34**	**91.59**	**89**	**292**	**15**	**24**	**5**	**4**	**243**	**1**	**2**	**2**

Table 4. Captures for 2018 season by site (roost or net) and date. Gray bat (MYGR) captures are divided by age (A=adult, J=juvenile, U=unknown) and sex (M=male, F=female). Recaptures are indicated after a plus (+). We also present data for big brown bats (EPFU), eastern red bats (LABO), tri-colored bats (PESU), and Mexican free-tailed bats (TABR). We did not band TABR, so recaptures were not discernible.

		Species (ages and sexes encountered indicated below species code)									
		MYGR						EPFU	LABO	PESU	TABR
Site Name	**Date**	**AF**	**AM**	**JF**	**JM**	**UF**	**UM**	**AF, AM, J**	**F + M**	**AF**	**AF, AM, J**
CB	Oct 4	4	29								
BLRIB	Apr 18		5					1	2		
	Apr 25		1					2 + 1			
	Jul 21	3	17		1			12	1		7
	Jul 22	4	9		3			7			40
	Aug 3							1 + 1			35
	Aug 9	1	4 + 1		1	1					24
	Sept 25	2 + 1	7					5 + 1			107
	Sept 26	3	15					5			14
	Oct 3	1	19								29
	Oct 14		25 + 5				1				53
MB	Apr 20	5	14								
	Apr 21	5	19 + 1								2
	Apr 28	4	7							1	
	Apr 29	2	3								1
	Apr 30	2									
	Jul 15	1	5 + 1								
	Aug 14	2	6								2
	Sept 28	2	25 + 1								2
	Oct 18		1 + 1								
HSC	Apr 19		6								
	Apr 27		10 + 1								
	Jul 26	5	27 + 1	4	3						
	Aug 6	2	17 + 2	2	6						
	Aug 15	8	40		2						
	Oct 1	4	33 + 5				0 + 1				
	Oct 8		12 + 3								
	Oct 10	1	20 + 1								
	Oct 19		4 + 2								
	Oct 25		0 + 1								
South of CB	Oct 13	1	20								
Sandy Bottom	Jul 18		1								

Table 5. Captures for 2019 season by site (roost or net) and date. Gray bat (MYGR) captures are divided by age (A=adult, J=juvenile, U=unknown) and sex (M=male, F=female). Recaptures are indicated after a plus (+). We also present data for big brown bats (EPFU), eastern red bats (LABO), silver-haired bats (LANO), eastern small-footed bats (MYLE), evening bats (NYHU), tri-colored bats (PESU), and Mexican free-tailed bats (TABR). We did not band TABR, so recaptures were not discernible.

		Species (ages and sexes encountered indicated below species code)										
		MYGR				EPFU	LABO	LANO	MYLE	NYHU	PESU	TABR
Site Name	**Date**	**AF**	**AM**	**JF**	**JM**	**AF, AM, J**	**AF, AM**	**A**	**AF, U**	**AM**	**AF, AM**	**AF, AM, JM**
	Apr 18	5	24 + 1									
	Apr 22	3	25 + 2								1	
	Apr 25	4 + 1	16									
CB	Jul 28	7	11		3							
	Aug 16	6	6									
	Sept 23	7	13									1
	Sept 30	3	17									
	Apr 23	1				1						
	Apr 24	2	5			1 + 1						
	May 6		8 + 2			4						10
	May 7		5			2						1
BLRIB	Jul 17	4	4			3						81
	Jul 24	5 + 1	4		2	1						1
	Jul 25	5	4									1
	Aug 12	7		1		1						8
	Sept 25		7			2						112
	Oct 9		3 + 2			2						15
	Apr 29	2	2 + 1									
	Apr 30											1
MB	Jul 29	6	3									
	Aug 14	5	14	2	1							
	Sept 18	2	4									12
	Oct 2	1	11 + 1									
	Apr 16		1									
	Jul 15	4	35 + 2	2	4							
HSC	Aug 1	3	9									
	Sept 16	3	4 + 1									
	Sept 26	1	10 + 2									
	Oct 5		23 + 6									
Davidson River	Jun 13		2						2		3	
	May 2							1		1		
Swannanoa River	Jul 26		2			2	1			1		
	Sept 20	1				4	4					

Roosts

Roost locations

The number of known gray bat roosts in NC has increased since the first roost was found in 2016. Prior to this study, we were aware of eight roosts in NC; this included two structures spanning Ivy Creek that we counted as one roost and that no longer exist. We radio-tracked bats to 14 roosts (five bridges, two culverts, three buildings, two sycamore trees, and two caves in TN (Figure 11, Table 6). Eight of the 14 were roosts newly discovered due to our radio-tracking efforts (two of the bridges, three buildings, one culvert, and the two trees). We also detected 18 additional roosts by opportunistic or planned structure searches (12 bridges and six culverts). With the roosts known prior to this study (n = 8), newly discovered roosts on this project (n = 26), and three new bridge roosts (Russ Avenue Bridge on Richland Creek found by NV5 Engineers and Consultants in April 2018, and McClure Creek Bridge on Pigeon River and Tanasee Gap Road Bridge on the North Fork of the French Broad River found by NCWRC in May and August 2020, respectively), we now know of 37 gray bat roosts in the NC portion of the French Broad River Basin (Figure 11; Table 6; Appendix D, Table D1). The NC gray bats also use two cave roosts in the TN portion of the basin, which were also known roosts prior to this study.

It is possible that gray bat roosts may be found throughout the French Broad River Basin of NC. We now know of roosts in many areas, except for the northeast corner of the basin (Avery and Mitchell counties; Figure 11). During our surveys, we did not find any gray bat roosts south of the Hwy 280 Bridge over the French Broad River (near the Asheville Regional Airport) or south of the Little East Fork of the Pigeon River (near Lake Logan). However, on 12 August 2020, NCWRC found three gray bats roosting in a bridge on Tanasee Gap Rd over the North Fork of the French Broad, which is west of Brevard, NC in Transylvania County (K. Etchison, pers. comm.) and is now the southernmost record in NC; we did not consider this bridge in our analysis of bridge characteristics. The westernmost gray bat roost we found in the basin was on Jonathan's Creek near Cove Creek (Medley Drive Bridge); however, because we have tracked gray bats along the Pigeon River into TN via aerial telemetry and have tracked bats to a known cave roost/hibernaculum (RC) near the Pigeon River in Newport, TN, it is possible that gray bats roost in other structures along the Pigeon River. Traditionally, since 2005, gray bats have been captured on the Pigeon River (NCWRC Pigeon River/Twelve Mile site) about 8 km upstream from TN. The easternmost gray bat roost we found was a culvert on George Fork Creek underneath 19E, about 2.5 km east of Burnsville.

Most gray bat roosts were centered on the French Broad River, the Pigeon River, and their tributaries (Figure 11). Six bridge roosts were on the French Broad River network (including the Tanasee Gap Bridge) and four were on the Pigeon River. Bridge and culvert roosts on tributaries to these rivers, found during this study or previously, are on Big Laurel Creek, California Creek, Dillingham Creek, Flat Creek, Gashes Creek, George Fork, Hayes Run, Ivy Creek, Jonathan's Creek, Little East Fork of the Pigeon River, Richland Creek, Shelton Laurel Creek, Smith Mill Creek, Stingy Branch, and a tributary of Lake Julian. There is a previously known bridge roost on the Cane River which joins the North Toe River to form the Nolichucky River and a bridge roost found during this study on Cattail Creek, a Cane River tributary. Finally, we found a culvert roost on George Fork, a tributary to Little Crabtree Creek, which runs into the South Toe River.

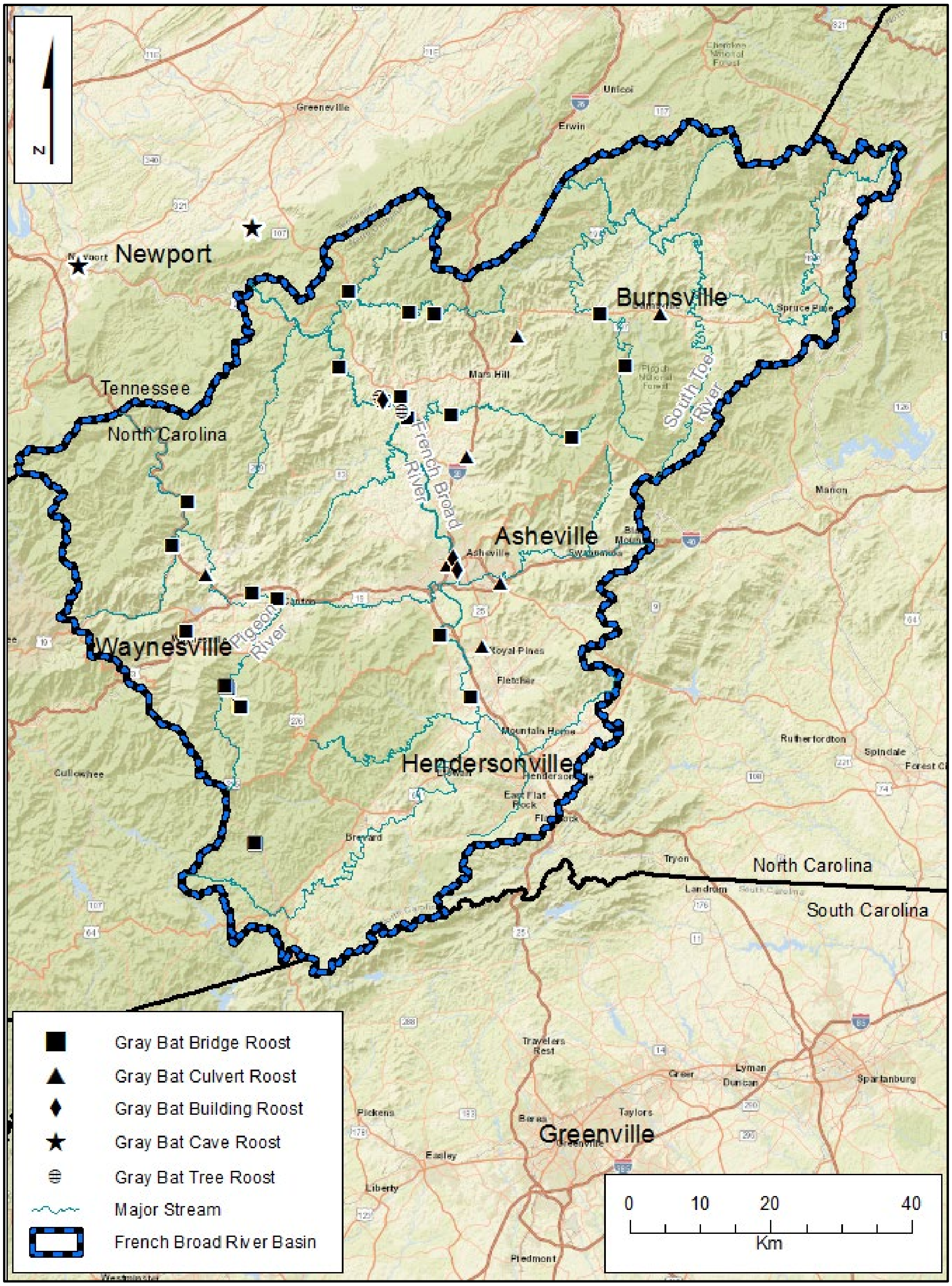


Figure 11. Thirty-nine structures where roosting gray bats have been found in the French Broad River Basin, North Carolina and Tennessee, March 2018–April 2020. Some roosts were located via radio telemetry (8), some through structure checks (20), some were known prior to the study (8 in NC and 2 in TN), and one was found by NCWRC in August 2020. Some structures overlap on the map.

Table 6. Known gray bat roosts in the French Broad River Basin of western North Carolina and eastern Tennessee. Gray bats from North Carolina were radio tracked to two hibernacula/maternity cave roosts in Tennessee.

Roost Name	NCDOT Structure #	Maximum Number of Bats[x]	# Radio-tagged Bats Used	How Roost Was Found	Other Species
RC (TN)[P]	n/a	n/a	12	Prior	n/a
CCC (TN)[P]	n/a	n/a	9	Prior	n/a
MB[P]	560328	1574	40	Prior	TABR
BlRIB[P]	100091	1505	98	Prior	EPFU, TABR
CB[P]	430445	1358	13	Search	-
HSC[P]	n/a	35	2	Prior	-
25/70 Bridge Over Hayes Run Rd.	560025	506	0	Prior	EPFU, TABR
Marshall Community Center	n/a	293	5	Telem	-
Lake Logan Road Bridge	430136	40	0	Search	EPFU
Gabriel's Creek Road Bridge	560004	31	0	Prior	MYLE
Shelton Laurel Bridge	560033	30	0	Search	-
Barnard Rd. Bridge	560113	29	0	Prior	EPFU, TABR
I-40 Arrington Bridge	430142	21	0	Search	EPFU
Little East Fork Bridge North	430090	11	0	Search	-
Big Laurel Road Bridge	560076	7	0	Search	EPFU, PESU
19/23 Smith Mill Creek Culvert	100769	5	0	Search	-
I-40/74A Culvert	100508	4	0	Search	-
Clyde McIntosh Bridge	990009	3	0	Prior	PESU (dead)
Hwy 280 Bridge WBL	440362	3	1	Telem	-
I-40/NC209 Culvert	n/a	2	0	Search	-
19E George Fork Crk Culvert	990022	2	0	Search	-
Dillingham Rd Bridge	100148	2	0	Search	MYLE
Flat Crk 19/23 Culvert	100409	2	0	Search	EPFU
Russ Avenue Bridge	430186	2	0	Search	-
Walnut Creek Rd/Big Laurel Creek Bridge	560071	2	0	Search	EPFU
I-40 Thickety Overpass	430236	1	1	Telem	EPFU
NC-197 Cattail Bridge	990046	1	0	Search	-
Al's Used Cars Building	n/a	1	1	Telem	-
Allen Avenue Culvert	n/a	1	1	Telem	-
California Crk Culvert	560161	1	0	Search	-
Hwy 280 Bridge EBL	440361	1	0	Search	-
Ivy Creek Bridge	n/a[+]	1	0	Prior	EPFU
Little East Fork Bridge South	430091	1	0	Search	-
Marshall Tree #1	n/a	1	1	Telem	-
Marshall Tree #2	n/a	1	1	Telem	-
McClure Creek Bridge	430147	1	0	Search	MYLE, PESU
Medley Drive Bridge	430072	1	0	Search	-
Mountain Energy Building	n/a	1	1	Telem	-

How roost was found categories: Prior = known prior to study, Search = found through structure searches, Telem = found via radio-telemetry

EPFU = Eptesicus fuscus, MYLE = *Myotis leibii,* PESU = *Perimyotis subflavus, TABR = Tadarida brasiliensis*

[x] Maximum number of bats (of any species) observed using the roost during study via exit counts, spotlight surveys, or radio-tracking

[+] New bridge that replaced two gray bat bridge roosts, 560008 and 560009 in 2017/2018; no gray bats have been observed using new bridge

[P] Primary roost

Russ Avenue and McClure Creek bridge roosts were found through structure searches by Calyx Engineers and Consulting and NCWRC in 2018 and 2020, respectively

Types of roosts

Two primary roosts in TN—RC and CCC—were used by gray bats tracked from capture sites in this study (Table 6). According to TWRA (pers. comm.), these caves are used by thousands of gray bats (5,000–250,000) in summer and winter. In NC, gray bat roosts with the highest numbers (≥ 1,000 bats) were considered primary; these were CB, BLRIB, and MB (Table 6). The BLRIB and MB bridges are large (longer than 200 m), whereas CB is only 64 m (smaller than the average). We also include the HSC as a primary roost because we consistently captured bats at the site, often later in the night (2–6 hours after sunset). The roost was frequented by gray bats—we captured many bats flying into the entrance at night and radio-tracked some bats to the roost at night—and may serve as an important "social site" or hub for the population. During this study, we counted ≤ 35 bats during any of six exit counts at this roost (Table 7). However, in 2017, NCWRC and USFWS counted 202 bats exiting the roost on one night.

Compared to the three primary bridge roosts, secondary roosts were used by fewer bats (Tables 6 and 7). Compared to the HSC, secondary roosts were used less consistently—i.e., we could reliably capture gray bats at HSC but did not always find gray bats when we examined the roosts we classified as secondary. In western NC, these secondary roosts included bridges, culverts, buildings, and sycamore trees (*Platanus occidentalis*). From 2018–2020, we found 14 new secondary bridge roosts (12 via searches and two via radio-telemetry), NV5 Engineers and Consultants found one new bridge roost (Russ Avenue Bridge NCDOT #430186) in April 2018, and NCWRC found two new bridge roosts (McClure Creek Bridge NCDOT #430147 and Tanasee Gap Road Bridge NCDOT #870093) in May and August 2020, respectively. Prior to this study, there were five known gray bat secondary bridge roosts in the French Broad River Basin, all found by visual searches. Secondary bridge roosts were used by 1–506 bats (in some cases by multiple species).

We counted 1–5 gray bats in each of seven secondary culvert roosts (Table 6). We found six new culverts by visually searching for bats and one culvert (Allen Avenue Culvert) via radio-telemetry. All but one of the culverts, the Allen Avenue Culvert, were underneath primary roads and "concrete box type." The Allen Avenue Culvert was a "pipe type" culvert and was ≤ 100 m from a primary road. All culvert roosts were relatively long (≥ 100 m), with a stream running through the culvert.

We radio tracked gray bats to three buildings and two sycamore trees (Table 6). The M Community Center (old high school building which currently serves as a community center), to which we radio-tracked five female gray bats, was ~215 m from the MB primary roost and was used by up to 293 bats. The other two building roosts, Al's Used Cars and the Mountain Energy buildings (both currently used as businesses), were used by single radio-tagged gray bats, male and female, respectively. The Al's Used Cars building was ~58 m from the entrance to the HSC primary roost and the Mountain Energy building was 1.6 km south of the HSC. Sycamore tree roosts were found in September 2018 and 2019 by tracking bats captured at MB roost site. Both trees were living. One of the trees, on the north bank of the French Broad River, was 0.7 km northwest of MB and measured 89 cm diameter at breast height (DBH). The other tree, on the south bank of the river, was 2.9 km southeast of MB and measured 81 cm DBH. One was used for a day and the other was used for two days.

On several occasions we detected radio-tagged gray bats (via ground and aerial telemetry) arriving near CB or nearby paper mill plant soon after dusk. This occurred on days when these bats were not detected roosting in CB. It is possible that radio-tagged gray bats were using a culvert underneath the paper mill that empties into the Pigeon River approximately 400 m south (upstream) of the bridge. The N2 telemetry tower on the French Broad River also recorded a single bat during the daytime on multiple days in late April to early May 2019. We suspect this bat was roosting in a structure (bridge, building, or tree) south of the N2 tower.

Table 7. Partial list of roost counts at primary and secondary gray bat roosts in the French Broad River Basin of North Carolina from June 2018–Sept. 2019. Table includes all simultaneous count days that included CB or BLRIB bridges and any other exit counts conducted at CB or BLRIB bridges. Additional counts were conducted at the MB and secondary roosts that are not included here (see Appendix D, Table D2 for full dataset).

Date	CB	BLRIB	MB	HSC	Other Secondary Roosts	Total
6/4/2018	**-**	**373^{+}**	**2^{+}**	**0**	**0**	**375**
7/3/2018	**-**	**731^{+}**	**240^{+}**	**0**	**15^{+}**	**986**
9/13/2018	**-**	**703^{+}**	**498^{+}**	**35^{+}**	**0**	**1236**
9/14/2018	361^{+}	-	-	-	-	361
10/12/2018	**61^{+}**	**382^{+}**	**8^{+}**	**-**	**0**	**451**
10/13/2018	-	546^{+}	-	-	-	546
10/14/2018	-	687^{+}	-	-	-	687
10/15/2018	-	623^{+}	-	-	-	623
10/19/2018	-	322^{+}	-	-	-	322
10/20/2018	-	235^{+}	-	-	-	235
4/17/2019	100^{+}	-	-	-	-	100
4/28/2019	199^{+}	-	-	-	35^{+}	234
5/1/2019	**32^{+}**	**626**	**82**	**0**	**2**	**742**
5/24/2019	120^{+}	-	-	-	-	120
6/4/2019	43^{+}	-	97^{+}	-	0	140
6/5/2019	-	1142	-	-	-	1142
6/12/2019	668^{+}	-	-	-	-	668
6/14/2019	-	375^{+}	-	-	-	375
6/19/2019	558^{+}	-	-	-	-	558
7/3/2019	**1358**	**812^{+}**	**550**	**0**	**100^{+}**	**2820**
8/28/2019	**128^{+}**	**1505**	**1020**	**9^{+}**	**74^{+}**	**2736**
9/14/2019	361^{+}	-	1574	-	67^{+}	2002

Coordinated emergence counts where we tried to count for bats at as many known roosts as feasible are in bold. Exit counts were performed for CB, BLRIB, and HSC. Spotlights and exit counts were performed for MB and other roosts.

$^{+}$Underestimate of the number of bats using roost, due to not searching/counting all crevices or because bats remained in the roost

Estimates of the roosting population

At the BLRIB, we were able to count bats from the sidewalk crevices on top of the bridge; however, counts from the top of the bridge do not accurately reflect the total number of bats or species roosting throughout the bridge. We mostly see big brown bats in the sidewalk crevices, but capture data show Mexican free-tailed bats and gray bats are more common than big brown bats. Further, a 2017 "snooper truck" survey by NCWRC estimated ~80% of the bats visible from underneath the bridge were gray bats. There is an expansion joint crevice that spans the width of the bridge (underneath the steel plate joint cover) that is not visible from above of the bridge, nor from below.

From simultaneous counts at the three primary bridge roosts, we estimated the total population to range from 451–2,820 gray bats (Table 7). Counts at BLRIB will include Mexican free-tailed bats; however, our capture data suggest free-tailed bats do not contribute to the high numbers of bats observed at CB and MB. Simultaneous counts show the gray bat population in the French Broad River Basin is at its peak in July–September, with 1,236–2,820 gray bats present; however, we counted 1,142 bats emerging from BLRIB on 5 June 2019. All three of the primary bridge roosts registered counts of over 1,000 bats. Simultaneous counts were higher in fall 2019 than in 2018, but this is most likely due to our knowledge of and ability to also count bats at the CB roost in 2019.

Counts were always low (0–35 bats) for HSC, which has multiple entrances and a lot of vegetation around the largest entrance and is thus difficult to count (Table 7); though there is artificial light near the entrance, we do not think this hinders counting at this site. We sometimes counted secondary roosts in conjunction with counts at primary roosts, but this added ≤ 100 bats to the grand total. However, we detected >100 bats at two secondary roosts—the M Community Center, which we assume were all gray bats because we tracked several to this roost, and the 25/70 Bridge over Hayes Run Stream, which we know also contained big brown bats and Mexican free-tailed bats (Table 6). Based on spotlight surveys, we suspect most bats using the 25/70 Bridge are big brown bats and Mexican free-tailed bats and, thus, we do not consider it a primary roost for gray bats.

Due to consistent use, MB is a good indicator of the seasonal fluctuation of the number of gray bats in NC (Figure 12). Collectively, the survey data from May 2018 to July 2020 show that 100–700 bats occupy the bridge in spring, followed by a decrease in the number of bats from May to early July. By mid-July, the number of bats increases, and by September there are ~1,000–1,600 bats using the MB. In late September to early October, the number of bats begins to dwindle as the bats move out of the bridge for winter.

We suspect the mid-summer decrease in bats at MB is driven by bats moving to other sites for birthing and pup rearing. We have evidence that the NC population of gray bats uses caves in TN during the summer. From 8 May–15 August 2019, we tracked eight female and two male gray bats, collectively, from the four primary roosts in NC (CB, BLRIB, HSC, and MB) to CCC (a cave) in TN. We also radio-tracked one post-lactating adult female bat to RC (a cave) in TN on 30 July 2019, two days after she was radio-tagged at CB on the Pigeon River in NC. Also, on 16 August 2019, Copperhead Consulting tracked (via aerial telemetry) a post-lactating female gray bat (bat BRR A6339) from MB, where she roosted that day, north on the French Broad River to near RC (Appendix H, Figure H13).

