



Bats of Richmond National Battlefield Park Following White-nose Syndrome

Public Version

Natural Resource Report NPS/RICH/NRR—2023/2520



ON THE COVER

Big brown bat (*Eptesicus fuscus*) captured at Fort Harrison, Richmond National Battlefield Park
NPS/NICHOLAS KALEN

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Natural Resource Report NPS/RICH/NRR—2023/2520

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Abstract

I conducted bat surveys at Richmond National Battlefield Park to assess the status of bat communities following potential impacts of the disease white-nose syndrome. This disease, caused by the fungus *Pseudogymnoascus destructans*, has severely reduced populations of several bat species in the eastern United States, threatening some with regional extirpation. Most affected species include the little brown bat (*Myotis lucifugus*), northern long-eared bat (*Myotis septentrionalis*), Indiana bat (*Myotis sodalis*), and tricolored bat (*Perimyotis subflavus*). During the summers of 2016–2020, I sampled sites with acoustic bat detectors and conducted capture surveys using mist nets to characterize bat communities with a focus on documenting WNS-imperiled species. I also conducted non-reproductive, or dormant, season acoustic and capture surveys from 2017–2021, to investigate potential local wintering by bats, especially northern long-eared bats, which have recently been discovered wintering in the Coastal Plain of North Carolina. Acoustic results identified the presence of ten bat species by echolocation calls: big brown bat (*Eptesicus fuscus*), eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), silver-haired bat (*Lasionycteris noctivagans*), little brown bat, northern long-eared bat, Indiana bat, evening bat (*Nycticeius humeralis*), tricolored bat, and Mexican free-tailed bat (*Tadarida brasiliensis*). Capture surveys documented big brown bats, eastern red bats, silver-haired bats, and evening bats. To examine habitat associations of bat species, I used generalized linear mixed models of a selection of variable candidates: habitat type, distance to water, minimum nightly temperature, and nightly precipitation to predict summer activity. Activity of big brown, eastern red, hoary, and Mexican free-tailed bats was highest in open habitats. *Myotis* spp. were most associated with mixed forest habitats. Tricolored bat activity was highest and evening bat activity was lowest in riparian and wetland habitats. To examine seasonality in bat species occurrence, I modeled acoustic activity in passes/night by Julian date using generalized additive models. Activity of big brown, eastern red, little brown, and tricolored bats was highest during summer. Activity of northern long-eared and Indiana bats was very low overall but was also highest in the summer. Tree bat species hoary, silver-haired, and Mexican free-tailed bat activity was highest in the spring and fall. Dormant season results suggest some winter occurrences for most bat species. Visual validation of echolocation calls revealed misidentifications were problematic for *Myotis* spp. little brown bat, northern long-eared bat, and Indiana bat, but diagnostic calls of all three species were recorded. Acoustic passes identified as northern long-eared bats suggest some individuals may be wintering nearby, but winter activity was very low and not indicative of large overwintering populations.

An internal NPS [version](#) of this document that includes an appendix with capture survey site coordinates is available and may be requested as needed.

Acknowledgments

W. Mark Ford, Unit Leader of the U.S. Geological Survey Virginia Cooperative Fish and Wildlife Research Unit and Associate Professor of Fisheries and Wildlife Conservation at Virginia Tech guided this study and contributed greatly to this report. Kristen Allen, National Park Service Natural Resource Manager, assisted with field surveys.

Introduction

The introduction and spread of white-nose syndrome (WNS) in the eastern United States has caused precipitous declines in several formerly widespread and abundant cave-hibernating bat species (Coleman and Reichard 2014a, Frick et al. 2010, Turner et al. 2011, Langwig et al. 2015). WNS is an infectious disease caused by the invasive, cold-adapted fungal pathogen *Pseudogymnoascus destructans*. The fungus was initially introduced to North America in New York in 2006 and spread to Virginia in 2009 (Reynolds et al. 2016, Turner et al. 2011). *Pseudogymnoascus destructans* grows on hibernating bats where it breaches the epidermis, thereby causing arousal from torpor, resulting in dehydration, premature expenditure of fat reserves, and often death (Ford et al. 2011, Frick et al. 2015). Initial reports of regional population losses from hibernacula surveys in the Northeast and the Mid-Atlantic have been extremely high for several species: northern long-eared bat (*Myotis septentrionalis*, 98%), little brown bat (*Myotis lucifugus*, 91%), tricolored bat (*Perimyotis subflavus*, 75%), Indiana bat (*Myotis sodalis*, 72%; Turner et al. 2011). In Virginia, fall swarm survey and hibernacula counts have shown declines of 99% for little brown bats, 89.5% for tricolored bats, and 33.5% for Indiana bats (Powers et al. 2015). Summer mist-netting capture rates in Virginia have declined by 95% for northern long-eared bats (Reynolds et al. 2016). Signs of reduced recruitment have also been observed post-WNS including a 77% reduction in juvenile northern long-eared bat captures and a 66% reduction in juvenile little brown bats in Virginia (Francel et al. 2012, Reynolds et al. 2016). The effects of WNS have drastically altered bat communities in the eastern United States and threaten several species with regional extirpation, and potentially extinction (Frick et al. 2015, Kalen et al. 2022). In 2015, the United States Fish and Wildlife Service (USFWS) listed the northern long-eared bat as a threatened species following impacts from WNS and, in 2022, listed it as endangered (Federal Register § 81:1900–1922, USFWS 2022a). Tricolored bats have also recently been proposed for listing as an endangered species (USFWS 2022b). The Indiana bat has been federally endangered since 1967 in response to declines associated with disturbances in hibernacula (USFWS 2007). The little brown bat is not federally protected presently but is under species status review and considered state endangered in Virginia (Straw et al. 2022, VDGIF 2016).