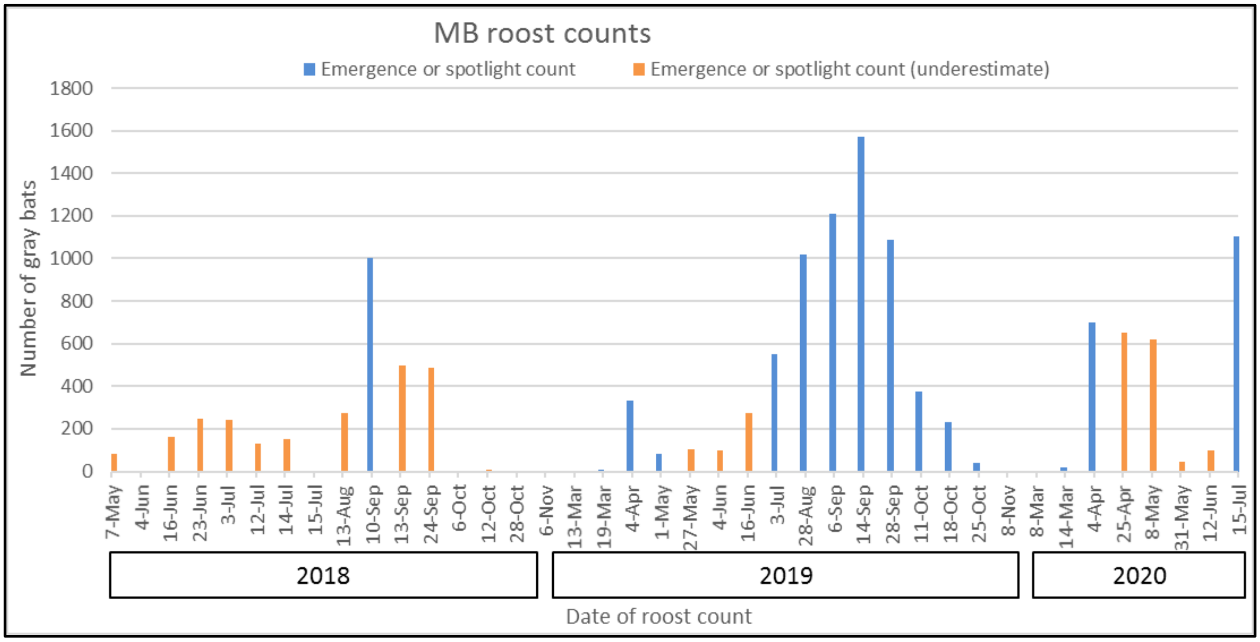


Figure 12. Gray bat population estimates for MB in the French Broad River Basin, western North Carolina, April 2018–July 2020. We used spotlights and binoculars to estimate the number of bats on some daytime visits and counted bats emerging from the bridge at dusk on other dates.

Proximity of roosts to roads and Transportation Improvement Projects (TIPs)

Excluding the two caves in TN, primary roosts in NC were, on average, 546 m from TIPs (17–2,042 m), 69 m from primary roads (0–170 m), 13 m from secondary roads (0–29), and 31–63 km from known gray bat caves in TN (RC or CCC; Table 8). Secondary roosts were, on average, 2,570 m from TIPs (0—10,701 m), 852 m from primary roads (0–7,102 m), 65 m from secondary roads (0–309 m), and 16–85 km from known gray bat caves in TN.

Table 8. Known gray bat roosts in the French Broad River Basin of North Carolina and, for each roost, distance to nearest transportation improvement project (TIP), primary and secondary road, and gray bat cave in Tennessee. "Int" indicates that a structure intersects a road or TIP point or polyline.

Roost name	NCDOT #	Nearest TIP[1]	Distance to nearest TIP (m)[1]	Distance to nearest primary road (m)[2]	Distance to nearest secondary road (m)[3]	Distance to nearest gray bat cave (km)[4]
CB[P]	430445	EB-5945	64	0	29	53
BLRIB[P]	100091	U-3403B	59	59	4	63
MB[P]	560328	R-5924	2042	170	1	31
HSC[P]	n/a	I-2513D	17	48	17	55
19/23 Smith Mill Crk Culvert	100769	I-2513B	195	0	39	55
19E George Fork Crk Culvert	990022	TA-6723	4000	0	18	59
25/70 Bridge	560025	U-6173	1186	1	2	32
Allen Avenue Culvert	n/a	U-2801A	694	80	35	67
Al's Used Cars Building	n/a	I-2513D	37	37	35	55
Barnard Bridge	560113	R-5837	3549	2208	1	23
Big Laurel Road Bridge	560076	B-6012	2906	4493	0	28
California Crk Culvert	560161	I-5831	5390	0	22	40
Clyde McIntosh Bridge	990009	TA-6723	4633	4	93	51
Dillingham Bridge	100148	B-6016	5015	3758	1	54
Flat Creek 19/23 Culvert	100409	A-0010AA	3004	0	103	44
Gabriel's Creek Road Bridge	560004	U-6173	3585	3433	1	39
I-40/74A Culvert	100508	I-6063	0	0	159	61
I-40 Arrington Bridge	430142	I-5924	11	1	77	37
I-40/NC 209 Culvert	n/a	I-5834	9	9	180	47
I-40 Thickety Overpass	430236	I-5834	1304	2	3	52
Ivy Creek Bridge	560008	U-6173	995	2	45	35
Lake Logan Road Bridge	430136	B-5920	3828	0	26	63
Little East Fork Bridge North	430090	B-5920	3398	2346	9	66
Little East Fork Bridge South	430091	B-5920	3678	2766	11	66
Marshall Community Center	n/a	R-5924	2009	229	73	31
Marshall Sycamore Tree #1	n/a	R-5924	1534	322	88	30
Marshall Sycamore Tree #2	n/a	U-6173	628	144	271	34
McClure Creek Bridge	430147	B-5920	4044	1	29	63
Medley Drive Bridge	430072	I-5924	166	166	1	42
Mountain Energy Building	n/a	U-5019C	132	952	17	56
NC 197 Cattail Bridge	990046	TA-6723	7863	2	90	56
NC 280 Bridge EBL	440361	R-5771	682	1	271	73
NC 280 Bridge WBL	440362	R-5771	645	2	309	73
Russ Avenue Bridge	430186	U-5839	3	3	81	54
Shelton Laurel Bridge	560033	B-5989	8985	0	40	16
Walnut Crk Rd/Big Laurel Crk Bridge	560071	B-5989	0	7102	0	25

[P]Primary roost. [1]NCDOT 2020-2029 Current STIP- September 2019. [2, 3]Route Class 1–3, 80, and 81 as primary roads and roadways of Route Class 4–7 and 9 as secondary roads. [4]Gray bat caves = Rattling Cave and Cedar Creek Cave in Tennessee.

Where were bats in the bridges?

Within bridges, bats had several options for roosting sites; all sites described here are from daytime observations. We tended to find gray bats in parallel crevices or perpendicular crevices in bridges. Usually bats were visible from underneath the bridge if they were in parallel crevices, as for example in MB (Figure 13) and the Gabriel's Creek Bridge. However, it was not always possible to see bats from above or below when they roosted in perpendicular crevices. For example, at CB, gray bats roosted in an expansion joint in the bridge that was above the pillars/cap and we could only see accumulated guano on the caps, but not roosting bats (Figure 14). At other bridges, occasionally we found gray bats in the expansion joint at the edge of the deck, adjacent to the guardrail, which made it possible to see bats in an otherwise obscured perpendicular crevice. For example, it was sometimes possible to see gray bats from above in BLRIB (Figure 15), though more often we saw big brown bats from this perspective. In the BLRIB, one crevice is partly visible from the upper deck and another crevice, offset from the first, is visible from underneath (best seen in a snooper truck due to bridge height).

Gray bats were sometimes observed in other crevices or gaps in bridges, also during the daytime, and sometimes this behavior was observed in conjunction with bats roosting in parallel or perpendicular crevices in the deck. At three bridges we observed gray bats in deck drainpipes that were clogged from above (see example photos in Appendix B, page 7). NCWRC observed a gray bat in a crevice in the sidewall of a guardrail and one tucked behind a swallow nest under a bridge prior to this study; during this study, we observed a bat roosting in the base of the guardrail crevice in the Shelton Laurel Bridge. Gray bats were sometimes observed hanging from the concrete deck beneath a bridge or on the side of a concrete I-beam.

Figure 13. The white arrow points to one of several parallel crevices in MB over the French Broad River in western North Carolina where gray bats were visible through binoculars and with the aid of a 1,000-lumen spotlight from the underside of the bridge.

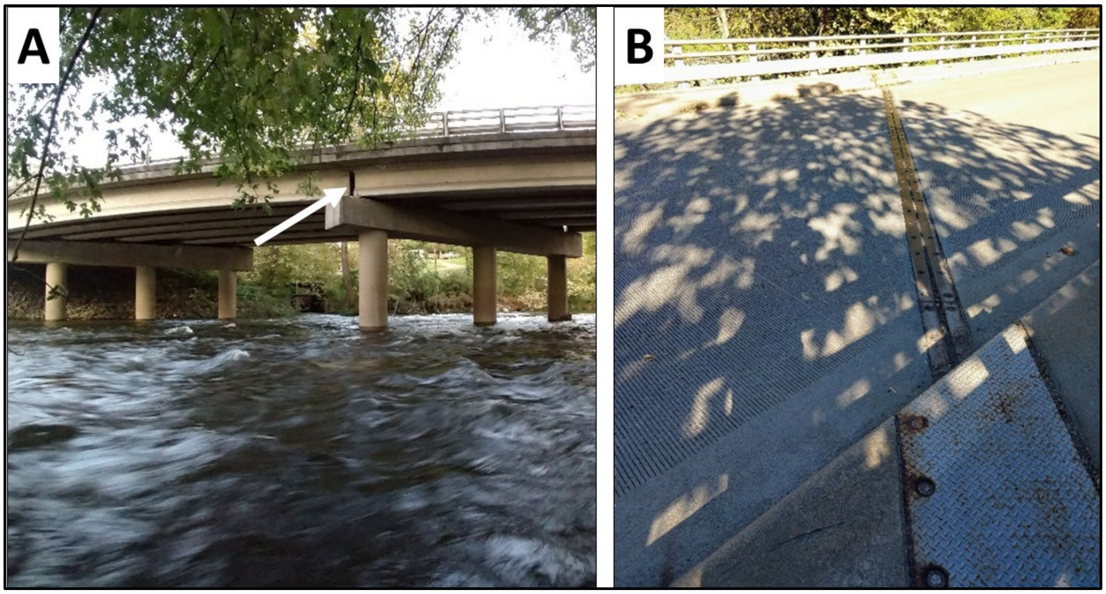


Figure 14. An arrow points to one of the perpendicular expansion joints where gray bats roosted in CB in Canton, North Carolina (A). The joint is capped by a metal strip and plates at the sides of the bridge, preventing views of bats inside the crevice (B).

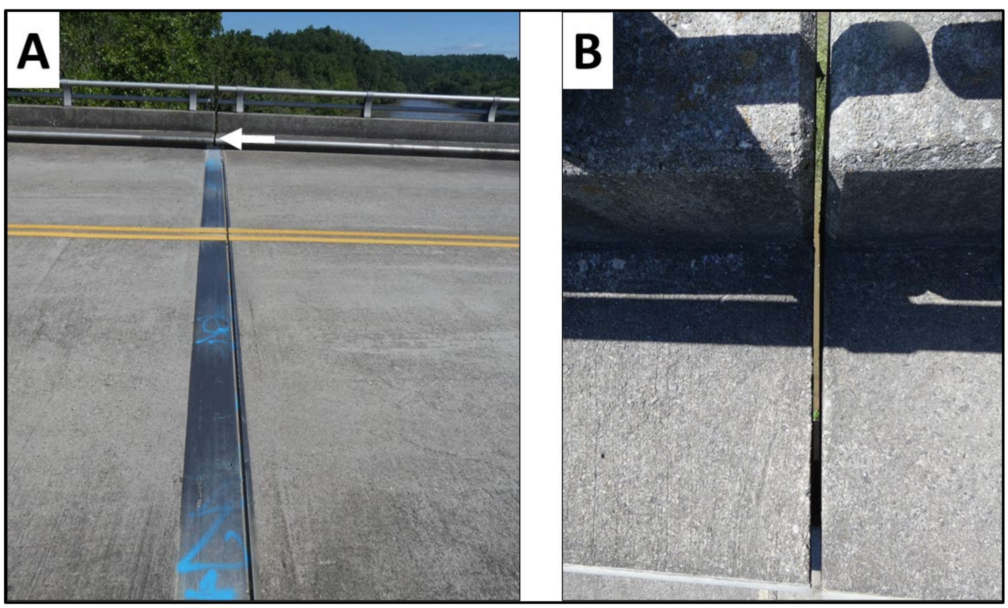


Figure 15. Gray bats roosted in the perpendicular expansion joints covered by metal strips in BLRIB (A). An arrow indicates an uncovered portion of a joint at the edge of the bridge. This joint continues to the guardrail (B). Bats were sometimes visible from above in this uncovered section.

Skin temperature data for bats roosting in bridges

We report on skin temperatures measured for bats roosting in BLRIB during spring, summer, and fall 2019. We also report bat skin temperatures for bats in CB in spring 2019 and MB during summer 2019. These skin temperature data serve as a proxy measurement for within-roost conditions. As heterotherms, bats allow their skin temperatures to drop to be near within-roost temperatures. Thus, these results on bat temperatures give an indication of the maximum and minimum temperatures in bridge roosts and the stability of those roosts. Summary statistics for within-roost temperatures (derived from bpm readings averaged over one-hour intervals) of the three bridges, along with ambient temperatures from equivalent periods are listed in Table 9.

Generally, bat temperatures within roosts appeared to be maintained independently of ambient temperatures. In the spring, when females would likely be pregnant, ambient temperatures were the coldest of the three seasons (Table 9). During spring, ambient temperatures ranged from 10–28 °C, with a mean of 20.6 °C. During this time, bat temperatures within roosts were warmer than ambient temperatures, averaging 32.5–33 °C for the two bridges we assessed in spring. In the summer, when females should be post-lactating, ambient temperatures were warmer, averaging 22.8 °C; however, bat temperatures within roosts were similar to spring, averaging 30–33 °C. In fall, as bats prepared for migration and hibernation, ambient temperatures were the warmest, averaging 23.3 °C; however, bat temperatures within roosts averaged 31 °C, which is cooler than in spring and summer.

Only at CB was there a significant correlation ($r^2 = 0.196$, $P < 0.001$) between ambient temperatures and within-roost temperatures. At CB (spring), within-roost temperatures were lowest in the morning, and became ~8 °C higher in the afternoon (Figure 16). In contrast, springtime temperatures of bats using BLRIB were highest in the morning (33.9 °C) but did not fluctuate with ambient temperature to the same degree.

For all bridges, the greatest difference between within-roost and ambient temperatures occurred during spring (Kruskall-Wallace test, $P < 0.001$), when within-roost temperatures were 11.7–13.1 °C warmer than ambient (Table 10, Figure 16). In summer and fall, within-roost temperatures were 7.1–9.4 °C warmer than ambient, with no significant difference among bridges. Differences between within-roost and ambient temperatures were greatest in the morning (12.8–16.3 °C) and the least around noon (2.8–11.2 °C). The body temperatures of bats tended to increase further above ambient in afternoon and evening. This pattern was most extreme in the spring at BLRIB and CB (Figure 16). Mean daytime within-roost temperatures day were not significantly different between CB and BLRIB bridges for the spring (Mann-Whitney U; $P = 0.34$, Table 9). However, springtime temperatures recorded within the CB were significantly more variable than recordings from BLRIB and were also significantly more variable than any other bridge and season (Levene test for equality of variance, $P < 0.001$).

During the summer sampling period, the BLRIB and MB bridges both provide a similar warm and stable microclimate for the bats. In both bridges, summer temperatures were very stable, with mean temperatures at the different sampling intervals varying by < 1 °C throughout the day (Table 9). Further, within-roost temperatures were always warmer than ambient temperatures and not correlated with ambient at either bridge (Figure 16). However, the mean temperatures recorded within MB were slightly cooler than at BLRIB (Mann-Whitney U; $P < 0.001$), and BLRIB was significantly warmer compared to ambient temperatures, than was MB.

Table 9. Seasonal measurements for ambient temperatures (°C) and within-roost temperatures recorded by temperature-sensitive radio transmitters attached to the backs of gray bats roosting at three bridges in the French Broad River Basin in western North Carolina. Ambient temperature data are from the weather station at the Asheville, NC (AVL) airport.

			Mean		Mean temperature during periods of the day*			
Season^	**Measurements for:**	**n**	**Temperature**	**Range**	**Morning**	**Noon**	**Afternoon**	**Evening**
Spring	*Ambient conditions*		*20.6*	*10.0–28.3*	*15.0*	*23.0*	*24.3*	*20.0*
	Bats in BLRIB	2	33.0	25.0–36.0	33.9	31.4	32.1	31.5
	Bats in CB	4	32.5	21.0–40.0	27.5	30.2	35.8	33.4
Summer	*Ambient conditions*		*22.8*	*13.3–31.7*	*18.5*	*26.5*	*26.3*	*23.7*
	Bats in BLRIB	3	33.0	20.0–40.0	32.7	32.8	33.2	32.3
	Bats in MB	3	30.0	24.5–34.5	30.0	30.1	30.7	30.6
Fall	*Ambient conditions*		*23.3*	*13.3–32.2*	*18.2*	*26.3*	*27.6*	*24.5*
	Bats in BLRIB	3	31.0	23.5–34.5	31.0	29.6	30.4	31.3

^ Spring is mid-April to mid-May 2019, Summer is mid-July to mid-Aug. 2019, and Fall is mid-Sept. to mid-Oct. 2019
*Morning = 6:00–8:00; Noon = 11:00–13:00; Afternoon = 15:00–17:00’; Evening = 17:00–19:00.

Table 10. Seasonal differences in the temperatures recorded for gray bats carrying temperature sensitive radio transmitters (within-roost) and ambient (weather station at the AVL Airport). To compare within-roost and paired ambient temperatures, we calculated mean, minimum, and maximum differences, and differences during four periods of the day (°C).

		Mean Difference		Mean temperature difference by period*			
Season^	**Bridge**	**(within-roost minus ambient)**	**Range**	**Morning**	**Noon**	**Afternoon**	**Evening**
Spring	BLRIB	13.1	1.6–20.7	16.3	10.6	9.0	12.9
	CB	11.7	−1.5–21.8	13.2	6.6	11.2	13.0
Summer	BLRIB	9.4	0.9–21.1	13.8	6.7	6.0	8.5
	MB	7.1	−2.6–19.2	11.6	3.4	4.8	6.9
Fall	BLRIB	8.7	−2.4–18.6	12.8	3.3	2.8	7.0

^ Spring is mid-April to mid-May 2019, Summer is mid-July to mid-Aug. 2019, and Fall is mid-Sept. to mid-Oct. 2019
*Morning = 6:00–8:00; Noon = 11:00–13:00; Afternoon = 15:00–17:00’; Evening = 17:00–19:00.

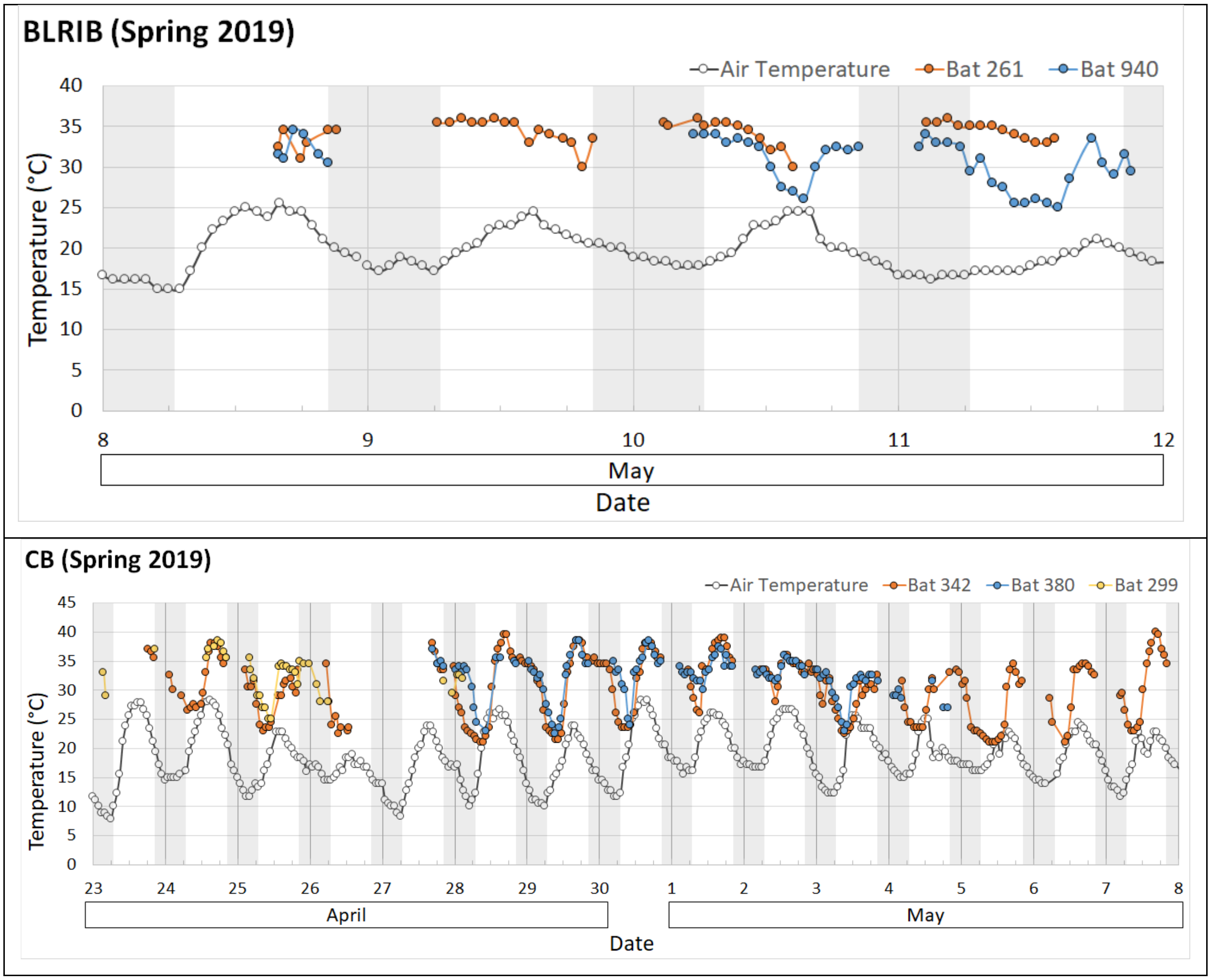


Figure 16. Temperatures recorded by transmitters attached to gray bats roosting in three primary bridge roosts (BLRIB, CB, and MB) in the French Broad River Basin in western North Carolina, April–May (spring), July–Aug. (summer), and Sept.–Oct. (fall) 2019.

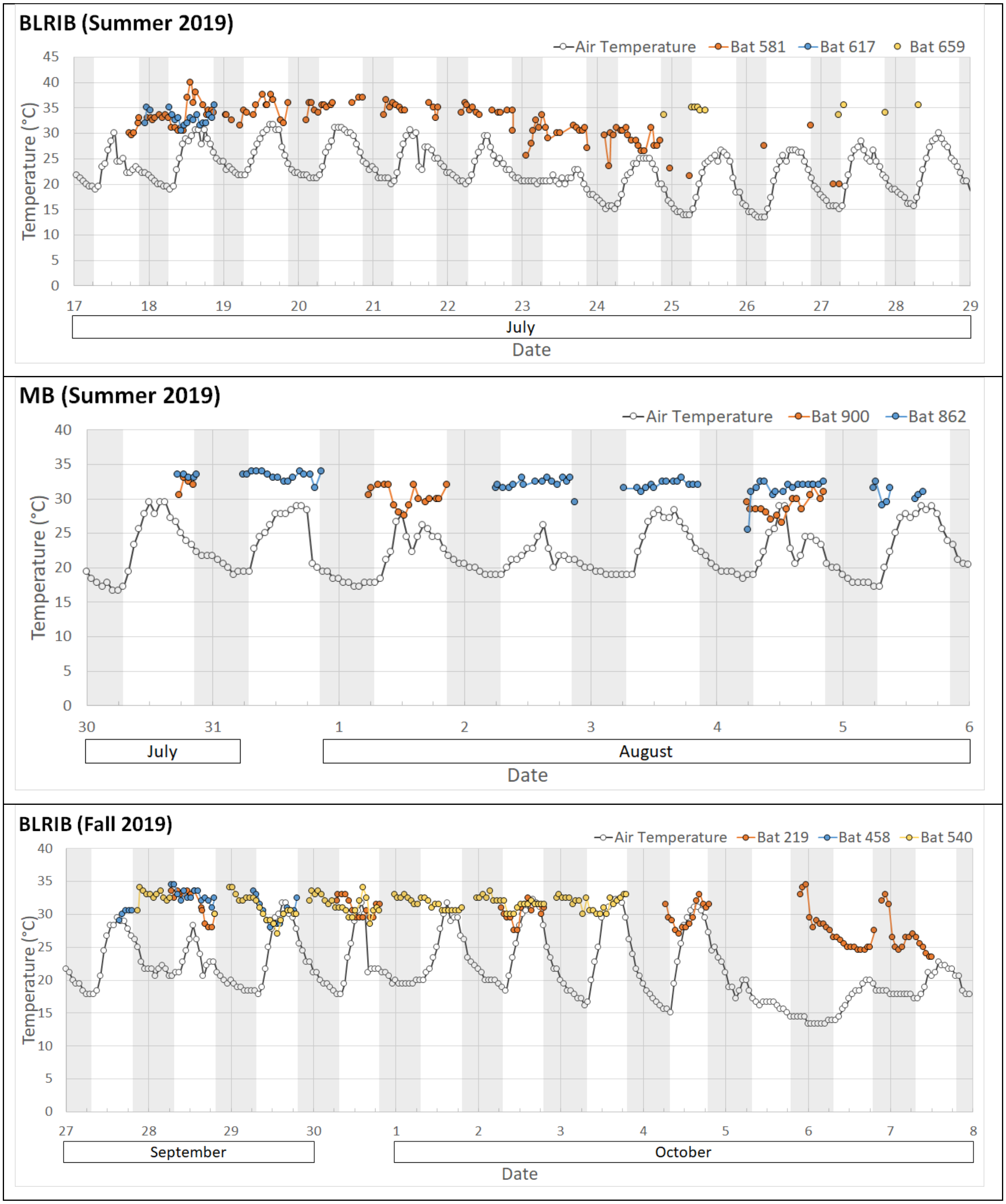


Figure 16 (continued).

During the fall period (27 Sept.–Oct.), daily ambient temperatures were 2–3 °C warmer than in the spring and the summer (Table 9). However, the within-roost temperatures at BLRIB were ~2 °C cooler than they were in the spring and summer. Bats maintained relatively high temperatures (averaging 31 °C) throughout the morning, but in middle of the day and afternoon, the temperatures of bats frequently fell very close to ambient (Figure 16).

In all bridges, the average daily within-roost temperature of individuals is 31–33 °C, excepting MB, where within-roost temperatures are only 30 °C. Bat skin temperatures within CB fluctuated to a much higher degree than was observed at BLRIB and MB. This fluctuation included a greater tendency for torpor (regularly allowing body temperatures to drop below 30 °C in the mornings), and frequently temperatures rose above 35 °C in the afternoon. Bats left the roost ~20 minutes after sunset, returning after only 45 minutes or up to nine hours later. We are unable to report on temperatures while foraging, as bats were out of range of the datalogging receivers once they left their roosts. Upon returning to the roost, their temperatures dropped through the rest of the night and into the morning. As ambient temperatures climbed and approached the bats' temperatures, bat skin temperatures climbed rapidly. Afternoon temperatures of individuals could reach ≥ 40 °C. As ambient temperatures fell in the evening, a decrease in the body temperatures of the bats typically followed. Commonly a brief rise in body temperature was detected just prior to the bats leaving the roost at dusk. Daily fluctuation of temperatures of individuals >15 °C were commonly observed at CB. In BLRIB and MB bridges, early morning body temperatures were held relatively high (>30 °C) and declined more slowly. The afternoon and evening rise above ambient temperatures was less dramatic than observed at CB and the daily fluctuations of the temperatures of individuals at BLRIB and MB bridges did not exceed 10 °C.

At BLRIB and MB bridges, bats showed a similar pattern to what we observed at the CB, but experienced a smaller drop in temperatures during the morning (e.g., compare temperatures of bats within BLRIB and CB bridges in Spring 2019 in Figure 16). These data suggest that BLRIB and MB bridges provide a more stable roosting habitat than does CB. The BLRIB is 15 m taller and MB is 156 m longer, which likely contributes to their more stable thermal environments when compared to CB.

Structures

Systematic bridge surveys

Of the 250 random bridges we surveyed within 400 m of major streams in the French Broad River Basin, 10 were found to be used by gray bats either during our initial systematic searches or during subsequent searches. Of the ten, ISU found nine from 2018–2020 and NCWRC found one in 2020. Of the nine bridges ISU found during searches, only one yielded gray bats on the initial search and at the other eight bridges we did not confirm use by gray bats until a second visit. The tenth bridge was also randomly selected and surveyed three times by ISU, yielding other species but not gray bats; subsequently, NCWRC found a single gray bat in this bridge in May 2020. Of the 250 random bridges we surveyed, 13 were being used by at least one other species (*Eptesicus fuscus, Myotis leibii, Perimyotis subflavus, Tadarida brisiliensis*), but not gray bats. We found only dead bats at two of the 250 random bridges (NCDOT # 100014 and 990093); we included those bridges in our modeling analysis.

Opportunistic bridge surveys

We searched at least 23 additional bridges opportunistically and found three bridges (Little East Fork bridges # 430090 and # 430091 and the Shelton Laurel Bridge #560033) being used by gray bats and four bridges (# 560102, # 560210, # 990038, and a private bridge at Sam's Club in Asheville) being used by big brown bats (*E. fuscus*), but not gray bats.

Surveys of structures adjacent to Transportation Improvement Project (TIP) point locations

TIP # B-5901 (440121 bridge replacement): We examined this bridge and saw no evidence of bats there on 16 June 2019.

TIP # B-5953 (100649 bridge replacement): We examined this bridge and saw no evidence of bats there on 20 June 2018 and 15 May 2020. We were unable to inspect the middlemost portion of the bridge over the river. In both 2018 and 2019, we detected many hours of foraging activity at the N2 telemetry tower, which is 1.3 km to the north of this bridge along the French Broad River (see *Bat detections on passive telemetry towers* section in *Foraging* below). This tower also recorded daytime observations for one radio-tagged bat on the south oriented antenna that faces the current bridge (# B-5953).

TIP # B-5989 (Walnut Creek Rd/Big Laurel Creek Bridge # 560071 bridge replacement): This bridge was selected for a systematic survey on 18 June 2019; we did not find any evidence of bats roosting there on that visit. We surveyed this bridge again on 15 April 2020 and found one gray bat and one big brown bat roosting in crevices where the deck meets the guardrail, visible from underneath to the side of the bridge. On 19 April 2020, we again saw two bats (we did not identify them) roosting in the bridge, and on three subsequent visits in 2020 (24 May, 12 June, and 25 June) we did not observe any bats using the bridge. We recorded moderate levels of gray bat foraging activity, mainly July–October, at the Big Laurel acoustic station ~100 m from the bridge (see *Acoustics* section below).

TIP # B-5992 (100007 bridge replacement): We examined this bridge on 20 June 2018 and on 24 May 2020. On the second visit, we found one bat (we were unable to identify the species) roosting in the crevice over the cap on the east end, north side of the bridge on our second visit. We were unable to inspect the middlemost portion of the bridge over the river.

TIP # I-2513C (I-26/I-40/I-240 interchange improvement): We surveyed seven bridges within this interchange area (bridges # 100066, 100182, 100253, 100254, 100273, 100334, and 100339) and did not find any evidence of bats. However, we were unable to examine some of the middlemost sections of the bridges, especially guardrail crevices on top of the bridges because of traffic. We recorded 11 radio-tagged gray bats with the radio-telemetry tower located on Hominy Creek at the eastern edge of this interchange (see *Bat detections on passive telemetry towers* section below; Tower W1; Tables 15 and 16).

TIP # I-4409 (I-40/SR 2500 interchange improvements and widening): We examined one bridge (# 100488) at the interchange and saw no evidence of bats there on 2 June 2019 and 15 May 2020. We also surveyed the bridge (# 100041) on SR 2500 that crosses the Swannanoa River on 13 June 2018 and did not find any evidence of bats using the bridge.

TIP # I-6018 (I-240/74A interchange improvement): We surveyed a culvert (I-40/74A Culvert # 100508) underneath I-40 at this interchange on five occasions. On 5 September 2019 we saw two gray bats roosting in the culvert, on 10 September 2019 we saw four gray bats roosting in the culvert, and on 4 April 2020 we saw one gray roosting in the culvert. During winter surveys on 16 December 2019 and 29 February 2020 we did not observe any bats inside of the culvert. We have not surveyed any bridges within this project area.

TIP # I-6021 (I-40/SR 2838 interchange improvement): We examined two bridges (# 100475 and # 100738) at this interchange. On 11 July 2019 we surveyed bridge # 100475, and on 19 June 2018 and 15 May 2020 we surveyed bridge # 100738; we did not see evidence of bats on any of these visits.

TIP # 14SP.20881.1 (870045 bridge replacement): We examined this bridge and saw no evidence of bats there on 22 June 2018.

Surveys of structures adjacent to select Transportation Improvement Project (TIP) line locations

TIP # A-0010 (I-26/Future 26): We inspected two bridges (# 100303, 100314) and two culverts (# 100774, HSC) adjacent to TIP # A-0010AA. We surveyed bridge # 100303 two times, first on 18 June 2019 and again on 15 May 2020, and saw no evidence of bats. We surveyed bridge # 100314 on 18 June 2019 and saw no evidence of bat use. We searched for bats at culvert # 100774 (underneath NC 251 at Reed Creek) on 12 September 2019 but saw no evidence of bat use. We have surveyed the HSC four times in winter months (December–March), finding 5 gray bats on 22 March 2019 and one gray bat on 23 March 2020. We did not observe any gray bats using the culvert on 14 December 2019 or on 1 March 2020. We have captured gray bats at the culvert as early as 16 April, when we began capture surveys, and as late as 25 October. In total, we captured 333 gray bats, some of which were recaptures, at the culvert. Also, in September 2017, NCWRC counted 202 bats exiting the culvert. We inspected two bridges (# 560093, 560547) and one culvert (Flat Creek 19/23 Culvert # 100409) adjacent to TIP # A-0010AB/AC. We inspected # 560093 on 10 June 2019 and 24 May 2020 and found no evidence of use by bats. We inspected # 560547 on 20 June 2018 and saw bat guano. In the Flat Creek Culvert, we saw two gray bats roosting on each visit on 4 September 2019 and 10 April 2020, one big brown bat on 18 December 2019, and no bats on 29 February 2020.

TIP # R-2588B (NC 191 widening): We inspected two bridges (# 440121, 440129) on NC 191 adjacent to TIP # R-2588B. We surveyed bridge # 440121 on 16 June 2019 and bridge # 440129 on 26 June 2019. We did not see any bats roosting in the bridges; we saw possible guano at bridge # 440121, but we were unable to determine if it was from a bat.

TIP # I-4400 (I-26 widening): We examined two culverts and two bridges on this portion of the I-26 Widening Project. On 13 September 2019 and 17 December 2019, we searched for bats at culvert # 440150, which goes underneath I-26 at Dunn Creek and at culvert # 440369, which goes underneath Upward Road (SR 1722) at Dunn Creek near the interchange with I-26. We did not find any evidence of bats at these two culverts. We inspected bridge # 440211 on 19 June 2018 and 16 May 2020 but were unable to inspect the entire bridge because of heavy traffic and construction. We did not find any evidence of bat use. We inspected bridge # 440221 on 11 June 2019 but were unable to inspect the middlemost section of the bridge due to heavy traffic. We did not find any evidence of bat use.

TIP # I-4700 (I-26 widening): We examined six bridges on this portion of the I-26 Widening Project. The bridges we surveyed, from south to north, were # 100068 (26 June 2019), # 100113 (28 June 2018), # 100211 (28 June 2018 and 7 November 2018), # 100214 (16 April 2019 and 12 July 2019), # 100253 (14 July 2018), and # 100254 (26 June 2019). We saw single tri-colored bats roosting at bridges # 100211 and # 100214 (both currently under construction/being replaced) on 7 November 2018 and 16 April 2019, respectively, but did not see evidence of bats using any of the other four bridges. The tri-colored bats were roosting underneath the southern end of the bridges, out in the open (not inside of a crevice), near the end walls. We observed them roosting underneath the bridges when we were there to maintain our telemetry tower stationed nearby and did not do a full survey of the bridges on these visits when we observed the bats. When we did a full inspection of the two bridges (# 100211 and # 100214 on 28 June 2018 and 12 July 2019, respectively), we were unable to inspect the middlemost sections of the bridges because of water levels and traffic. We also did not inspect the drainpipes over water. From 24 July and 24 October 2018, our passive telemetry tower (S1) adjacent to the bridges recorded 16 individual radio-tagged gray bats on 23 different nights for a total of 14 hours and 53 minutes. Tower S1 was not operational until 5 June 2018, so we did not gather data there for the 16 gray bats carrying coded transmitters in mid to late April 2018. From 17 April to 21 October 2019, the telemetry tower recorded 29 individual gray bats on 60 different nights for a total of 14 hours and 17 minutes (see *Bat detections on passive telemetry towers* section under *Foraging*, below). In 2018 and 2019, we documented foraging location estimates for four gray bats at or near the two bridges, and we have detected foraging bats on a few occasions at the bridges but were not able to triangulate the bats' exact locations. For example, on 19 August 2018, within a time span of 20 minutes (20:30–20:50) we documented five individual radio-tagged bats that all roosted in the BLIRB that day flying near the I-26 bridges on the French Broad River (one of the bats may have flown over land north of the bridges). We waited underneath the bridges for the bats to fly from the west (upstream), pass the bridges on the river, and depart to the east/northeast (downstream or over land). As we actively listened, we detected bats for only 30 seconds or up to a few minutes before they moved on.

TIP # R-5744 (Balfour Parkway): We inspected one bridge (# 440211) on I-26 over Clear Creek in the proposed study area of TIP # R-5744 (we obtained the study area boundary from the Public Meeting Map available at NCDOT.gov) on 19 June 2018 and 16 May 2020. We were unable to inspect the entire bridge because of heavy traffic and/or construction and we did not see any evidence of bat use. We also inspected bridge # 440018, which is just south of the study area, on Clear Creek Road (SR 1503) over clear creek on 19 June 2018. We did not see any evidence of bat use.

Modeling

Comparing bridges used by any bat species (n = 38) to bridges where we did not detect bats (n = 225), five terms were significant in the logistic regression model (Table 11). Bats were more likely to be found in bridges that were farther from primary roads and for which a lower percentage of the surrounding landcover was urban/suburban. Bats were more likely to be found in longer bridges, with gaps > 1 cm available in the bridge deck, and with concrete beams underneath the bridge. Because we were not able to statistically compare bridges used by gray bats to bridges used by other bats, we suggest the characters of bridges used by any bat are likely important to gray bats when selecting bridge roosts in the French Broad River Basin. We note that bridges surveyed were always within 400 m of a major stream, which may have biased us against finding any effect of distance to water.

Bridges used by bats were about 1 km from primary roads, whereas unused bridges were closer (736 m; Table 12). In a 1-mile (1.6-km) buffer around bridges used by bats, an average of 18% of the landcover was urban/suburban, while this cover type was a higher percentage (mean = 28%) of the landscape around unused bridges. Bridges used by bats were about twice as long (averaging ~80 m) and more likely to have deck gaps >1 cm and concrete beams underneath. However, not all bridges used by bats had these characters and there was some variation when considering bridges used by gray bats versus bridges used by other bats. Deck gaps >1 cm were present in 57% of bridges used by gray bats and 80% of bridges used by all bats (Table 12). Concrete beams were found under 43% of bridges used by gray bats and 20% of bridges used by other bats.

Table 11. Significant parameters (bolded), estimates, standard errors (S.E.), *z* scores, and P values for terms in a global model comparing bridges used by any bat species to bridges in which we did not detect bats during systematic and opportunistic searches of 263 bridges in the French Broad River Basin of western North Carolina, April 2018 to June 2020.

Parameter	Estimate	S.E.	*z*	P
Bat use (intercept)	-6.34	1.44	-4.40	<0.001
Distance from primary road	**<0.01**	**<0.01**	**2.90**	**<0.01**
Distance from secondary road	<-0.01	<0.01	-0.39	0.70
Distance to water	<0.01	<0.01	0.13	0.90
Distance to major water	<0.01	<0.01	1.86	0.06
Urban/suburban	**-3.55**	**1.26**	**-2.83**	**<0.01**
Agricultural	1.04	1.87	0.56	0.58
Bridge length	**0.01**	**<0.01**	**2.92**	**<0.01**
Bridge width	0.01	0.05	0.27	0.79
Guardrail gap	-0.02	0.71	-0.03	0.98
Deck type	1.46	1.36	1.07	0.28
Deck gap	**1.26**	**0.62**	**2.06**	**0.04**
Bridge azimuth	-0.48	0.50	-0.94	0.35
Under type	1.21	0.67	1.80	0.07
Beam type	**1.68**	**0.59**	**2.86**	**<0.01**
Parallel gap	0.77	0.72	1.06	0.29
Perpendicular gap	0.92	0.56	1.66	0.10

Table 12. Average values for variables tested in a model comparing bridges used by any bat species to bridges where we did not detect bats during surveys in the French Broad River Basin in western North Carolina. We separated bridges used by gray bats (which sometimes also held other species, n = 23 bridges) from bridges at which we detected use only by other bat species (n = 15), but we also present the combined data used in the model (n = 38 bridges).

Variable	MYGR bridges n= 23	Other bat bridges n= 15	All bat bridges (combined) n = 38	Bridges without bats n = 225
Distance to primary road (m)	**1152 ± 407**	**763 ± 281**	**999 ± 269**	**736 ± 88**
Distance to secondary road (m)	47 ± 16	28 ± 10	40 ± 11	59 ± 16
Distance to water (m)	42 ± 33	18 ± 8	33 ± 20	33 ± 5
Distance to major water (m)	579 ± 260	34 ± 14	364 ± 162	94 ± 8
Distance to nearest MYGR cave (m)^	47574 ± 3530	48430 ± 2813	47912 ± 2381	58796 ± 1338
Pct. urban/suburban within one mile	**19 ± 5**	**16 ± 4**	**18 ± 3**	**28 ± 2**
Pct. agriculture within one mile	15 ± 3	19 ± 4	17 ± 2	14 ± 1
Bridge length (m)	**82 ± 15**	**80 ± 12**	**81 ± 10**	**42 ± 3**
Bridge width (m)	11 ± 1	11 ± 1	11 ± 1	9 ± 0.4
Pct. of bridges with guardrail gaps	83%	93%	87%	51%
Pct. of bridges with concrete decks	100%	93%	97%	69%
Pct. of bridges with deck gaps > 1 cm	**57%**	**80%**	**66%**	**28%**
Pct. of bridges with N/S azimuth	48%	47%	47%	49%
Pct. of bridges with concrete underside	87%	73%	82%	56%
Pct. of bridges with concrete beams	**43%**	**20%**	**34%**	**10%**
Pct. of bridges with parallel gaps <1 cm	30%	13%	24%	13%
Pct. of bridges with perpendicular gaps < 1 cm	61%	67%	63%	25%

^not included in the tested model

Culvert surveys, March to October

In the French Broad River Basin of NC, we know of eight culverts used by gray bats from March–October. This includes HSC found by NV5 Engineers and Consultants, Inc. in 2017. In 2019, we found six new culverts by visually searching for bats and one culvert (Allen Avenue Culvert) via radio-telemetry. We have observed (via spotlight searches and/or mist netting and harp trapping) gray bats using culverts between 22 March and 25 October. At HSC, while inside to install and/or remove temperature loggers, on 22 March 2019 we observed five gray bats roosting and on 23 March 2020 we observed one gray bat roosting. In October, we captured 1–43 gray bats at the culvert in a single night (we surveyed the culvert a total of 6 times in October), and have captured a gray bat at the entrance to the culvert as late as 25 October in 2018. In October 2018, the number of bats we captured at the HSC dwindled from 43 bats on 1 October to one bat on 25 October. We did not attempt to capture bats at the culvert past 25 October in either 2018 or 2019. In the six culverts where we found gray bats via visual searches, we observed 1–5 gray bats using each culvert on a visit in April and a second visit in September or early October. We made an opportunistic visit to the Allen Avenue Culvert on 18 September 2019 and did not observe any bats. However, we radio-tracked a single adult male gray bat (bat BRR A6361) to it during the evening of 4 October 2019 and entered the culvert 5 October 2019 to confirm the roost. We only observed the single radio-tagged gray bat using the culvert.

Foraging

Results from active telemetry (ground and aerial)

We collected 1,062 foraging location estimates for 45 gray bats (Figure 17, Table 13, Table 14; 31 females, 13 males, 1 unknown; mean 23.6 location estimates/bat) and obtained a sufficient number (≥ 32) of locations to make 100% minimum convex polygons (MCP) foraging ranges for 12 bats (1 female and 1 male in 2018, 9 females and 1 male in 2019). Foraging range sizes for focal bats averaged 2,838 ha (range 15–22,578 ha). Bats tended to fly relatively far from primary roosts; seven bats flew over 10 km away and one was detected ~17 km from a primary roost. For all tracked bats, foraging points were on average 3.1–3.8 km from primary roosts.

Gray bats mainly foraged along the two major streams (French Broad River and Pigeon River), but also foraged on smaller streams and nearby areas (Appendices G and H). Most often, bats would leave their daytime roosts flying either up or down stream. On rare occasions, bats would quickly leave the stream they were roosting on and take off in direction away from the water, likely to travel to a familiar foraging area. In NC, bats foraged an average of 377 m from major streams (0–5,099 m; mode = 2 m) and 480 m from other streams/water bodies (0–1,398 m; mode = 31 m). Often bats flying north on the French Broad River (downstream) would cross I-26 on the river, then either continue to follow the river towards Asheville or cross over land near Long Valley Lake on Biltmore Farms property before rejoining the river. Continuing further north (downstream) bats crossed under or over I-40 and I-240/I-26 before foraging north of Asheville or moving on towards Marshall. We tracked some bats from BLRIB to HSC, where they seemingly entered the culvert. As noted earlier, the culvert not only serves as a day roost, but likely also serves as a night roost or social site. Bats also foraged along other parts of the French Broad River; e.g., we tracked gray bats foraging as far south as the Asheville Regional Airport (foraging bats were also recorded by telemetry towers further south, including south of US 64) on the French Broad River and at various locations north along the river all the way up into TN.

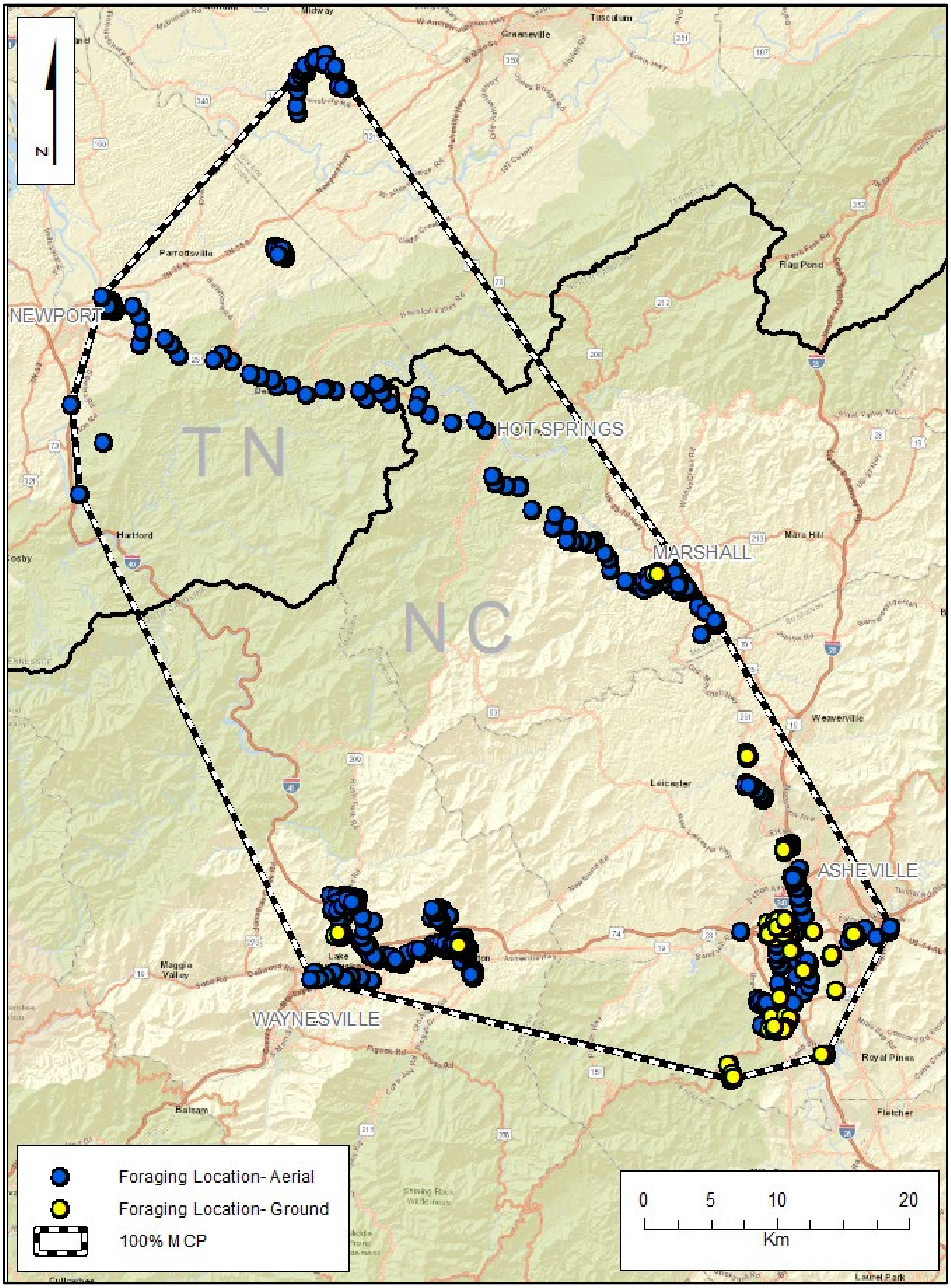


Figure 17. Foraging location estimates collected on the ground and via aerial telemetry for gray bats captured in North Carolina in 2018 and 2019. The minimum convex polygon (MCP) was made using locations from all gray bats with location estimates.

Table 13. Characteristics of foraging points for 16 gray bats tracked for 1–8 nights each in May–October 2018 in North Carolina and Tennessee. We present the mean and range (in parentheses) for each bat and means for all bats in 2018 at the bottom. We did not calculate area covered for bats with <32 locations and we do not present ranges for bats with only one location.

		Distance to Closest (minimum - maximum)								
Bat (sex)	**Number of Foraging Points**	**Mean Distance to STIP (m)[1]**		**Mean Distance to Primary Road (m)[2]**		**Mean Distance to Secondary Road (m)[3]**		**Mean Distance to Primary Roost (m)[4]**		**Area Covered (ha)[5]**
NCWRC A3740 (F)	166[g]	285	(6 - 2668)	268	(3 - 2648)	234	(2 - 416)	3460	(1628 - 5415)	3235
NCWRC A4403 (M)	32[a]	427	(1 - 2144)	664	(4 - 2144)	104	(2 - 526)	1932	(54 - 5260)	1059
NCWRC A4456 (M)	20[c]	131	(2 - 297)	126	(2 - 297)	133	(11 - 298)	1271	(763 - 5863)	-
NCWRC A3737 (F)	15[g]	205	(13 - 742)	201	(0 - 742)	105	(4 - 235)	4576	(3522 - 4920)	-
NCWRC A3863 (M)	13[g]	140	(20 - 376)	140	(20 - 376)	61	(8 - 144)	701	(93 - 978)	-
NCWRC A3960 (M)	13[g]	2808	(2603 - 2955)	185	(33 - 294)	341	(261 - 397)	9881	(9653 - 10128)	-
NCWRC A5579 (M)	11[a]	1804	(1128 - 2138)	200	(33 - 646)	116	(8 - 232)	722	(102 - 1448)	-
NCWRC A3519 (F)	10[g]	489	(261 - 726)	489	(261 - 726)	242	(9 - 447)	1374	(1251 - 1516)	-
BRR A5551 (M)	7[a]	1385	(332 - 1712)	1048	(332 - 1537)	87	(0 - 265)	4871	(4234 - 5389)	-
NCWRC A5589 (F)	6[a]	425	(32 - 857)	92	(29 - 302)	62	(6 - 175)	483	(156 - 797)	-
NCWRC A3524 (M)	4[a]	1317	(887 - 1665)	1062	(868 - 1283)	262	(90 - 399)	4150	(2636 - 5341)	-
NCWRC A3905 (F)	2[a]	11801	(10563 - 13039)	1191	(587 - 1794)	188	(0 - 376)	10621	(8637 - 12605)	-
NCWRC A3757 (F)	2[g]	1496	(1494 - 1498)	435	(432 - 437)	98	(97 - 100)	896	(894 - 899)	-
NCWRC A3507 (F)	2[g]	232	(173 - 292)	232	(173 - 292)	164	(99 - 229)	3962	(3895 - 4029)	-
BRR A5577 (M)	1[a]	406	.	406	.	14	.	627	.	-
NCWRC A4451 (M)	1[g]	47	.	47	.	73	.	850	.	-
2018 Mean		1462.4		424		143		3148.56		2147

[1]NCDOT 2020-2029 Current STIP- September 2019. [2, 3]NCDOT Route Class 1–3, 80, and 81 as primary roads and roadways of Route Class 4–7 and 9 as secondary roads. TN roads with MAF/TIGER Feature Class Codes (MTFCC_CODE) of S1100 and S1200 as primary roads and any other codes as secondary roads. [4]Primary Roosts = CB, BLRIB, MB, HSC, CCC (TN), and RC (TN). [5]Minimum convex polygon area was only calculated for bats with ≥ 30 foraging locations. [a]Locations collected by aerial telemetry only. [c]Locations collected by combination of ground and aerial telemetry. [g]Locations collected by ground telemetry only. F = female, M = male.

Table 14. Characteristics of foraging points for 29 gray bats tracked for 1–6 nights each in April–October 2019 in North Carolina and Tennessee. We present the mean and range (in parentheses) for each bat and means for all bats in 2019 at the bottom. We did not calculate area covered for bats with <32 locations and we do not present ranges for bats with only one location.

		Distance to Closest (minimum - maximum)								
Bat (sex)	Number of Foraging Points	Mean Distance to STIP (m)[1]		Mean Distance to Primary Road (m)[2]		Mean Distance to Secondary Road (m)[3]		Mean Distance to Primary Roost (m)[4]		Area Covered (ha)[5]
BRR A6286 (F)	83[a]	854	(46 - 2112)	500	(6 - 1671)	74	(1 - 332)	8088	(260 - 11913)	4592
BRR A6339 (F)	80[a]	11211	(1133 - 23602)	1183	(5 - 4574)	202	(0 - 833)	6862	(540 - 15330)	22578
BRR A5696 (F)	58[c]	643	(7 - 1011)	408	(7 - 988)	96	(2 - 230)	5884	(101 - 10018)	492
BRR A6382 (F)	53[a]	937	(5 - 2996)	641	(5 - 1922)	64	(3 - 300)	1573	(347 - 4044)	364
BRR A6346 (F)	53[c]	243	(6 - 1777)	121	(2 - 860)	80	(5 - 170)	6386	(5996 - 8214)	328
BRR A5615 (M)	45[a]	532	(7 - 2199)	307	(7 - 969)	65	(5 - 292)	4901	(54 - 8017)	826
BRR A6255 (F)	40[a]	1769	(1276 - 2908)	609	(99 - 1672)	184	(12 - 529)	981	(316 - 1801)	38
BRR A5645 (F)	38[a]	399	(191 - 659)	103	(12 - 254)	54	(1 - 121)	1698	(1341 - 2066)	15
BRR A6344 (F)	35[a]	1594	(91 - 2807)	1586	(91 - 2807)	182	(16 - 376)	3808	(390 - 5142)	496
BRR A6283 (F)	32[a]	149	(20 - 534)	149	(20 - 534)	45	(2 - 124)	670	(149 - 1197)	34
BRR A5644 (F)	27[a]	30242	(28037 - 31624)	1958	(435 - 3176)	219	(1 - 725)	15712	(13849 - 16893)	-
BRR A6367 (F)	27[a]	472	(0 - 1426)	313	(0 - 885)	52	(2 - 159)	2323	(228 - 7264)	-
BRR A5691 (F)	25[c]	114	(1 - 265)	114	(1 - 265)	35	(1 - 101)	612	(392 - 827)	-
BRR A6345 (F)	21[a]	378	(70 - 696)	273	(3 - 569)	300	(11 - 654)	972	(411 - 1619)	-
BRR A5642 (F)	20[a]	19525	(18761 - 19924)	2002	(1614 - 2763)	244	(74 - 426)	10608	(10000 - 10928)	-
BRR A6349 (F)	20[a]	388	(207 - 605)	388	(207 - 605)	443	(300 - 677)	865	(521 - 1105)	-
BRR A6291 (F)	14[a]	189	(48 - 325)	195	(48 - 314)	68	(20 - 209)	241	(94 - 454)	-
BRR A6331 (F)	13[a]	748	(22 - 1694)	752	(270 - 1396)	122	(5 - 297)	3406	(905 - 5387)	-
BRR A6380 (F)	12[a]	174	(47 - 325)	170	(47 - 325)	32	(3 - 87)	514	(131 - 720)	-
BRR A5657 (M)	11[a]	1266	(1040 - 1463)	1037	(791 - 1190)	143	(38 - 245)	1540	(1267 - 1691)	-
Coded	10[a]	1148	(732 - 1822)	827	(676 - 1105)	146	(8 - 235)	1488	(1069 - 2202)	-
BRR A5617 (F)	9[a]	2139	(1488 - 2939)	728	(76 - 1540)	208	(108 - 352)	7128	(6289 - 7934)	-
BRR A6435 (F)	7[g]	208	(1 - 756)	254	(1 - 756)	211	(64 - 400)	3811	(3411 - 4431)	-
BRR A5622 (M)	7[g]	4186	(4067 - 4336)	4179	(4060 - 4310)	84	(8 - 190)	5160	(4711 - 5535)	-
BRR A6326 (F)	7[g]	1560	(1520 - 1611)	509	(360 - 612)	172	(104 - 235)	947	(823 - 1041)	-
BRR A6338 (F)	6[a]	5228	(1465 - 23116)	444	(142 - 631)	173	(33 - 441)	1511	(1214 - 2398)	-
BRR A6361 (M)	2[g]	632	(522 - 742)	526	(494 - 558)	104	(41 - 166)	4990	(4872 - 5107)	-
BRR A5690 (F)	1[a]	16649	.	17	.	336	.	5960	.	-
BRR A6332 (F)	1[a]	2104	.	492	.	259	.	633	.	-
2019 Mean		3644.2		717		152		3768		2976

[1]NCDOT 2020-2029 Current STIP- September 2019. [2, 3]Route Class 1–3, 80, and 81 as primary roads and roadways of Route Class 4–7 and 9 as secondary roads. TN roads with MAF/TIGER Feature Class Codes (MTFCC_CODE) of S1100 and S1200 as primary roads and any other codes as secondary roads. [4]Primary Roosts = CB, BLRIB, MB, HSC, CCC (TN), and RC (TN). [5]Minimum convex polygon area was only calculated for bats with ≥ 30 foraging locations. [a]Locations collected by aerial telemetry only. [c]Locations collected by combination of ground and aerial telemetry. [g]Locations collected by ground telemetry only. F = female, M = male.

It was not common for us to detect a bat foraging away from water, but we sometimes did. For example, on 16 August 2019, Copperhead tracked (via aerial telemetry) bat BRR A6339, a post-lactating adult female gray bat, from MB flying approximately 5 km north on the French Broad River before she left the river flying northwest approximately 13 km over land and then rejoined the river briefly. She then flew an additional ~11 km over land before rejoining the river again (Appendix H, Figure H13). We sometimes tracked bats on land near CB (e.g., bat BRR A6382 flew from CB area across land and I-40 to forage over land on at least two nights, Appendix H, Figure H22) and we occasionally picked up bats flying over the north end of the Biltmore property south of I-40 and the French Broad River. We tracked an adult female (bat BRR A6346) north from BLRIB across the Biltmore Forest community and/or Biltmore property, across Hendersonville Rd in Asheville, to where it foraged multiple nights near I-40 and Sweeten Creek Road, between two smaller streams, and also near Gashes Creek by Alternate 74 (Appendix H, Figure H16). We later found gray bats roosting in a culvert where Gashes Creek runs underneath I-40 (I-40/74A Culvert #100508).

We tracked bats to four reservoirs: Enka Lake, Lake Julian, Lake Junaluska, and Long Valley Lake. On 6 May 2018, we detected an adult male gray bat (bat NCWRC A3953) foraging at Enka Lake near Candler, NC. The bat was radio-tagged at BLRIB on 18 April, roosted in the bridge from 20 April–11 May, and was detected by the N4 telemetry tower on the French Broad River north of Marshall from 01:23–01:25 on the 13 May. We never detected the bat afterwards and were not able to map out its foraging range. We detected another bat carrying a coded tag (at the time we did not have a receiver to identify the unique ID for the bat) foraging at the lake on 8 May 2018. The next year, on three consecutive nights, 19–21 July 2019, we detected one or more bats carrying a coded tag and flying at Enka Lake, but at the time we did not have a receiver to identify the unique ID for the bat(s). We also detected an adult post-lactating female gray bat (band BRR A6465) foraging at Enka Lake at 23:10 on 25 July 2019; she was radio-tagged at BLRIB on 24 July. BRR A6465 was also detected at the S1 telemetry tower on 25 July from 21:21–21:27, then again at 05:49–05:51 in the morning before dawn. We did not detect her on any other telemetry towers that night and suspect she flew from the French Broad River to Enka Lake over land, at least in part. We did record BRR A6465 on the W2 tower on Hominy Creek and S1 tower on several subsequent nights, and on the N1, N2, and N3 towers on 1 August, but did not map out a foraging range for this bat. We also detected an unknown coded tag again at Enka Lake on 30 July 2019. We tracked an adult male gray bat (bat BRR A6361) south from the BLRIB before he left the river to cross I-26 just south of the Long Shoals Road Bridge (NCDOT # 100053) up to Lake Julian (Appendix H, Figure H29). Then he crossed Lake Julian before crossing over Long Shoals Road and entering a culvert near Allen Avenue in Asheville. The next day we found the bat roosting inside the culvert. We also recorded 13 bats on the radio-telemetry tower station at Lake Julian, but it is unclear whether or not these bats were foraging on Lake Julian or along the French Broad River (1 of the 2 directional antennae was pointing towards the river). On 3 October 2019, Copperhead tracked an adult female gray bat (bat BRR A6286), via aerial telemetry, foraging over Lake Junaluska; although we never found a roost for this bat, she was captured at BLRIB (Appendix H, Figure H26). We have also tracked at least three gray bats foraging at, or near, Long Valley Lake on Biltmore Farms property.

Foraging activity near roads and Transportation Improvement Projects (TIPs)

Gray bats sometimes foraged over primary and secondary roads, which is to be expected given that major roosts are in bridges on main roads. Further, primary and secondary roads often intersect or are adjacent to major rivers and streams on which gray bats forage. For a fast-moving bat, it was difficult for us to pinpoint locations as either road or stream when we tracked bats near the intersection of a road and a waterway. On average, foraging locations for all tracked bats were relatively close to secondary roads (143–152 m; Tables 13 and 14). However, foraging points tended to be farther from primary roads (averaging 424–717 m across two years).

Ten bats foraged within 10 m of a TIP and 11 bats foraged within 100 m of a TIP. Twenty-four bats were never detected within 100 m of a TIP. In our calculations of distance between foraging points and TIPs (Table 13 and 14), we used a line feature rather than a polygon feature for the I-26 Connector Project TIP (I-2513), which underrepresents the number of foraging points close to this TIP. We documented 130 location estimates from six different foraging gray bats within the I-2513 project polygon (I-2513_Project Study Area_072314 shapefile; Figure 18). Most of these foraging locations were within 1.5 km of where I-40 crosses the French Broad River, south of Amboy Road and the Carrier Park area in West Asheville. These foraging locations were along the river, near I-40, or in forested/field areas of the Biltmore property. On multiple nights, a foraging bat stopped moving while on the Biltmore property in a forested area just south of I-40, suggesting the bat was night roosting there. We also documented one foraging location within the I-2513 study area near Sand Hill Road (SR-3412) in the Ragsdale Creek/Lake Ashnoca area. The other foraging locations within the I-2513 project study area were along the French Broad River from just south of the Craven Street (SR-3408) bridge to around the HSC. However, we did track bats foraging north of the HSC along the river without obtaining location estimates via triangulation. In sum, wherever the I-2513 project comes near the French Broad River, we documented foraging gray bats.

We also documented foraging activity near other TIPs, such as U-3403B on NC 191, I-4700 on I-26 (mainly along the French Broad River where the bridge crosses), I-5889 and I-6063 on I-40, U-4739 on Amboy Road (SR-3556), U-5019 along the French Broad River, U-5019E on the Craven Street Bridge, EB-5945 on Champion Drive (NC 215) in Canton, and I-5834/I-6051 on I-40 northwest of Clyde (Appendices G and H).

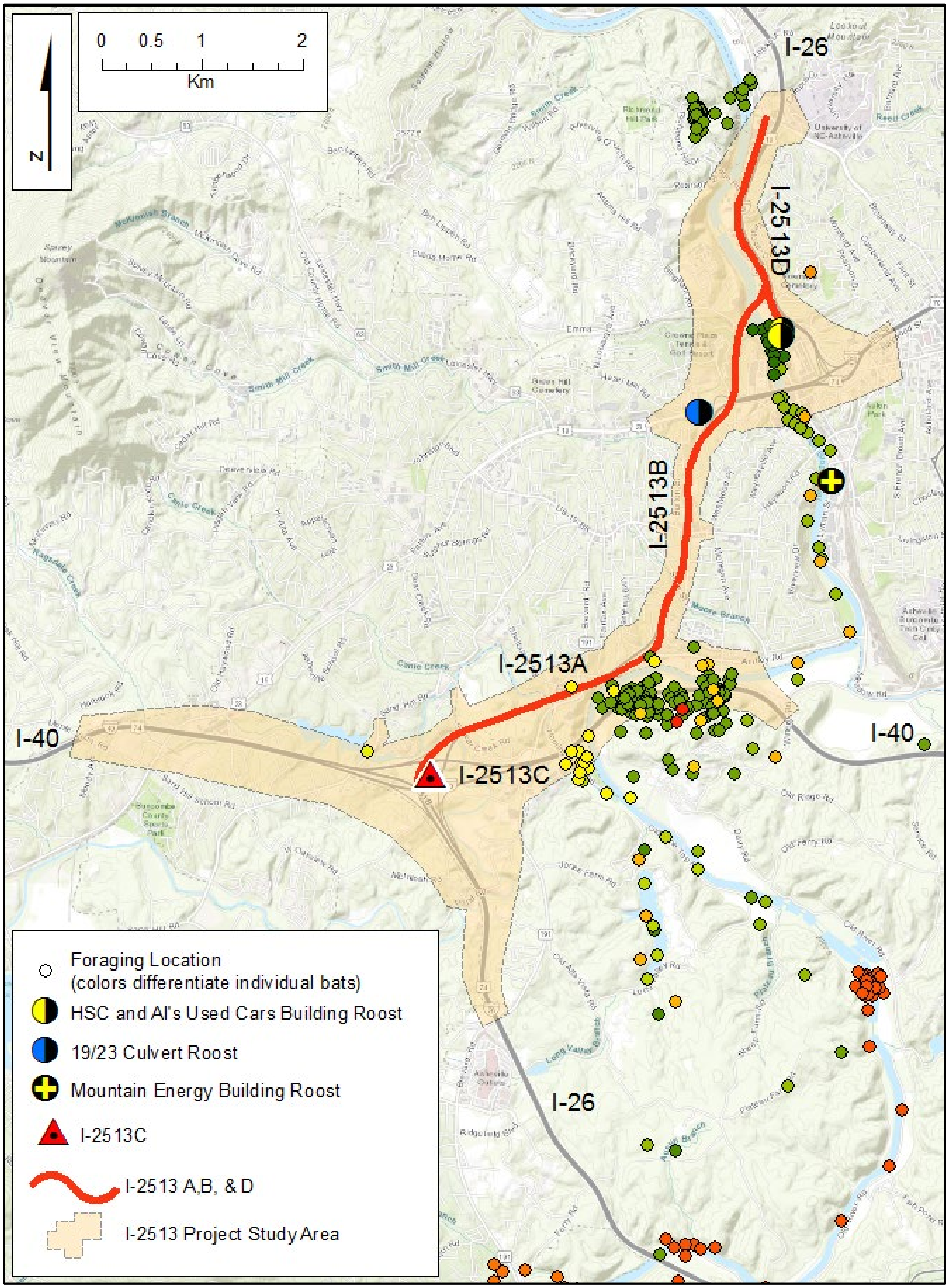


Figure 18. Roost and foraging location estimates from 2018 and 2019 for gray bats in and around the I-26 Connector Project (TIP # I-2513) in Buncombe County, NC.

Bat detections on passive telemetry towers

In 2018, the passive telemetry towers detected 42 of 45 bats carrying coded radio tags on 77 nights from 19 April to 24 October. Recordings of individual radio tagged bats at night, which we term 'bat activity', lasted from less than one minute to up to 5.5 hours. Bat detections were concentrated along the North-South axes (Figure 19). The North axis, with four towers along the French Broad River north of downtown Asheville, recorded 81% of all bat activity in 2018 (Table 15), which suggests this river corridor is a significant foraging and migration route for gray bats in this region. The N1 and N4 towers recorded 55+ hours over 54 nights and 42+ hours over 45 nights, respectively. Though each tower recorded 22 individual bats, these high hourly values were driven by many hours of recordings for two individual bats at each tower; we suspect these bats rested at night roosts within range of the tower. One bat detected by the N1 tower for ~12 hours over a period of several days was an individual that roosted in a nearby building (Al's Used Cars Building) on a few different days in Spring 2018. A bat detected for ~19 hours on the N4 tower could have night roosted in a tree, as it was confirmed day roosting in a sycamore tree during the same time period (late September 2018). The South axis, which included towers on the French Broad south of Asheville and Lake Julian, recorded about 17% of all bat activity. Although the S1 tower under the I-26 Bridge on the French Broad River was not deployed until July 2019, it still detected 16 bats over 23 days and almost 15 hours. This tower is north of BLRIB, so bats roosting in this bridge may pass by this tower on their way to the bridge from downstream portions of the French Broad River. The S2 tower at Lake Julian, 0.8 km from the French Broad River, was visited by six bats over 14 nights. Towers on the East and West axes generally recorded no bat activity. Still, data from the W1 and W2 towers demonstrate that Hominy Creek west of Asheville is an important foraging area for a smaller number of bats (8 unique individuals detected on these two towers over about 3.5 hours). The W4 tower was not functioning properly in 2018.

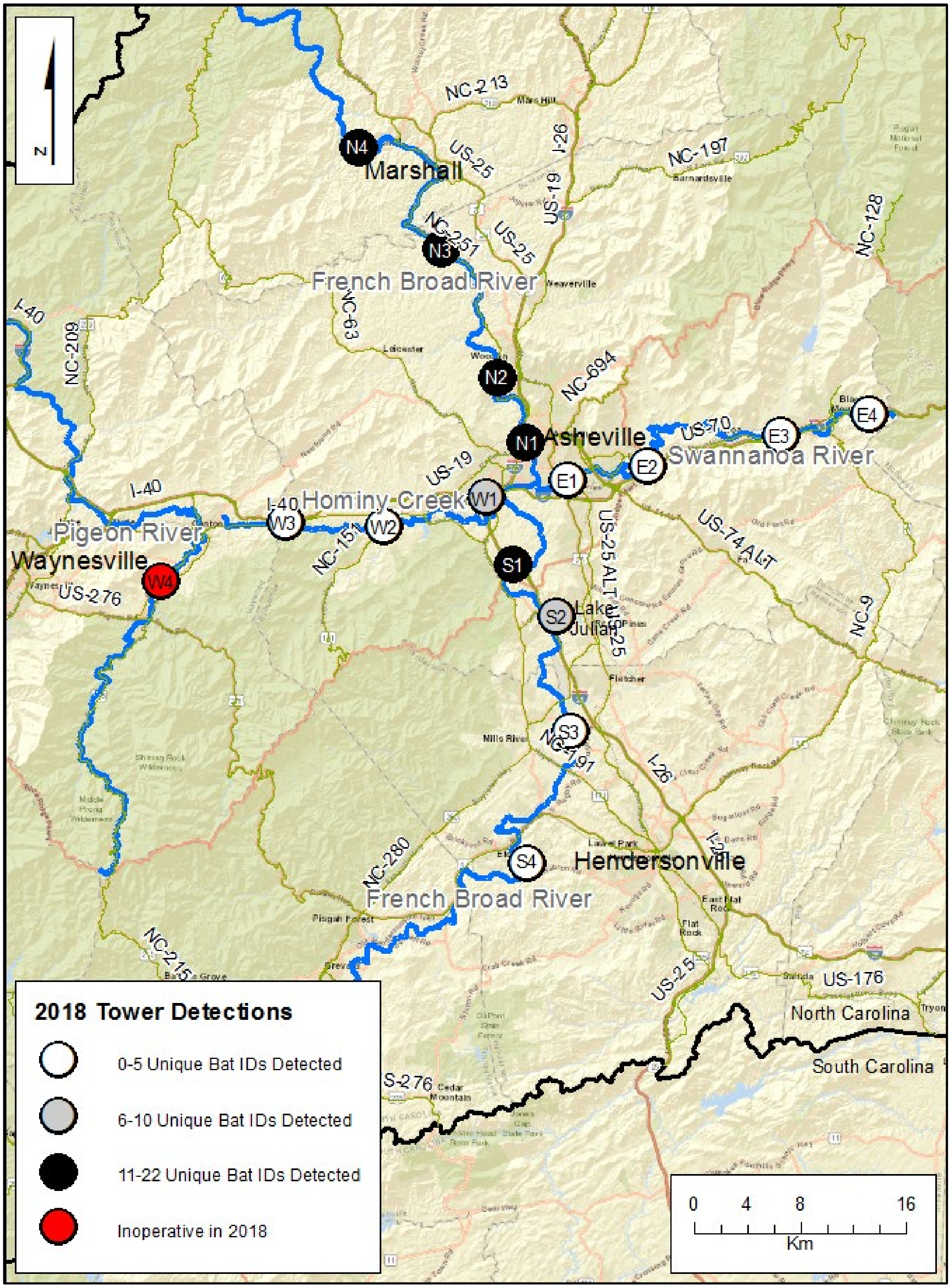


Figure 19. Locations of 16 radio-telemetry towers used to detect foraging gray bats in the French Broad River Basin of western North Carolina in 2018. The towers are distinguished by the number of unique individual radio-tagged bats detected during the period, April– October 2018.

Table 15. Nighttime bat activity detected by 16 fixed telemetry towers positioned along East, North, South, and West axes in the French Broad River Basin in western North Carolina, April to October 2018.

Tower	Location	Total time bats recorded (hh:mm:ss)	Proportion of all tower activity	Number of unique bat IDs	Number of nights bats detected
E1	Swannanoa at Antique Mall	0:00:00	0.00	0	0
E2	Swannanoa at Anchor Steam	0:02:11	< 0.01	1	2
E3	Swannanoa at Ingles HQ	0:00:00	0.00	0	0
E4	Ridgecrest	0:00:00	0.00	0	0
N1	FBR at Hill Street Culvert	55:28:12	0.39	22	54
N2	FBR at Sewage Dept	12:38:17	0.09	17	38
N3	FBR at Panther Branch	2:49:12	0.02	11	16
N4	FBR at Little Pine	42:46:56	0.30	22	45
S1	FBR at I-26	14:53:35	0.11	16	23
S2	Lake Julian	6:39:41	0.05	6	14
S3	FBR at Super Sod	2:06:45	0.01	4	7
S4	FBR at Cummings Cove	0:00:00	0.00	0	0
W1	Bear Crk Campgrd-Hominy Crk	3:07:35	0.02	6	6
W2	Hominy Crk-Candler	0:29:44	< 0.01	2	8
W3	Hominy Crk-Wiggins Rd.	0:00:00	0.00	0	0
W4	Pigeon River	-	-	-	-

In 2019, the passive telemetry towers detected 38 of 49 bats carrying coded radio tags on 85 nights from 17 April to 21 October. Again, most of the bat detections were along the North-South axis (Figure 20). Bat activity on each tower lasted from less than one minute to 5 hours and 22 minutes. The North axis detected about 66% of all bat activity in 2019 (Table 16), driven by almost 27 hours of detections at N1, near HSC, and almost 14 hours of activity near N2. One bat accounted for about half of the bat activity on N2; because we recorded ~19 hours of daytime activity for this bat (not included in these calculations), we suspect it was day roosting in a nearby structure (e.g., bridge, building, or tree). It is also possible the sewage treatment plant near this tower promotes high productivity in the river and, hence, this section could be good foraging habitat for gray bats. The South axis recorded 27% of all activity in 2019. Though the S1 tower recorded bats for fewer hours (~14) than the N1 and N2 towers, the S1 tower recorded more individuals (29) and on more nights (60). As in 2018, activity on the S1 tower is likely a function of bats flying past the tower as they commute along the river to/from BLRIB roost. The S2 tower at Lake Julian remained important for a few individuals (7 over 20 nights). Interestingly, we detected one male bat who visited the area near the S4 tower the evening he was captured at BLRIB (6–7 May). He foraged near the tower from midnight to about 2:15 am and was then detected by the S2 tower at Lake Julian around 3:30 am. The East and West axes each accounted for about 3% of the total bat activity. The East towers along the Swannanoa River collectively recorded 10 different bats for a little over two hours of foraging time. Activity on the W1 and W2 towers was similar to 2018. One adult female was detected on the W4 tower on 3 May, four days after she was captured at MB. Later the same night, she was detected at the E3 tower on the Swannanoa River.

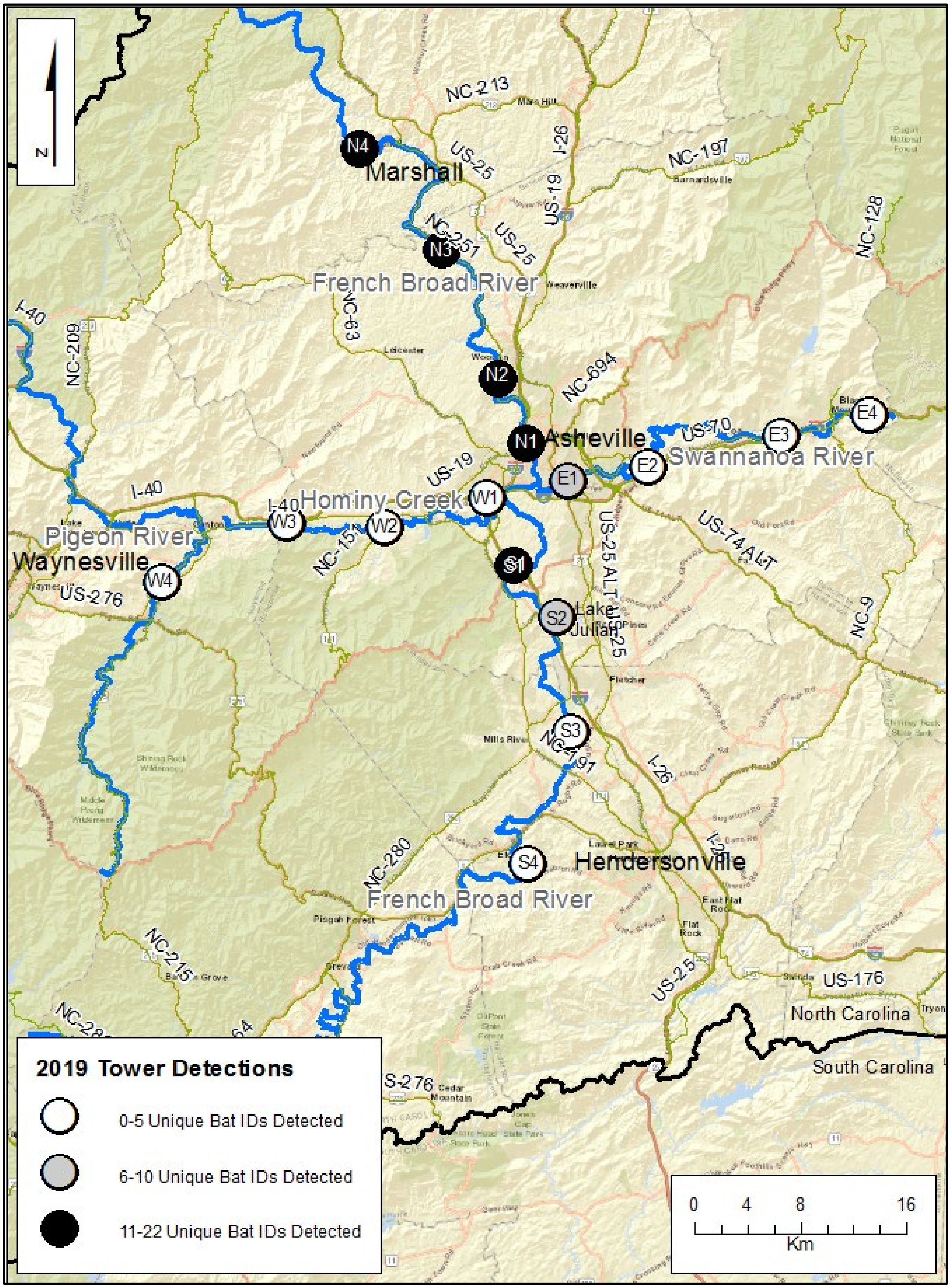


Figure 20. Locations of 16 radio-telemetry towers used to detect foraging gray bats in the French Broad River Basin of western North Carolina in 2019. The towers are distinguished by the number of unique individual radio-tagged bats detected during the period, April– October 2019.

Table 16. Nighttime bat activity detected by 16 fixed telemetry towers positioned along East, North, South, and West axes in the French Broad River Basin in western North Carolina, April to October 2019.

Tower	Location	Total time bats recorded (hh:mm:ss)	Proportion of all tower activity	Number of unique bat IDs	Number of nights bats detected
E1	Swannanoa at Antique Mall	0:34:02	0.01	9	14
E2	Swannanoa at Anchor Steam	0:27:45	0.01	1	5
E3	Swannanoa at Ingles HQ	1:16:44	0.02	2	1
E4	Ridgecrest	0:00:00	0.00	0	0
N1	FBR at Hill Street Culvert	26:58:40	0.40	17	34
N2	FBR at Sewage Dept	13:53:30	0.21	20	37
N3	FBR at Panther Branch	2:18:11	0.03	14	23
N4	FBR at Little Pine	1:49:17	0.03	19	27
S1	FBR at I-26	14:17:07	0.21	29	60
S2	Lake Julian	3:16:57	0.05	7	20
S3	FBR at Super Sod	0:06:36	< 0.01	3	3
S4	FBR at Cummings Cove	0:24:29	0.01	1	2
W1	Bear Crk Campgrd-Hominy Crk	0:19:57	< 0.01	5	6
W2	Hominy Crk-Candler	1:53:30	0.03	2	11
W3	Hominy Crk-Wiggins Rd.	0:00:00	0.00	0	0
W4	Pigeon River	0:05:19	< 0.01	1	1

Migration

Telemetry data show that bats migrate out of the NC portion of the French Broad River Basin during the fall. Following are accounts of likely migration activity for radio-tagged gray bats detected by the telemetry towers and datalogging receivers set at the entrance to a known hibernaculum. From these examples, we suggest the migration period spans from ~mid-September to early November. This is corroborated by MB exit counts, as the roosting population declines and evacuates the bridge by the middle of October (Figure 12) and by acoustic data (see below). There is much variation among individuals, which could relate to sex, age, body condition, and destination.

Data from fixed telemetry towers

In both 2018 and 2019, fixed telemetry towers recorded radio-tagged bats moving northwards and presumably out of NC between September and October.

> Bat NCWRC A4407, an adult male, was radio-tagged at HSC on 8 October 2018 and roosted in BLRIB from 11 October until 14 October 2018. He was recorded by radio-telemetry towers around Asheville on 8, 9, 11, and 14 October. On 14 October he was recorded on the north towers that night, and subsequently never heard from again. Given the time of year (when bats likely migrate) and the fact that this bat was recorded by the S1, N2, N3, and then N4 towers, and never heard from again, the French Broad River may have served as a migration route for this bat to head to a hibernaculum, possibly in TN.

> Bat NCWRC A3704, an adult female, was radio-tagged at BLRIB on 26 September 2018. We never found any additional roosts for her after that, but she was recorded by the S1 telemetry tower, then by the N1, N2, and N3 towers. In January 2019 she was observed hibernating in RC near Newport, TN.

> Bat BRR A6353, a post-lactating adult female, was radio-tagged at HSC on 16 September 2019 and picked up by the N1, N3, and N4 towers later that night. She roosted in MB on 17–18 September, then was picked up by the N4 tower, which is north of MB, on the night of 18 September. She was last detected on the antenna that was oriented northwards. After that, we never detected her roosting in NC again.

> Bat BRR A6256, an adult male, was radio-tagged at MB on 2 October 2019 and roosted in the bridge from 3–5 October, and 7 October. From 03:40-03:43 in the early morning of 8 October he was detected flying north past the N4 tower. We never detected him roosting in NC again.

> Bat BRR A6254, an adult male, was radio-tagged at MB on 2 October 2019, roosted in the bridge on 3–4 October, and then was detected by the N4 tower north of the bridge on the night of 4 October. He was last detected on the antenna that was oriented northwards at the N4 tower. After that, we never detected him roosting in NC again.

> Bat BRR A6232, an adult male, was radio-tagged at BLRIB on 9 October 2019. He roosted in the bridge from 10–13 October, and was detected by the S1, S2, and S3 towers during that time period. On the night of 13 October, he was detected moving north of the bridge on the S1, N2, and N4 towers. He was last detected on the antenna that was oriented northwards at the N4 tower. After that, we never detected him roosting in NC.

At least five other bats were also detected by the north axis of towers in September and October 2019, after which we never detected them again.

Bats detected by telemetry at RC near Newport, TN

Tracking beeper bats on the ground and via air was difficult due to weather. We did not detect bats migrating away from the Asheville area via active radio telemetry. However, in fall 2018 and 2019, we recorded radio-tagged bats at RC near Newport, TN.

In fall 2018, we recorded one female and four males via data loggers:

Bat NCWRC A4451 (151.389) was an adult male radio tagged at BLRIB on 3 October 2018. He roosted in BLRIB off and on throughout October and up until 5 November. He was detected at RC on the morning of 6 November. Based on the detection at RC the morning of 6 November, we suggest he traveled to the cave, 73 km north, in one night (5–6 November).

Bat BRR A5589 (151.513) was the only female we detected at RC in 2018; she was radio tagged on 13 October 2018 at BLRIB. This bat foraged around the paper mill along the Pigeon River on the night of 15 October but disappeared around 23:15 (see Appendix G, Figure G11). The next night, 16 October, we heard her foraging in the same spot, but she disappeared again at 19:50. The plane was grounded that night due to storms. Based on the detection at RC the morning of 17 October, we suggest 151.513 traveled to the cave (≥ 54 km) in one night (16–17 October).

Bat NCWRC A4406 (151.148) was an adult male radio tagged at HSC on 10 October 2018. He roosted in BLRIB 16–17 October. He was detected at RC on 22 October.

Bat BRR A5579 (151.239) was an adult male radio tagged at MB on 18 October 2018 and detected foraging around the bridge that night (see Appendix G, Figure G14). He roosted in MB again on 20 October and again 27–28 October. Based on the detection at RC the night of 28 October at 23:48, we suggest he traveled to the cave, 47 km north, in a few hours on one night (28 October).

Bat NCWRC A4403 (151.350) was an adult male radio tagged at HSC on 19 October 2018. Shortly after being tagged, he moved to BLRIB (see Appendix G, Figure G16). He roosted in BLRIB until 30 October. He was detected at RC on the evening of 31 October.

In fall 2019 we recorded three adult female gray bats via data logger and one adult female gray bat at emergence time at the entrance to RC:

Bat BRR A6367 (151.179) was an adult female radio-tagged at CB on 23 September 2019. We detected her at RC on 27 September.

Bat BRR A6283 (151.740) was an adult female radio-tagged at CB on 30 September 2019. On 1 October we detected her near the paper mill in Canton and on 3 October we recorded her at RC.

Bat BRR A6255 (151.940) was an adult female radio-tagged at MB on 2 October. She roosted in MB on 3 October 2019 and was recorded at RC, 47 km away, shortly after midnight on the night of 3 October. We detected her again at RC on 18 October.

Bat BRR 6286 (151.261_B) was an adult female radio-tagged at CB on 30 September 2019. On 1 October we detected her near the paper mill in Canton and via radio-telemetry we heard her at emergence from RC on 7 October. We also heard a bat carrying a coded radio tag at RC on 7 October 2019.

Winter Surveys

Gray bats have not been found hibernating in NC, but gray bats from NC have been found hibernating in a cave in TN. Since July 2016, NCWRC biologists have surveyed 69 hibernacula (caves and mines) in western NC but have not found any gray bats (K. Etchison, NCWRC, personal communication). Despite NCWRC banding 40 gray bats in NC between 2005 and 2017, no gray bats with NC armbands were observed or captured in TN prior to this study (Chris Ogle, TWRA and Riley Jackson, UT-Knoxville, personal communication). On 18 January 2019, TWRA recovered 33 hibernating gray bats with NC armbands (NCWRC and BRR prefixes) in RC near Newport, TN (Table 17). We found 26 of the armband numbers in our database and NCWRC had record of one of the bats (NCWRC A2715) originally captured in 2016 at BLRIB. The remaining seven bands with either NCWRC or BBR prefixes must have been misread during the hibernacula survey, as the numbers did not match our records. In RC, there were also many other bats with armbands not read during the survey (the total gray bat count during the survey was 250,689; TWRA 2019), so it is likely that additional gray bats from NC were using the cave as a hibernaculum.

We observed gray bats using HSC only in late March, as noted in the *Culvert surveys, March to October* section under *Structures* above. We did not see any gray bats using any of the other 13 culverts when we visited them in December 2019 and February 2020. However, we did find gray bats using all six of the known gray bat culverts (culverts used by gray bats discovered in late-September and early-October) from 4–11 April 2020 when we entered them to remove temperature loggers. On 18 December 2019, we found one big brown bat using the Flat Creek culvert underneath US 19/23 (NCDOT #100409) ~55 m from the west entrance. On 28 February 2020, we also saw two tri-colored bats using the Hyatt Creek culvert (NCDOT # 430097) underneath the intersection of I-74 and Hyatt Creek Road (SR 1168) ~59 m from the upstream entrance.

Table 17. Records of gray bats captured in North Carolina and found hibernating at RC near Newport, Tennessee on an 18 January 2019 survey by TN Wildlife Resources Agency. Seven other bats with North Carolina armbands (NCWRC and BRR prefixes) were recovered, but the numbers were misread. The age listed is from the time of first capture.

Bat	Age and Sex*	Date(s) of Capture	Capture Site (Other Roosts)
NCWRC A2715	AF	8/30/2016	BLRIB
NCWRC A3957	AM	4/19/2018, 7/26/2018	HSC (BLRIB)
NCWRC A3962	AM	4/20/2018	MB
BRR A5495	AM	7/26/2018	HSC
BRR A5466	AM	7/26/2018	HSC
NCWRC A3536	JM	8/6/2018	HSC
NCWRC A3532	JM	8/6/2018	HSC
NCWRC A3524	AM	8/6/2018, 10/10/2018	HSC (BLRIB)
NCWRC A3517	AM	8/14/2018	MB
NCWRC A3508	AM	8/15/2018	HSC
NCWRC A3504	AM	8/15/2018	HSC
NCWRC A3735	AM	8/15/2018	HSC
NCWRC A3716	AM	8/15/2018	HSC
NCWRC A3704	AF	9/26/2018	BLRIB
NCWRC A3703	AM	9/26/2018, 10/1/2018	BLRIB, HSC
NCWRC A3927	AM	9/28/2018	MB
NCWRC A4478	AM	10/1/2018	HSC
NCWRC A4473	AM	10/1/2018	HSC
NCWRC A4468	AM	10/3/2018	BRP
NCWRC A4451	AM	10/3/2018	BRP
NCWRC A4466	AM	10/3/2018	BRP
NCWRC A4469	AM	10/3/2018	BRP
NCWRC A4418	AM	10/4/2018	CB
NCWRC A4433	AM	10/4/2018, 4/18/2019, 4/22/2019	CB
BRR A5553	AM	10/14/2018	BLRIB
BRR A5570	AM	10/14/2018	BLRIB

*AM = Adult Male, AF = Adult Female, JM = Juvenile Male

Temperatures in culverts

From mid-December 2019 to mid-March 2020, the iButton datalogger data showed that temperatures in 12 culverts ranged from −4.5°C to 18.5°C (Table 18). HSC was the warmest, with the mean temperature being 0.9–3.8°C warmer than other culverts. HSC never dropped below 0°C, whereas 10 other culverts did. The Smith Mill Creek Culvert (NCDOT # 100769) underneath U.S. 19/23 also stayed at or above 0°C. The shortest culvert (#990022), which was only ~100 m in length, was also the coldest culvert.

Table 18. Temperatures recorded in 12 culverts in the French Broad River Basin in western NC from 19 December 2019 to 9 March 2020. Temperatures were recorded by 3–14 iButton dataloggers per culvert, depending on culvert length (see Table 2 for lengths).

Culvert	Month	T_{mean} (°C)	T_{min} (°C)	T_{max} (°C)
100297	Dec	7.4	-1	15.5
	Jan	6.5	-4	16
	Feb	6.9	-1	13.5
	Mar	6.8	-0.5	14.5
	Mean	**6.8**		
I40-Hwy209	Dec	8.7	0.5	16.5
	Jan	8.1	-2	15.5
	Feb	8.3	0	14.5
	Mar	8.1	0	15.5
	Mean	**8.3**		
HSC	Dec	10.4	3	15
	Jan	9.8	1	15
	Feb	9.4	1	17
	Mar	9.1	3	13.5
	Mean	**9.7**		
100409	Dec	8.9	0.5	16
	Jan	7.8	-3.5	16
	Feb	8.0	0	13.5
	Mar	7.6	1	12.5
	Mean	**8.0**		
100442	Dec	8.8	-2	15
	Jan	8.0	-4	15.5
	Feb	8.2	0	13.5
	Mar	8.1	0	13
	Mean	**8.2**		
100469	Dec	9.4	0.5	14.5
	Jan	8.7	-2	15.5
	Feb	8.7	1	13
	Mar	8.4	1	12.5
	Mean	**8.8**	0.9	

Culvert	Month	T_{mean} (°C)	T_{min} (°C)	T_{max} (°C)
100508	Dec	8.8	-1.5	14.5
	Jan	8.1	-5	14.5
	Feb	8.2	-1.5	17
	Mar	7.9	0	12.5
	Mean	**8.2**		
100769	Dec	8.8	1	14
	Jan	7.9	0	14
	Feb	7.9	1.5	12.5
	Mar	7.7	1.5	11
	Mean	**8.0**		
430097	Dec	8.7	1.5	16
	Jan	8.1	-2	16
	Feb	8.3	0.5	15
	Mar	8.0	1	14
	Mean	**8.3**		
430252	Dec	6.5	-1.5	13.5
	Jan	6.0	-4	16.5
	Feb	6.4	-2	14.5
	Mar	5.9	-2.5	12.5
	Mean	**6.2**		
560161	Dec	8.0	1	17
	Jan	7.1	-1	18.5
	Feb	7.1	0.5	15
	Mar	6.7	0	15
	Mean	**7.2**		
990022	Dec	6.9	-2.5	14.5
	Jan	5.7	-4.5	15.5
	Feb	5.8	-3	15.5
	Mar	5.8	-1	12
	Mean	**5.9**	3.8	

When we examined the longer-term and detailed temperature data for the HOBO deployed in the concrete portion of HSC, placed approximately 279 m from the western entrance to the culvert, we observed that the culvert temperature is relatively warm in winter, always staying above freezing, even when outside air temperatures drop below 0°C (Figure 21). Importantly, the minimum temperature recorded by the HOBO during winter (6.2°C) was warm enough to prevent supercooling and death, which is more likely for *Myotis* bats when air temperature drops to below 0°C (Davis and Reite 1967). The culvert is cool in summer (as low as 15.6°C), with a peak temperature of 21.7°C. These cool temperatures are within the range of ambient temperatures of caves used as maternity roosts by reproductive female gray bats (means range from 13.9–26.3°C for six caves in the Tennessee River Valley measured by Tuttle, 1975). A large colony of gray bats can heat its immediate roost environment (e.g., a dome in a cave ceiling) to a temperature averaging 10°C higher than the cave's ambient temperature (Tuttle, 1975), making a cold roost more suitable for pup development. On the late March days (2019 and 2020) when we observed gray bats in HSC, minimum HOBO temperatures inside the culvert were 9–11°C (Figure 21).

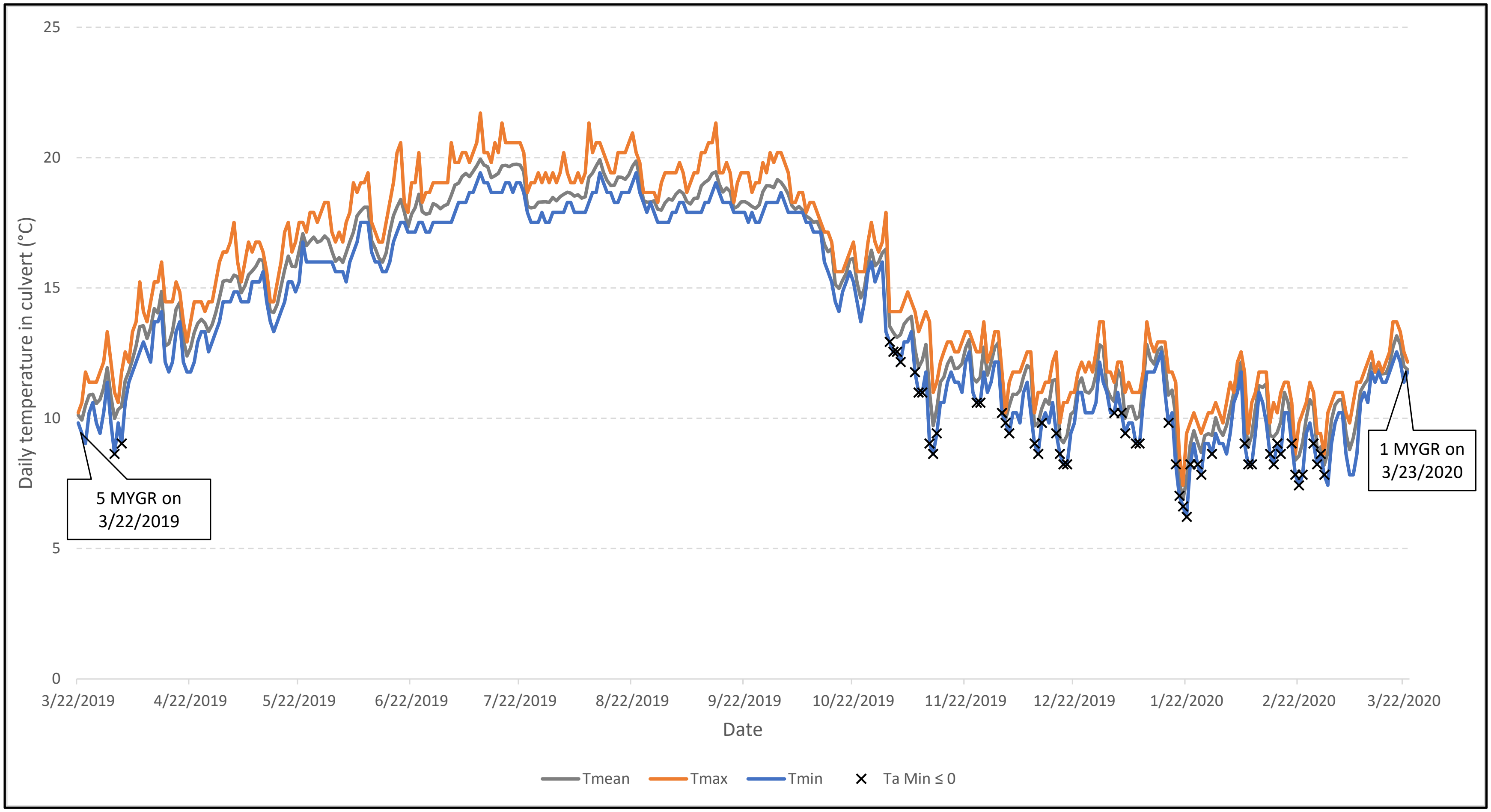


Figure 21. Temperature data recorded by a HOBO datalogger deployed in HSC from March 2019 to March 2020. T_{mean}, T_{min}, and T_{max} are shown, and days when outside temperature (T_a) was 0°C or lower are indicated by × marks. Days when bats were observed inside the culvert are shown in callout boxes.

Acoustics

We recorded gray bat calls at every acoustic station, but activity levels varied by station (Table 19, Figure 22). Six stations detected relatively high gray bat activity (mean of ≥ 1 gray bat call per night). This included the Swannanoa River east of Asheville, the Pigeon River in Clyde, Spring Creek west of Marshall, Turkey Creek #1 and #2 north of Leicester (we consider these to be one station, as one replaced the other), Hominy Creek in Candler, and Jonathan's Creek near the I-40 exit for Cataloochee. At Spring, Creek, Hominy Creek, Jonathan's Creek, and Turkey Creek, gray bat activity was >10% of total bat activity (Table 19). Natural land cover around these high activity stations ranged from only 3% at Pigeon River to 71% at Spring Creek (Appendix I, Table I1), indicating that surrounding land cover was probably not the primary factor explaining the high bat activity. Six stations had moderate levels of activity, ranging from 0.21–0.88 gray bat calls per night. This included Big Laurel Creek north-northeast of Marshall, Cane River west of Burnsville, French Broad River North (north of Marshall), Mills River west of the town of Mills River, French Broad River Middle south of the Asheville Airport, and North Toe River in Spruce Pine. Sites with lower activity (≤0.07 calls per night) were Mud Creek in Hendersonville, French Broad River South (south of Brevard), and South Toe River south of Micaville. We measured distance to Rattling Cave or Cedar Creek Cave, whichever was closer (Table 19); acoustic stations were 23–93 km from a maternity cave. There was a negative correlation in activity level (% MYGR calls; Table 19) and distance to maternity cave (Pearson's $r = -0.51$, $P < 0.05$); a visual assessment of the data showed that activity levels were highest for acoustic stations within 60 km of one of the two caves.

We note that it would be difficult to capture all of the gray bat activity on the French Broad River from any of the three acoustic stations on this river, as the center of the river was ~16–55 meters from the edge and the mics might not be able to detect bats flying at the midpoint (Table 19). The same could also be true of the South Toe River (19 m to midpoint) and North Toe River (12 m to midpoint). However, we recorded between 54,484 and 62,424 calls for all bat species at French Broad River Middle, French Broad River South, and South Toe River, suggesting gray bat activity may be a low proportion of overall bat activity at these sites.

In both 2018 and 2019, gray bat activity was highest in the latter part of summer and into early fall (Figure 23). By November, activity had dropped to near zero. We saw a pulse of acoustic activity beginning in late March–early April in 2019 and 2020. We see a striking decrease in activity in late May–late June 2019. We cannot infer the same pattern for June 2018, as only one station was active at that time.

When we examined activity patterns for individual acoustic stations, we saw both spatial and temporal variation in gray bat activity across the French Broad River Basin (Figure 24). Along the French Broad River itself, there was greater and more sustained activity (from April to October) at the North station, which was north of Marshall, NC. There was less activity at the Middle station, which was south of BLRIB, and a distinct lull in mid-summer 2019. There was very low activity at the South station, which was closer to the South Carolina border, with no obvious pulses in activity.

The temporal pattern for Hominy Creek was similar to French Broad River North, in that gray bats were recorded from April to October and at relatively high levels. The Pigeon River station recorded 50–350 calls/week in 2018, but <50 calls/week in 2019. Due to repeated flooding, we moved the station farther from the river's edge in 2018, which likely explains the decrease in detected activity. The Swannanoa River station recorded high activity from July to October, a pattern we also observed at

Spring Creek, Jonathan’s Creek, and Big Laurel Creek. Mills River had relatively low activity, but it was also concentrated in the July to October period. For some stations, peak activity started later (in late July or August) or was interrupted by a lull—i.e., Turkey Creek, Cane River, and North Toe River. Like French Broad River South, some stations recorded very low levels of gray bat activity across the entire season—i.e., Mud Creek and South Toe River.

Table 19. Acoustic stations deployed in the French Broad River Basin from 14 June 2018 to 3 May 2020. We present distance to waterway center (measured on aerial photo), total mic nights (typically two mic nights/station per calendar date), and we calculate gray bat (MYGR) calls/mic night. We also present total calls for All Bats, as identified by BCID. Note that Turkey Creek #2 replaced Turkey Creek #1, which flooded repeatedly.

Site	Estimated Distance to Middle of Waterway (m)	Distance to Cave (km)*	First Recording	Last Recording	Total Mic Nights	Total MYGR Calls	MYGR/Mic Night	Total All Bat Calls	% MYGR Calls
Swannanoa River	9	60.8	7/4/2018	4/28/2020	944	2596	2.75	77656	3.34%
Pigeon River	16	52.5	8/24/2018	4/12/2020	884	2237	2.53	47813	4.68%
Spring Creek	3	23.9	7/5/2018	4/14/2020	873	1645	1.88	13075	12.58%
Hominy Creek	10	56.1	7/3/2018	5/3/2020	937	1701	1.82	15970	10.65%
Turkey Creek #1	4	40.1	6/14/2018	12/27/2018	253	399	1.58	19954	2.00%
Jonathan's Creek	7	43.0	9/8/2018	4/13/2020	988	1367	1.38	10012	13.65%
Turkey Creek #2	8	39.8	1/14/2019	4/30/2020	545	590	1.08	4422	13.34%
Big Laurel Creek	6	25.1	9/8/2018	4/14/2020	770	674	0.88	58189	1.16%
Cane River	12	50.7	9/7/2019	4/28/2020	945	749	0.79	28958	2.59%
French Broad River North	55	29.2	9/15/2018	4/12/2020	961	750	0.78	31261	2.40%
Mills River	8	75.1	12/17/2018	5/1/2020	791	346	0.44	16577	2.09%
French Broad River Middle	25	75.6	9/8/2018	5/1/2020	790	327	0.41	54484	0.60%
North Toe River	12	75.1	12/13/2018	4/28/2020	760	158	0.21	9267	1.70%
Mud Creek	6	87.2	12/8/2018	5/1/2020	661	48	0.07	15774	0.30%
French Broad River South	16	93.6	7/22/2018	4/28/2020	995	65	0.07	56522	0.11%
South Toe River	19	64.7	10/24/2018	4/14/2020	761	34	0.04	62424	0.05%

* Distance to closest maternity cave: Jonathan's Creek and Pigeon River stations are distances to RC, the remaining stations are distances to CCC.

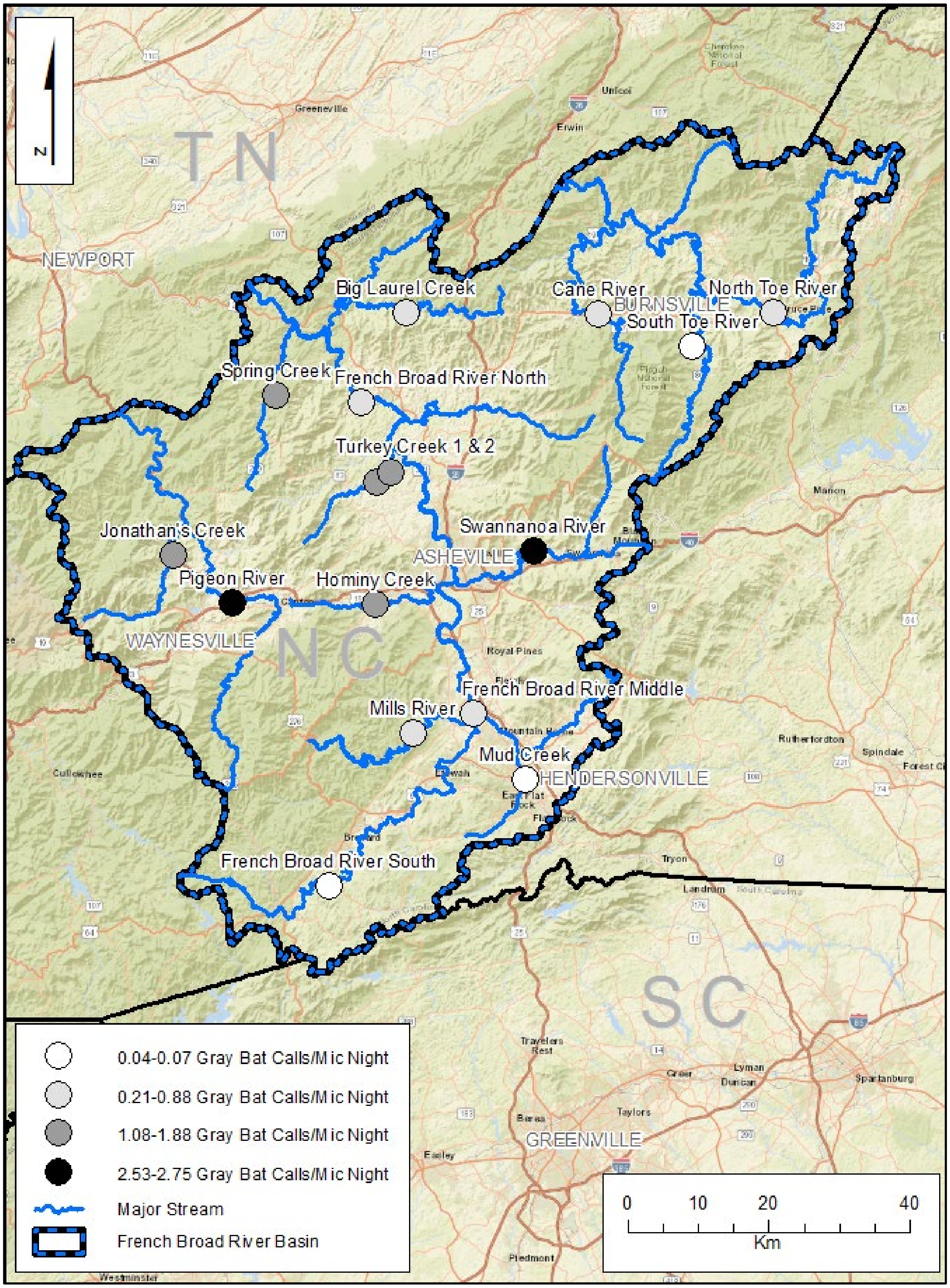


Figure 22 Locations of acoustic monitoring stations in the French Broad River Basin where we deployed Anabat detectors to listen for bat calls between June 2018 and April 2020. Acoustic monitoring stations are distinguished by the number of gray bat calls recorded per mic night.

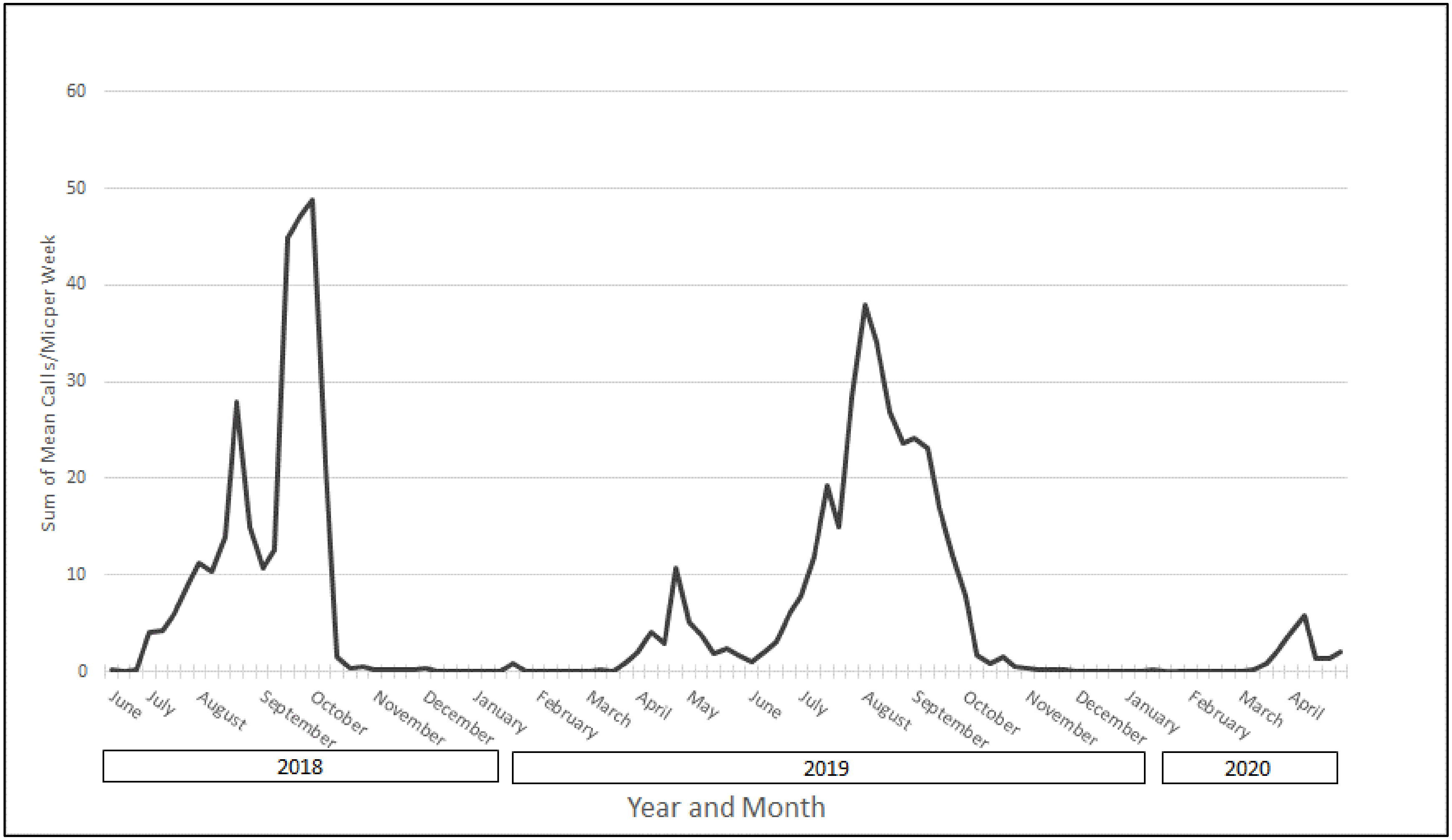


Figure 23. Acoustic data (mean gray bat calls/mic/night) for each week from the second week of June 2018 to the fourth week of April 2020. Each week 1–15 acoustic stations were active. We summed the means across acoustic stations active in each week.

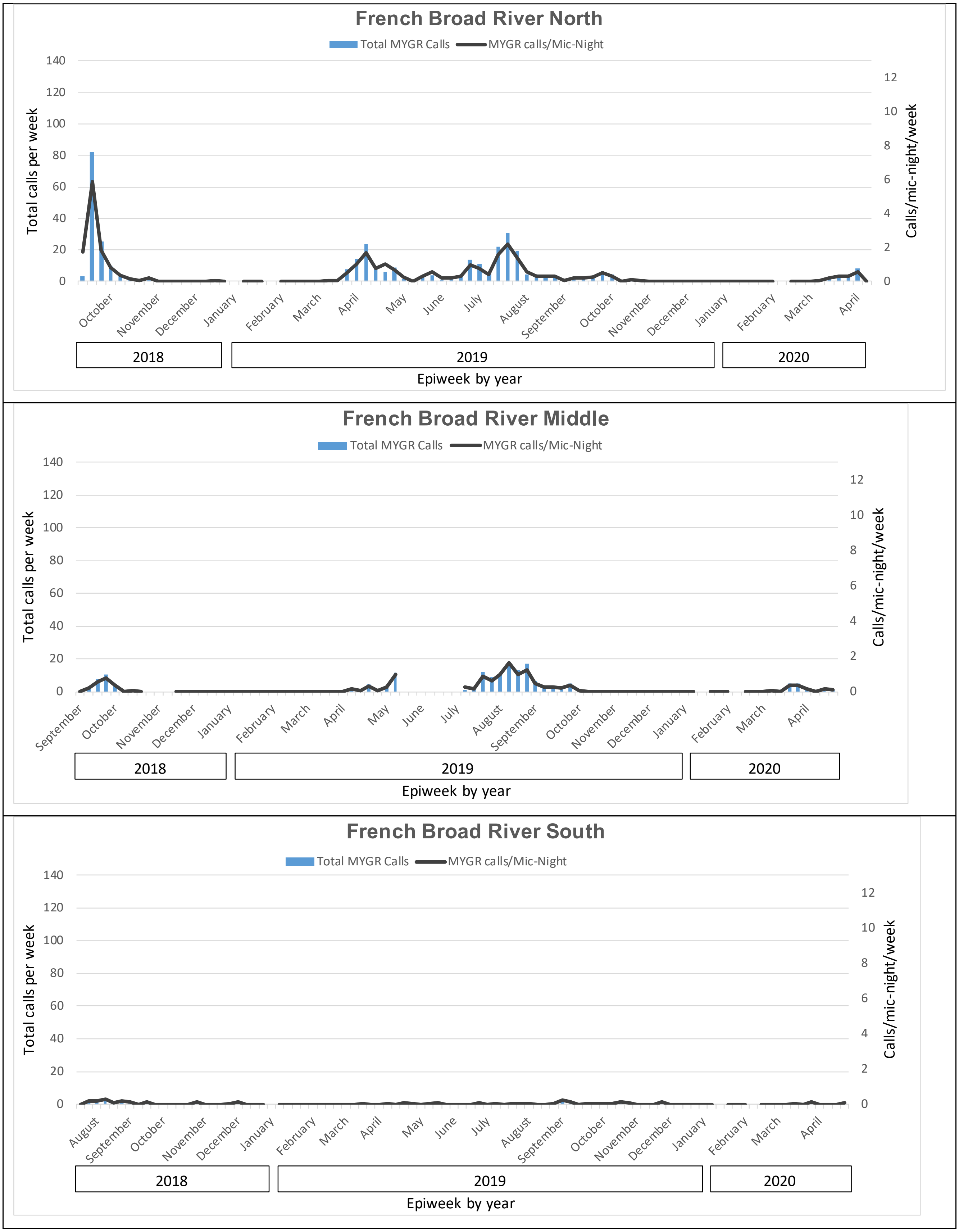
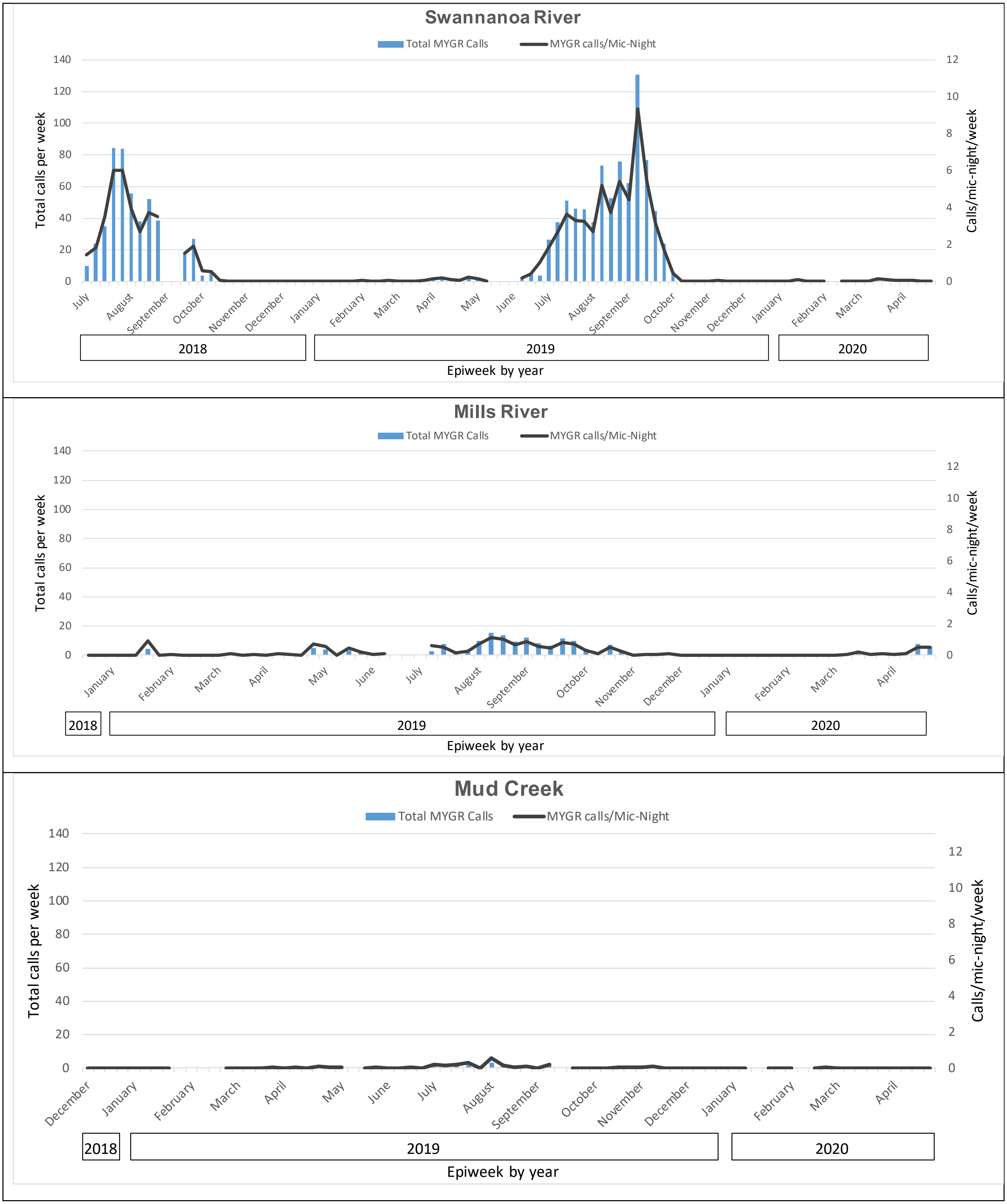


Figure 24. Total gray bat calls by week on left Y axis and mean calls (calls/mic-night/week) on right Y axis for 15 acoustic stations deployed throughout French Broad River Basin, 2018–2020. Initial deployment date varied (see first week on X axis) and stations were sometimes inoperable due to flooding, etc. (gaps in data). Stations with particularly high activity are denoted by an * and the Y axis differs on those figures.



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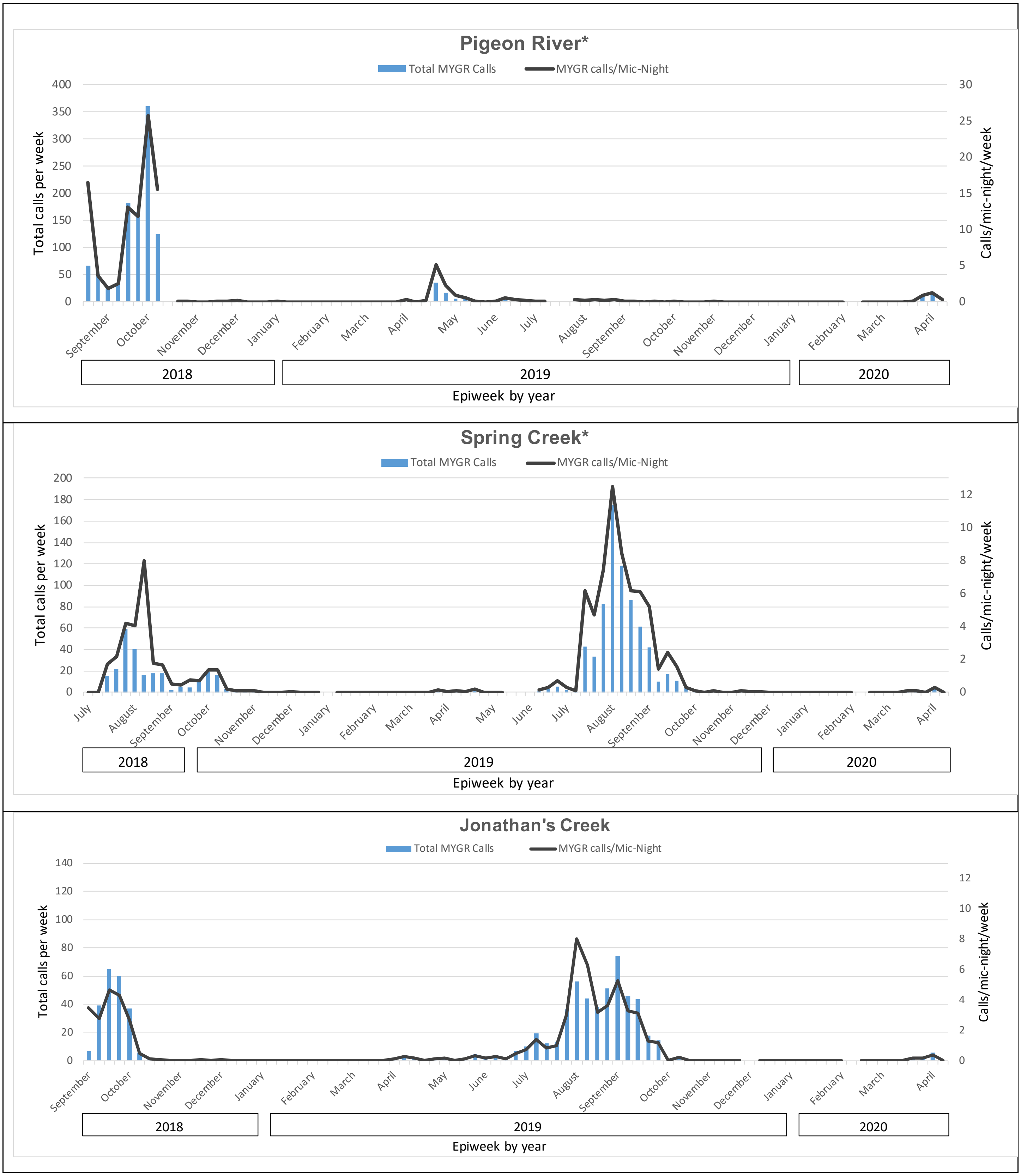

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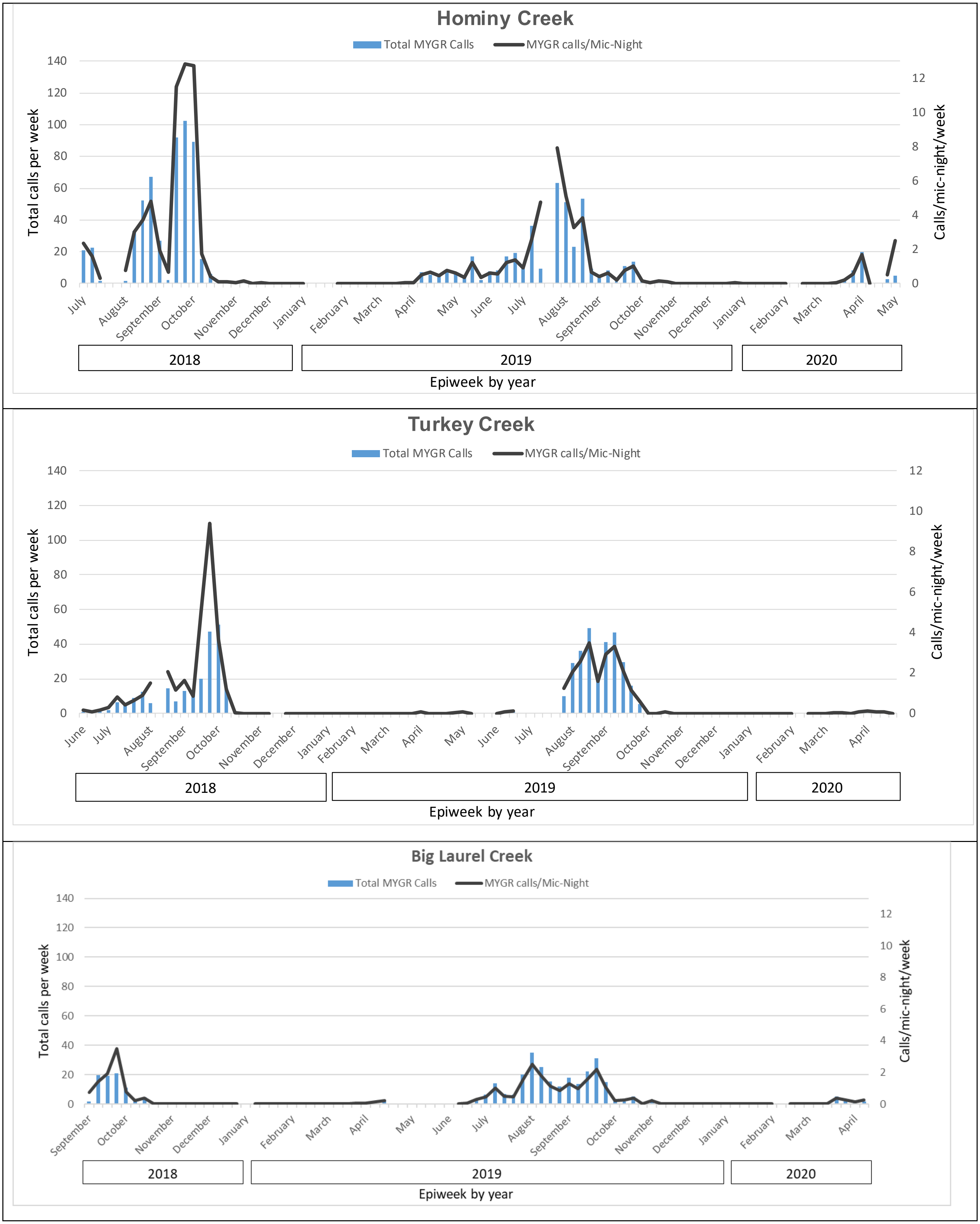

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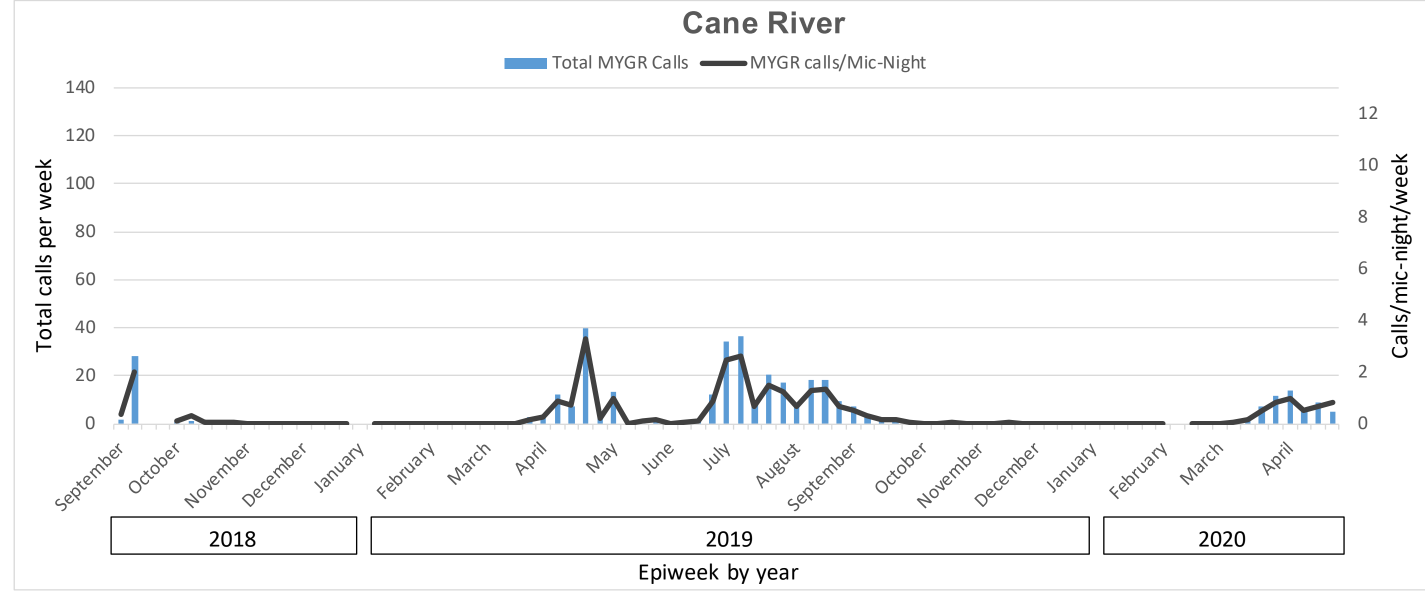

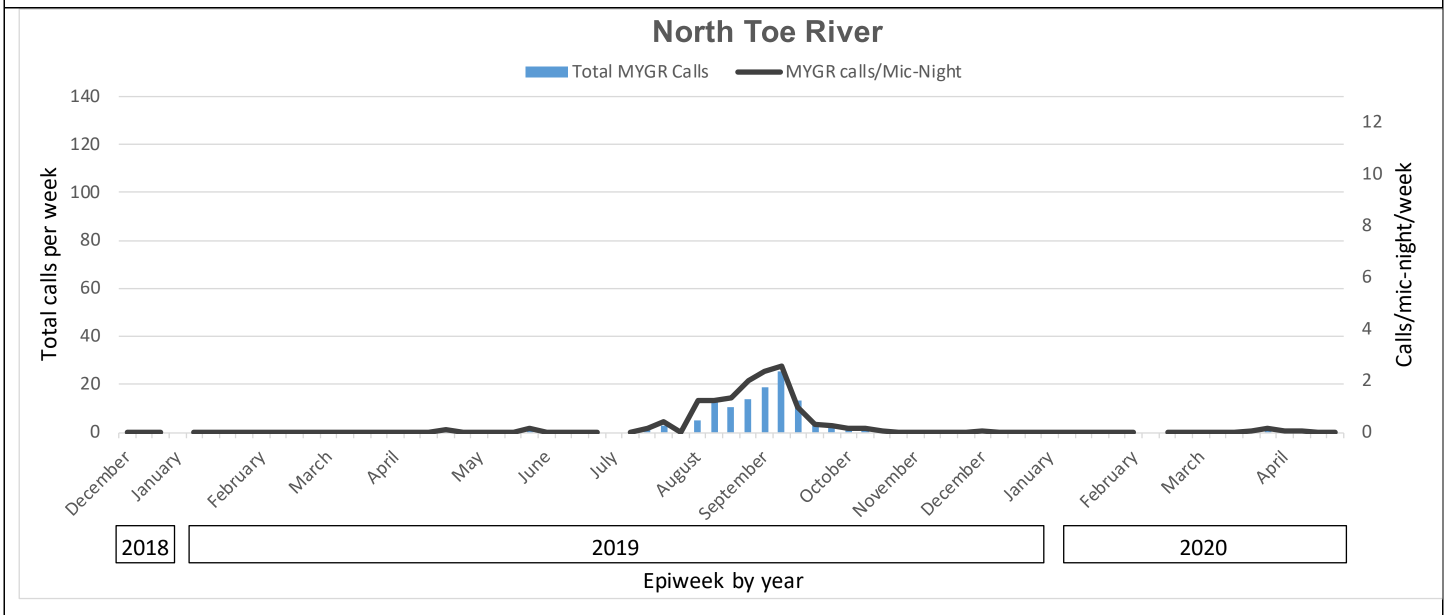

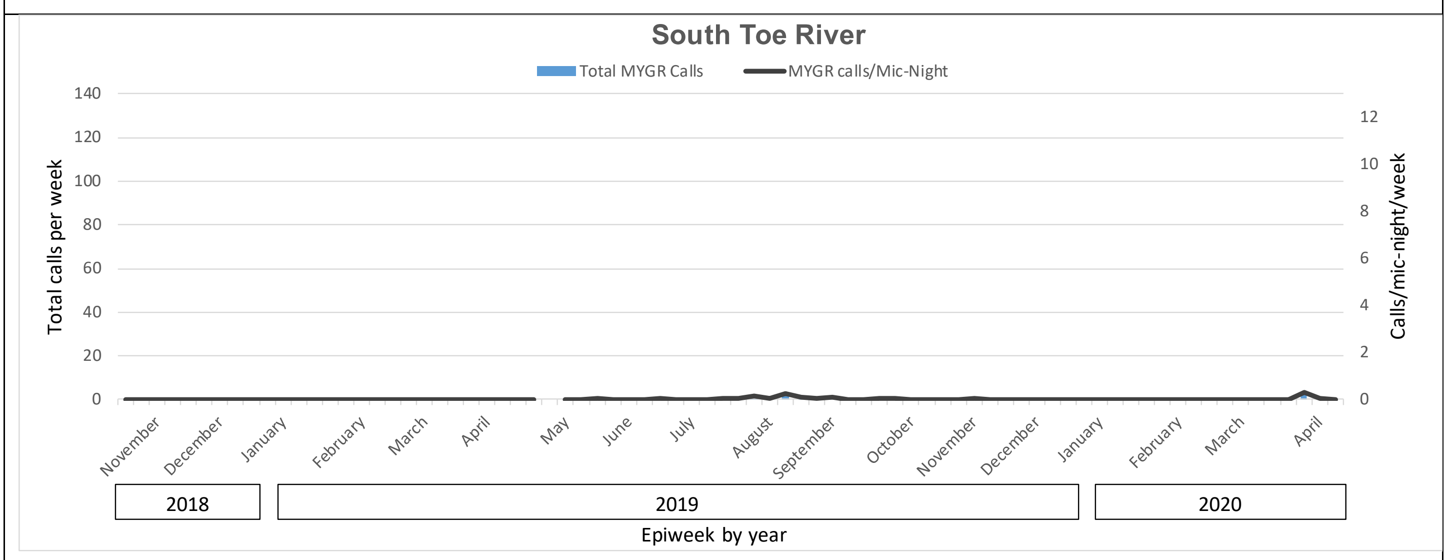

Figure 24 (continued).

Findings and Conclusions

Distribution

Our effort has shown that gray bats are distributed throughout much of the French Broad River Basin in western North Carolina (Figure 25). We lack records north of the Burnsville–Spruce Pine corridor and west of the I-40 and Hwy 276 interchange near Waynesville, although NCWRC has records of gray bats in bridges in Swain and Cherokee counties. In the southernmost portion of the basin, we do not know of any primary roosts, but have recorded gray bat echolocation activity at multiple sites, detected bats via telemetry, and NCWRC captures gray bats at a site on the Davidson River. Further, as of August 2020, we know that gray bats are using the North Fork of the French Broad River in Transylvania County, NC. On two days in September and October 2019, Copperhead Consulting and NCWRC discovered a single gray bat and five big brown bats roosting in a bridge on Hwy 601 in Surry County, NC (K. Etchison, NCWRC, personal communication), which is over 120 km (75 miles) northeast of our easternmost record. Further, in September 2020, NCWRC and USFWS located gray bats using two bridges in McDowell County near Marion, NC, 39 km (24 miles) east of our Swannanoa River acoustic station and 23 km (14 miles) south of the North Toe River acoustic station. Powers et al. (2016) reported that one gray bat was captured in a mist net on a stream in Wythe County, Virginia, which is north of Allegheny County, NC. Therefore, the gray bat's distribution in NC could be much broader than what we have discovered in this study. We suggest more searches are needed in the areas lacking data within the French Broad River Basin and in other parts of western NC.

Gray bat observations tended to be on major waterways and water bodies, though that is partially a function of where we were able to search. This finding is consistent with previous knowledge on gray bats. For example, in northern Arkansas, gray bats frequently forage over the Illinois and White rivers, reservoirs, and smaller bodies of water; open water comprised 63–87% of their home range areas in that study (Moore et al. 2017). In the Tennessee River Valley, reservoirs were used more than expected and rivers less than expected, which may be explained by higher productivity or odds of foraging success over slow or stagnant water at the margins of the reservoirs (Tuttle 1976a). Informed by tracking light-tagged gray bats in Missouri, LaVal et al. (1977) suggested gray bats prefer larger bodies of water after observing that bats were more often detected flying downstream versus upstream.

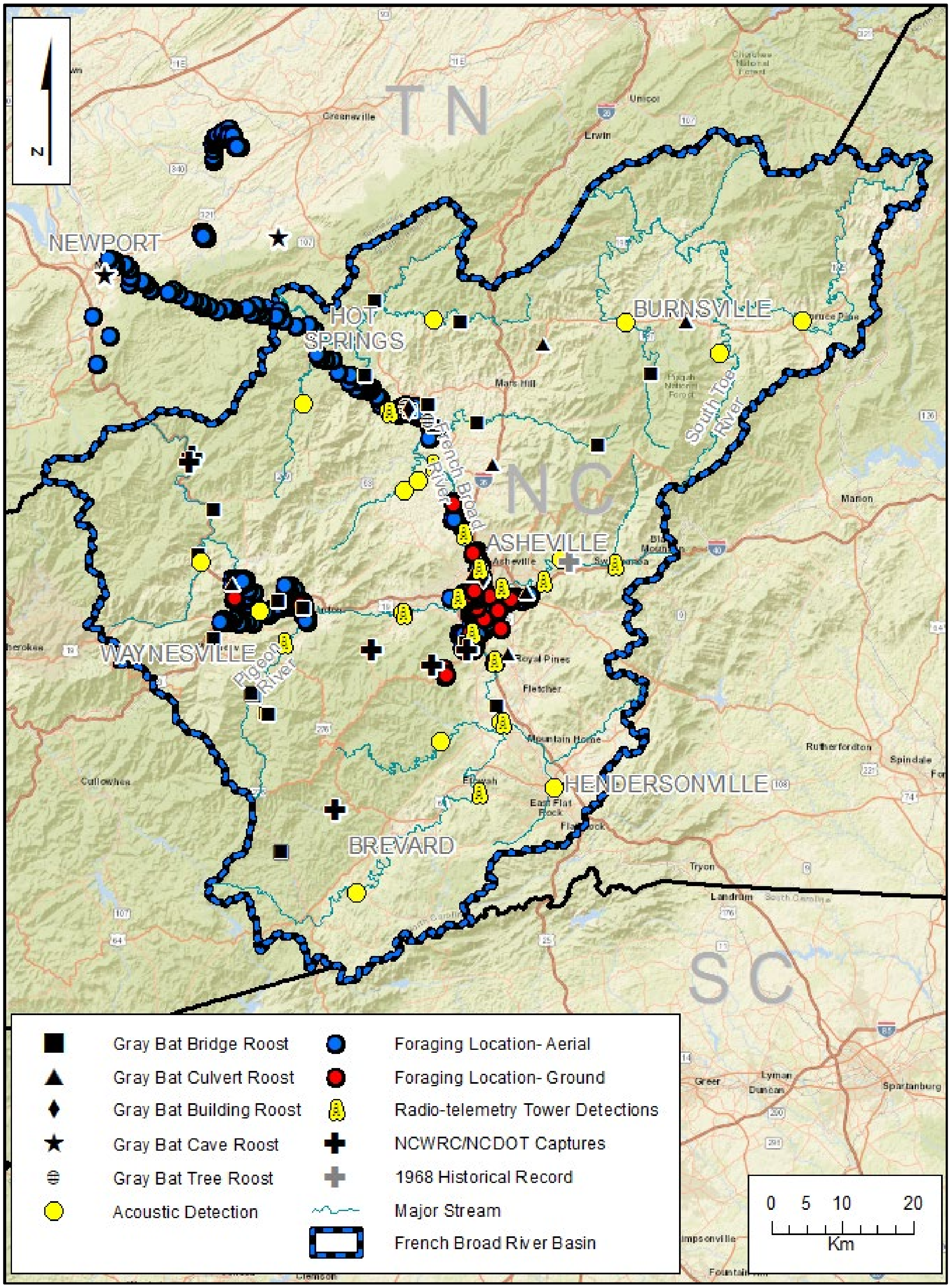

Figure 25. Known French Broad River Basin gray bat roosts, capture sites, acoustic detections, foraging locations, and one of a few historical records that existed prior to the beginning of this study in April 2018. Two gray bat rabies submissions from Buncombe County (we have no specific location) in the years 2000 and 2001 are not on the map.

Importantly, the gray bat's distribution does not appear to be constrained by proximity to natural roosts, though activity levels may be higher near such roosts. The few studies examining gray bat space use have found that they are capable of traveling long distances from roost sites to foraging areas (e.g., up to 41 km from a colony roost site in Arkansas, Moore et al. 2017; about 30 km from a release site in Alabama, Thomas and Best 2000). For at least a portion of the population we studied, natural roosts are near Newport and Houston Valley, TN, which are 58–69 km from our study area center (as defined for telemetry towers). Gray bats' capacity for using anthropogenic structures such as bridges, culverts, and buildings may allow them to roost and forage beyond the areas where they might be expected based on karst topography, including western NC.

Roost sites

This study significantly expanded our knowledge of roosts used by gray bats in the French Broad River Basin in NC, as we knew of eight before March 2018 and now know of 37 roosts. Most of these roosts are bridges, found via radio telemetry or systematic or opportunistic searches. As expected, gray bats also used culverts, but we did not expect to find them using buildings or trees. Buildings served as secondary roosts in our study; two buildings seemed to be opportunistic roosts for only a single bat in each case, whereas we documented up to 293 gray bats using the M Community Center. This building likely served as a "spillover" roost for the population roosting in the nearby MB. Trees were only used in fall and by single bats; these may also be opportunistic roosts for bats foraging and commuting along the river. While there was no prior knowledge of gray bats using trees, in April 2019, Copperhead Consulting also detected a gray bat roosting in a tree, which was a dead green ash (*Fraxinus pennsylvanica*) about 5 km from a maternity cave in Putnam County, TN (Samoray et al. 2020).

The three most significant bridge roosts—BLRIB and MB on the French Broad River, and CB on the Pigeon River—have some common features. The three structures are made from concrete and have long, deep crevices running either perpendicular or parallel to the bridge deck. These crevices are mostly covered from above, shielding bats from the elements and likely trapping warm air inside the crevice. Within-roost temperatures averaged 11–13 °C warmer than the outside air temperature; these warmer temperatures should facilitate energy conservation by allowing bats to warm passively. Both the BLRIB and MB bridges were >200 m in length; larger bridges have a high thermal mass, which allows them to retain heat longer and to offer more stable temperatures when compared to smaller bridges. The CB was only 64 m long and its' within-roost temperatures were more variable than was observed for the larger bridges. Our migration telemetry data indicate that all three bridges were within a night's commute of two known primary maternity cave roosts in TN; MB was only 31 km from a known cave and BLRIB was farthest, at 63 km away.

Comparing bridges used by any bat species to bridges where we did not detect bats, a few key characters were important. Bridges used by bats tended to be in less developed areas—away from primary roads and with less urban/suburban development surrounding the bridge. Bats may selectively roost in less developed areas if such areas offer access to better foraging habitat or alternate roost sites, or buffer against stressors such as pollution, noise, predation risk, and human disturbance. We note that the three primary bridge roosts used by gray bats were on or near a primary road; a large bridge that can accommodate more bats may be more likely to exist near a primary road. Bats also tended to use longer bridges with crevices in the bridge deck and concrete beams underneath. Crevices created by expansion joints or the juxtaposition of pre-formed concrete sections are likely the safest sites for bats to roost in a bridge, as they provide protection from the elements if covered from above and allow bats to hide from predators. Bektas et al. (2018) also found that both bridge-scale characters and the character of the surrounding landscape were important predictors of bat use of 126 bridges of 517 surveyed in Iowa. For example, in their study, bats were more likely to use bridges made of pre-stressed concrete or continuous steel that were taller and deeper (wider). However, bats also were more likely to be found using bridges with more wetland cover within 0.1 mile (i.e., over or near water).

It may be relatively common for gray bats to use bridges as either stopover, bachelor, or maternity roosts. Sasse (2019) detected gray bats using 21 bridges in Arkansas, mainly during spring; however, he only searched guardrail crevices and, thus, only reports on bats roosting singly or in pairs. During 118 visits to a metal bridge in Indiana with concrete I-beam sidewalls underneath, Cervone et al. (2016) observed use by thousands of bats, including *Myotis* species and tri-colored bats. However, Cervone et al. (2016) detected only two gray bats at this bridge, which was distant from the normal range of gray bats in Indiana. Powers et al. (2016) reported that up to 1,500 bats, including gray bats, use a bridge in Scott County, Virginia. Johnson et al. (2002) located gray bats night roosting under two I-beam (material not specified) bridges in northern Georgia; bats hung from cracks in the porous concrete ceiling. Johnson et al. (2002) suspected that other bridges might serve as night roosts, as they recorded gray bat echolocation calls at 15 of 37 bridges surveyed. Around 4,000 gray bats use a concrete bridge in Jessamine County, Kentucky, roosting inside deep parallel crevices on the underside of the bridge (R. Larsen, Eco-Tech Consultants, personal communication). At least 500 gray bats used the expansion joints in a gate room of a dam at Woods Reservoir in south-central TN (Martin 2007).

There are few records of gray bats using culverts as roosts, which is a little surprising given that culverts at least visually mimic the conditions found in the caves gray bats naturally inhabit during summer and winter. Our work enhances knowledge of culvert use, but there is still much to learn. The first report of gray bats in a culvert-style structure is a scant report from Hays and Bingman (1964) on the existence of a maternity colony of 400 gray bats using a storm sewer near Pittsburg, Kansas. Subsequently, Timmerman and McDaniel (1992) described a 160-m long storm drain used by ~8,000 gray bats in Independence County, Arkansas. The concrete drain ranges from 1–1.7 m in height and from 2–7 m in width; water is present year-round, and the structure sometimes floods to the ceiling. In a paper detailing the status of gray bats in Virginia, Powers et al. (2016) briefly note that a maternity colony uses a “long” box culvert extending from Virginia to Tennessee (from Google Maps, we estimate the length to be ~430 meters); this structure houses up to 9,000 gray bats. As with caves, it is difficult to observe bat populations in culverts without disturbing the bats. We found emergence counts to be an unreliable way to assess the significance of HSC in Asheville and suggest that a better way to count bats is to have a qualified biologist enter the culvert in July or August to count bats using night vision and infrared light. The culvert is clearly important to gray bats in the French Broad River Basin, as we frequently captured bats there and often detected bats foraging nearby (on the N1 tower). Spring, summer, and fall temperature data from HSC showed that this culvert is at the lower end of the range of temperatures known for maternity caves used for pup development (Tuttle 1975); however, our capture successes at this site suggest HSC at least serves as an important “cave-like” site for interactions among members of the NC gray bat population. We did not turn our attention to other culverts in the basin until late in the study, as this was not one of our original aims. Thus far, we know of seven other culverts used by this population of gray bats, but we suspect there are more. For example, our telemetry data suggest gray bats may be using a culvert near CB. Given the observations of large gray bat colonies in culverts and drains made by researchers in other states, it is imperative that more attention is paid to culverts in the French Broad River Basin.

Simultaneous exit counts at roosts give us the best indicator of the size of the gray bat population in the French Broad River Basin. We counted 451–2,820 gray bats emerging from known roosts during this project, with the highest counts from July to September. It was important to conduct simultaneous counts, as we have confirmed via radio telemetry that individual bats switch between the primary structures and occasionally use secondary roosts. We conservatively estimate the population in the French Broad River Basin includes at least 2,820 gray bats. The NC gray bat population appears to be significantly smaller than the population in TN, as in 2006 there were at least 14 caves in TN that supported summer populations in the thousands or tens of thousands (ranging from 1,500–84,650 bats; Martin 2007). However, it is important to recognize the potential continuity of the TN-NC population, as we showed bats easily move back and forth across the border. Additional searches in new areas or structures and subsequent simultaneous counts at all major roosts will further inform the NC population estimate.

Roost fidelity is a well-established phenomenon for bats in general (Lewis 1995) and for gray bats, in particular (Tuttle 1976b). Recaptures of banded bats showed that individual gray bats demonstrate strong annual and within-year fidelity to the NC portion of the French Broad River Basin and to primary roosts. We also observed population-level fidelity to the basin, primary roosts, and some secondary roosts (e.g., M Community Center and Gabriel's Creek Road Bridge). High roost fidelity is directly related to the permanency of a roost (Lewis 1995); thus, bridges, culverts, and buildings used by gray bats could continue to serve as roost sites for gray bats for the lifespan of the structure. Bats may be more likely to show fidelity to high quality roosts, reaping benefits of group occupancy (e.g., safety, optimal microclimate, and thermal stability) and being able to engage in behaviors that maintain social relationships (Lewis 1995). Disturbance may decrease roost fidelity, though sensitivity to disturbance varies across different bat species (Lewis 1995) and likely different circumstances. Tuttle (1976b) observed that gray bats would move to new roost locations within winter hibernacula following human disturbance and they speculated that gray bats might move to an entirely new cave in the face of significant disturbance. Likewise, in summer, gray bats might move to an alternate roost when disturbed, if a suitable roost is available.

We observed that gray bats occasionally roosted with other bat species, which is important to consider when assessing population size. We most often found gray bats sharing a roost with big brown bats, but they also shared roosts with other *Myotis* species, tri-colored bats, and Mexican free-tailed bats. The presence of the latter species poses the biggest challenge for assessing gray bat population sizes via exit counts, as free-tailed bats tend to roost in very large colonies (thousands or millions of bats). We only detected free-tailed bats at three gray bat bridge roosts. It is possible free-tailed bats are limited to structures that meet certain criteria for space or for satisfying their physiological demands.

Capture data from 2018 and 2019 showed the gray bat population in the French Broad River Basin in NC is mostly male bats (73–82% of captures). We caught 10% more adult females in 2019 than in 2018, which might reflect natural annual variation; additional annual surveys would yield better information on the colony's makeup. Juveniles were ≤ 5% of our captures in each year. Tuttle (1976b) determined that gray bats segregate into maternity and bachelor colonies using different cave sites, though bachelor colonies may include both adult males and non-reproductive females. Based on his definition, the NC population we studied most closely matches the demographics of a bachelor colony. However, we did not have the ability to discern bat ages until late in the season and note that Tuttle (1976b) demonstrated that the proportion of adult females to adult males using a particular roost site can vary from spring to summer to fall.

Multiple lines of evidence suggest the gray bat population reduces its activity in the French Broad River Basin from mid to late May to early July. We did not attempt to capture bats during this period but exit counts and spotlight checks at the MB showed that the population size decreased dramatically. Interestingly, however, we counted 1,142 bats emerging from BLRIB on 5 June 2019 but detected only ~100 bats in MB on the previous day. Combined, our acoustic data yielded a similar pattern of low gray bat activity in the basin from May to July, which is the strongest evidence that at least a portion of the gray bat population leaves the French Broad River Basin during summer. During this time period, we detected some of our radio-tagged bats at RC and CCC in TN. We cannot say for sure why gray bats would be less active in the basin during what should be the pregnancy and lactation period for the females that comprised 13—23% of our captures, but surmise that some of their biological demands—e.g., access to a stable climate that is protected from predators and the weather—may be better met by natural roost structures. Aside from the two trees we located, we know of no natural roosts for gray bats in western NC, which has a lower prevalence of caves compared to neighboring TN. Similarly, there are no known important hibernacula for gray bats in Virginia, despite the presence of significant summer populations in caves, bridges, and a culvert (Powers et al. 2016). Gray bats seek out warm caves for pup-rearing (Tuttle 1976b); because BLRIB and MB bridges were warmer than ambient and relatively stable, we suggest temperature may not be the driver of mid-summer roost switches. It is also possible that gray bats leave NC to take advantage of seasonally productive foraging grounds in reservoirs or other waterbodies in TN or elsewhere.

Foraging Areas

As expected from previous work on the species, streams and rivers were important foraging areas for gray bats in the French Broad River Basin. Active radio telemetry, particularly aerial telemetry, allowed us to detect gray bats foraging over land and away from water, but we rarely observed this behavior. With radio telemetry, it was most common for us to detect bats moving along the French Broad River or the Pigeon River. The passive telemetry towers confirmed the importance of the French Broad River and Hominy Creek corridor west of Asheville as foraging or commuting routes for gray bats, as our most active stations were N1–N4, S1–S3, and W1–W2. Of note is the fact that we rarely detected gray bats on the E1–E3 telemetry towers on the Swannanoa River, but we recorded the highest rate of echolocation activity (2.75 calls/mic night) at the Swannanoa River acoustic station. We confirmed that bats captured on the Swannanoa River will occasionally roost in BLRIB. We hypothesize that gray bats travel to this portion of the Swannanoa River via some overland pathway, perhaps avoiding the more urbanized part of the Swannanoa River that would take them past the E1–E2 towers. However, more targeted active radio telemetry efforts along this portion of the Swannanoa River would give us more insights into gray bats' behaviors in east Asheville.

Via acoustic monitoring, we learned that there is also relatively high gray bat foraging activity over smaller rivers and moderate-sized streams within the basin. Such waterways may present "goldilocks" conditions, being just right for acoustic detectors to record gray bats from the water's edge due to the short distance across the water and being just right for gray bats' foraging and commuting needs. The relatively high acoustic activity at sites like Spring Creek, Turkey Creek, and Jonathan's Creek suggests many gray bats fan out across the French Broad River Basin to forage over these moderate-sized streams. Lesser activity at other sites indicates that fewer bats travel to smaller streams (e.g., Big Laurel Creek) and rivers that are more distant from known primary roosts (e.g., Cane River and North Toe River). Because we recorded gray bats on every perennial stream we surveyed, we propose that gray bats are likely active to some degree over most of the French Broad River Basin. However, gray bat acoustic activity was highest at sites within 60 km of the two closest known maternity caves in TN.

Land cover should be an important indicator of high activity foraging sites if urban/suburban development corresponds with low quality foraging habitat and natural land cover corresponds with higher quality habitat. Our stationary acoustic points and telemetry towers were not set up to assess landscape use, but the data from these structures suggest gray bats do not avoid developed areas. For some high activity acoustic sites, such as Hominy Creek, Jonathan's Creek, and Pigeon River, natural cover types represented less than 20% of the landscape in a 1-mile buffer surrounding the site. Likewise, the high activity N1 telemetry tower had > 75% urban/suburban cover in the surrounding 1-mile buffer. However, the low detection rate on the E1–E3 towers, which are surrounded in a 1-mile buffer by >50% urban/suburban land cover, indicate that not all streams moving through developed areas are optimal foraging grounds. It is likely gray bats' foraging preferences are driven by distance to roost sites, as well as the nature of the waterway itself—the width and depth of the waterbody, water temperature, and the influence of inputs (e.g., sewage, fertilizer, or pollutants) that may enhance or diminish the productivity of the aquatic system. The S1 and N1–N4 towers are all downstream on the French Broad River from BLRIB. These towers detected the greatest numbers of bats and on the most nights, which supports LaVal et al.'s (1977) hypothesis that gray bats move downstream for more productive foraging. Their hypothesis may also partly explain the low activity in the NC portion of the French Broad River Basin for a portion of the year, if female gray bats need to move to more productive foraging grounds to meet the energetic demands of pregnancy and lactation. Weller et al. (2009) considers the various energetic strategies male bats may use during summer and points out that we know very little about their reproductive strategies. If males adopt a "low maintenance" strategy in summer, then they may not need to move to more productive foraging grounds; however, if males need to prepare energetically for the fall mating period, it would make sense for them to seek out productive foraging sites to add to their own fat stores during summer.

Gray bats can move long distances when foraging or commuting, and we affirmed this through our work. While we often lost radio-tagged bats (suggesting long moves) and sometimes recorded bats flying >10 km from roosts, bats foraged an average of <4 km from primary roosts. Because primary roosts were on major waterways, some gray bats likely found suitable foraging grounds relatively close to their roosts. Like Moore et al. (2017), however, we found substantial variation among distances moved by different individuals, likely related to the nature of their movements. For example, in October 2019, a female with 83 foraging points (BRR 6286; Appendix H, Figure H26) foraged 0.3–11.9 km west of CB, using only 4,592 ha over three nights; this bat was later detected at RC, which is 53 km from the CB, but this movement was not included in her foraging range. In August 2019, we detected female BRR 6339 (80 points collected; Appendix H, Figure H13) foraging over a much larger area—22,578 ha; however, this large area was covered in one night as she travelled downstream on the French Broad River northwest of MB while moving towards Newport, TN. When we collected fewer foraging points (<50), we estimated that bats used relatively small foraging areas (≤ 1059 ha), but we predict we would have found larger foraging areas had we been able to collect more data for each bat. Aerial telemetry was more productive than ground-based active telemetry, so we suggest this technique be employed where there is the need for fine-scale data on gray bat foraging habits. Telemetry towers also provided valuable data about bat movements and identified important foraging and commuting sites. When compared to aerial telemetry, passive towers are substantially less expensive on a per night basis; however, maintaining such towers over a long period requires that a steward be present in the area for battery checks, data downloads, and rescuing equipment from flooding.

Migration

Telemetry, exit counts, and acoustic data all generally agree that gray bats move out of the French Broad River Basin in NC from mid-September to early November. This is a long window of time, but consistent with prior knowledge on bat migration to hibernacula. For example, Pettit and O'Keefe (2017) used a 17-year dataset for a maternity colony of Indiana bats (*Myotis sodalis*) in central Indiana to show that departure for hibernacula 78–156 km away begins ~20 August and extends to 31 October. In that study, low temperatures, low amounts of precipitation, and higher wind speeds were factors associated with the breakup of the Indiana bat colony and departure for hibernacula. Tuttle (1976b) agrees that gray bat migration begins from 1–15 September in the TN River Valley, with some bats (usually males) remaining in the maternity area until mid-October.

Gray bats return to the French Broad River Basin as early as late March. We observed low numbers of gray bats using MB and HSC on various days from 8–23 March in 2018–2020. By early April 2019 and 2020, there were hundreds of gray bats roosting in MB. The bulk of spring migration likely occurs in April (Tuttle and Stevenson 1977), with females generally departing from hibernacula before males (Tuttle 1976b). Bats appear to aggregate in the primary bridge roosts for a short period, before disappearing for some of May and June, as noted above. Guthrie (1933a) reports a related behavior—female gray bats "pass through" a maternity cave in Boone County, Missouri in April, but do not become "abundant" in the maternity cave until June, when they are pregnant. Perhaps there is a period during spring migration when gray bats prefer alternate roosts to their summer maternity sites. If the NC sites serve as alternate roosts to the primary cave roosts in TN, then we might find that female gray bats make up a higher proportion of the NC population from April to May and then again after pups are volant, from August to October. To really tease out the answer to this question, it may be worth conducting regular capture surveys at HSC from April to October. As it is a focal point for the Asheville-area colony, surveys at this roost site could be a reliable index of the population demographics across the active season.

Via radio telemetry and banding returns, we confirmed that gray bats migrate between two TN caves—RC and CCC—and NC. These caves are likely favored destinations due to their relatively close proximity to our known primary roosts (< 75 km away) and because each is close to the French Broad River (2.4–7.5 km away) and RC is only 0.4 km from the Pigeon River. However, it is possible that gray bats commute to NC from more distant winter or summer sites in TN or elsewhere, as they can move very long distances. For example, in the TN River Valley, three gray bat winter hibernacula are on average 241 km from seven documented summer maternity caves (Tuttle 1976b). Further, Tuttle (1976b) determined that a colony of gray bats moves > 580 km when traveling between a hibernaculum in northern Alabama and a maternity cave in northern Florida.

Via radio telemetry, we determined that some individual gray bats use the French Broad River to commute to RC in TN. We suspect the Pigeon River is also a commuting pathway, but further targeted radio telemetry could confirm this route. Tuttle (1976b) notes that gray bats should try to minimize the distance traveled for energy savings and reported that some individuals migrate over the Cumberland

Mountains rather than following longer routes on waterways to move between caves. For example, it is feasible that some gray bats take the shortest overland route to commute between CB and RC; this overland route is the 53-km distance we have presented in this report. However, some bats may travel along the Pigeon River, which would be a much longer migratory route, but perhaps with more feeding opportunities. When the river is used as a migratory corridor, it seems likely that gray bats will stop over to roost at bridges along the route, as observed for gray bats in Arkansas (Sasse 2019).

Recommendations

The goal of this research was to gather the information needed to allow NCDOT and USFWS to enter into a programmatic consultation/agreement for the gray bat in NCDOT divisions 13 and 14. This agreement will outline ideas to develop species-specific avoidance and minimization measures for a program-wide gray bat mitigation and monitoring plan. The plan would describe monitoring methods and frequency, mitigation success criteria, and provisions for adaptive management if unforeseen circumstances arise. In the Conclusions section above, we made several recommendations regarding the need for additional study to understand gray bat ecology in the French Broad River Basin of NC. We close this report with a few management considerations and recommendations related to the plan goal mentioned above.

We did not gather any data on gray bat susceptibility to disturbance, although bats sometimes flew when we approached them under bridges. Our recommendations below are made with the assumption that gray bats may be disturbed by human activity.

Once gray bats have been documented using a structure, we suggest that this structure be considered a known gray bat roost unless the structure is modified to make it unsuitable for gray bats to roost. We expect the list of known gray bat roosts will continue to grow with additional survey work by NCDOT, NCWRC, and their partners. To ensure that NCDOT maintenance personnel are aware of known gray bat roosts, we suggest NCDOT biologists coordinate with NCWRC and USFWS to acquire an updated list of all known gray bat roosts by the end of the calendar year. This list can be provided by NCDOT biologists to Division maintenance personnel prior to the beginning of March each year. Known gray bat roosts should be searched prior to demolition or any maintenance activities that might disturb, harm, or kill bats at roost. Gray bats can be difficult to differentiate from other bats, especially the four other *Myotis* species present in western NC. Thus, when inspecting structures, we recommend that qualified personnel diligently inspect all potential locations (see Appendix B, pages 5–10 for examples of places bats might roost).

When scheduling maintenance activities, it is important to recognize that gray bats are transient and highly mobile. As we have demonstrated in this study, gray bats may use some structures, even primary roosts, sporadically. Thus, one visit to a structure may not give sufficient information about presence/absence of gray bats. During the active season, we strongly recommend that bat surveys of bridges, culverts, and buildings be conducted close to the time of any maintenance, renovation, or demolition activities that might disturb, harm, or kill bats occupying the structure.

We note that gray bats are likely to be active in the French Broad River Basin in NC from mid-March to mid-November, though this time period might be extended with a warming climate. There are no known hibernacula in NC and our data show that gray bats are least likely to be in the French Broad River Basin in NC from December to February. However, given that winter temperatures in HSC ~280 m from the entrance were always > 6 °C, we note it is possible bats could use this culvert even when outside air temperatures drop below 0 °C. We recommend delineating a stepwise process for evaluating structures and projects that would allow for certain project activities to occur based on time of year, likelihood of bat presence, and a structure check near the project start date.

Although average summertime temperatures were relatively cool (< 20 °C) inside HSC, its microclimate was still similar to some cold cave roosts documented by Tuttle (1975) and, thus, we recommend checking for maternity or bachelor roosts in this and other culverts prior to demolition. While bridges less closely mimic cave conditions, our data show that large bridges provide bats with relatively warm microclimates that may be more attractive to maternal bats than cool caves. We recommend further work to understand the demographics of the gray bat colonies using the primary bridge roosts we studied.

Our foraging data show that gray bats are most likely to be active near large, perennial streams, which is consistent with prior work showing that gray bats are riparian specialists (e.g., LaVal et al. 1977, Moore et al. 2017). While there is some error in our foraging telemetry (likely ± 150 m), foraging points were on average 377 m to major streams and 480 m to non-major streams in the NC Hydrography layer, but our calculation of the data modes showed points were most often within 31 m of either size stream and most (>69%) of foraging points were within 250 m of a major stream. Thus, we recommend considering potential direct or indirect effects to gray bat foraging habitat for any project in the French Broad River Basin that is within 250 m (0.15 miles) of a major stream such as those where we established our acoustic stations (Figure 22). We do not discount the value of small streams, which feed into the larger streams and could also serve as foraging habitat for gray bats. We also note that at least 13 gray bat roosts were >250 m from major streams.

Considering that there are recent NC gray bat distribution records outside the French Broad River Basin and known populations in TN and Virginia, we recommend additional survey work to assess the spatial and temporal distribution of gray bats in other river basins in NC.

Implementation and Technology Transfer Plan

We produced a variety of research products that we are transferring to NCDOT. As an appendix, we provide an extensive review of published articles and reports on the gray bat and we also provide a manual with directions and photos to guide bridge surveys. We provide capture data and bridge characteristics in appendices, as well as coordinates for long-term monitoring sites. We also provide maps of gray bat points (capture sites, roosts, foraging points) overlaid with transportation improvement projects and roads. We provide shapefiles of roosts, foraging points, and bridges checked, with metadata. We identified important characteristics of bridges used by bats and provide a modified bridge check datasheet that NCDOT could use in future bridge assessments.

We suggest NCDOT biologists and maintenance staff will benefit from the data we have provided on known gray bat roost locations in the French Broad River Basin. These same personnel will be able to assess bat presence at structures with aid from the manual (Appendix B). NCDOT biologists could gain a better understanding of gray bat biology by reading the literature review (Appendix A) and associated PDFs of published works. NCDOT biologists will be able to use shapefiles and data in tables and maps to relate known gray bat locations to current and future projects.

To implement these products, we recommend NCDOT ensures its employees and contractors follow standardized procedures for assessing structures for the presence of bats, learn how to recognize gray bats from other species when assessing structures, and be comfortable using GIS to overlay known gray bat locations with project data.

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