Historically, the eastern United States has supported a moderately diverse and abundant community of bats with two broad categories of species: “cave bats,” that generally migrate to caves or similar subterranean habitats to hibernate during the winter, and migratory “tree bats,” that generally migrate to tolerably warm climates in southern or coastal portions of their range during the winter. These long-distance migratory tree bats do not engage in extended periods of hibernation, and therefore, are believed to be unsusceptible to WNS. They are, however, prone to mortality from wind turbine collisions and barotrauma (Arnett et al. 2008). Species such as eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), and silver-haired bat (*Lasionycteris noctivagans*) appear most affected by wind turbine mortality, however, deaths of other species including cave-hibernating bats have been observed (Arnett et al. 2008, Kunz et al. 2007).

Prior to WNS, most bat surveys in the eastern United States focused on identifying if endangered Indiana bats were present in forests during the summer or hibernacula in the winter within a regulatory monitoring and clearance context. As such, often little regard was given to assessing the

greater extant bat community. Accordingly, much remains unknown about most aspects of bat species' distribution, migration, and overall ecology in localities such as Richmond National Battlefield Park where Indiana bats historically have been presumed absent. Surveys have increased significantly in frequency after WNS with greater focus on WNS-imperiled species that had previously received little attention. Recently, populations of northern long-eared bats have been observed year-round in the Coastal Plain of North Carolina, where avoidance of cave hibernacula has allowed them to remain free of WNS impacts (Jordan 2020). In 2015, a maternity colony of Indiana bats was documented in Caroline County, Virginia beyond its previously known range in the Mid-Atlantic (St. Germain et al. 2017).

Following the severe impacts of WNS on several bat populations, there has been a great need to conduct large-scale, long-term monitoring of bat species communities to guide current and future conservation actions and to gain understanding of bat community distributions and seasonal movements. Richmond National Battlefield Park (RICH) may constitute significant high-quality bat habitat in a rapidly urbanizing portion of southeastern Virginia and likely supports diverse species communities, including several most-imperiled by WNS. Investigating summer occurrences and, potentially, reproduction of imperiled bat species at localities such as RICH is essential to bat conservation following WNS. Furthermore, potential year-round occurrence of northern long-eared bats needs to be assessed. To evaluate bat species community composition at RICH, I conducted acoustic and capture surveys with specific focus on species most-impacted by WNS: little brown bat, northern long-eared bat, Indiana bat, and tricolored bat.

Study Area

Richmond National Battlefield Park (RICH) includes 13 units totaling over 1,650 hectares. My sampling focused on nine larger units with significant bat forage and roosting habitat and included: Beaver Dam Creek, Cold Harbor, Fort Harrison, Gaines' Mill, Glendale, Malvern Hill, North Anna, Totopotomoy Creek, and Turkey Hill units (Figure 1 through Figure 8). Located from the southeast to north of Richmond, units Fort Harrison, Malvern Hill, and Glendale are in Henrico County, and Beaver Dam Creek, Cold Harbor, Gaines' Mill, North Anna, Totopotomoy Creek, and Turkey Hill are in Hanover County. All units fall within the upper Coastal Plain physiographic province, with the exception of Drewry's Bluff which lies on the edge of the lower Piedmont. Individual units vary in vegetation cover type and condition as well as surrounding development. Some units are surrounded by agricultural lands and moderately rural residential areas, along with some forest, whereas Beaver Dam Creek is bordered by more densely residentially and commercially developed areas to the north and bottomland forests to the south. Approximately 50-60% of the collective units are forested with the majority being upland mid- to late successional oak (*Quercus* spp.)-hickory (*Carya* spp.) and oak-beech (*Fagus grandifolia*) forest. Pine species loblolly (*Pinus taeda*) and Virginia pine (*P. virginiana*) are common. About 10% of the area is wetland and another 10% is managed open grassland, shrubland, and agricultural land. Park units are within the James and Chickahominy River watersheds.



Figure 1. Bat summer acoustic detector sites from 2016–2020 at Richmond National Battlefield Park, Virginia, units Cold Harbor (upper), Gaines' Mill (lower left), and Turkey Hill (lower right).

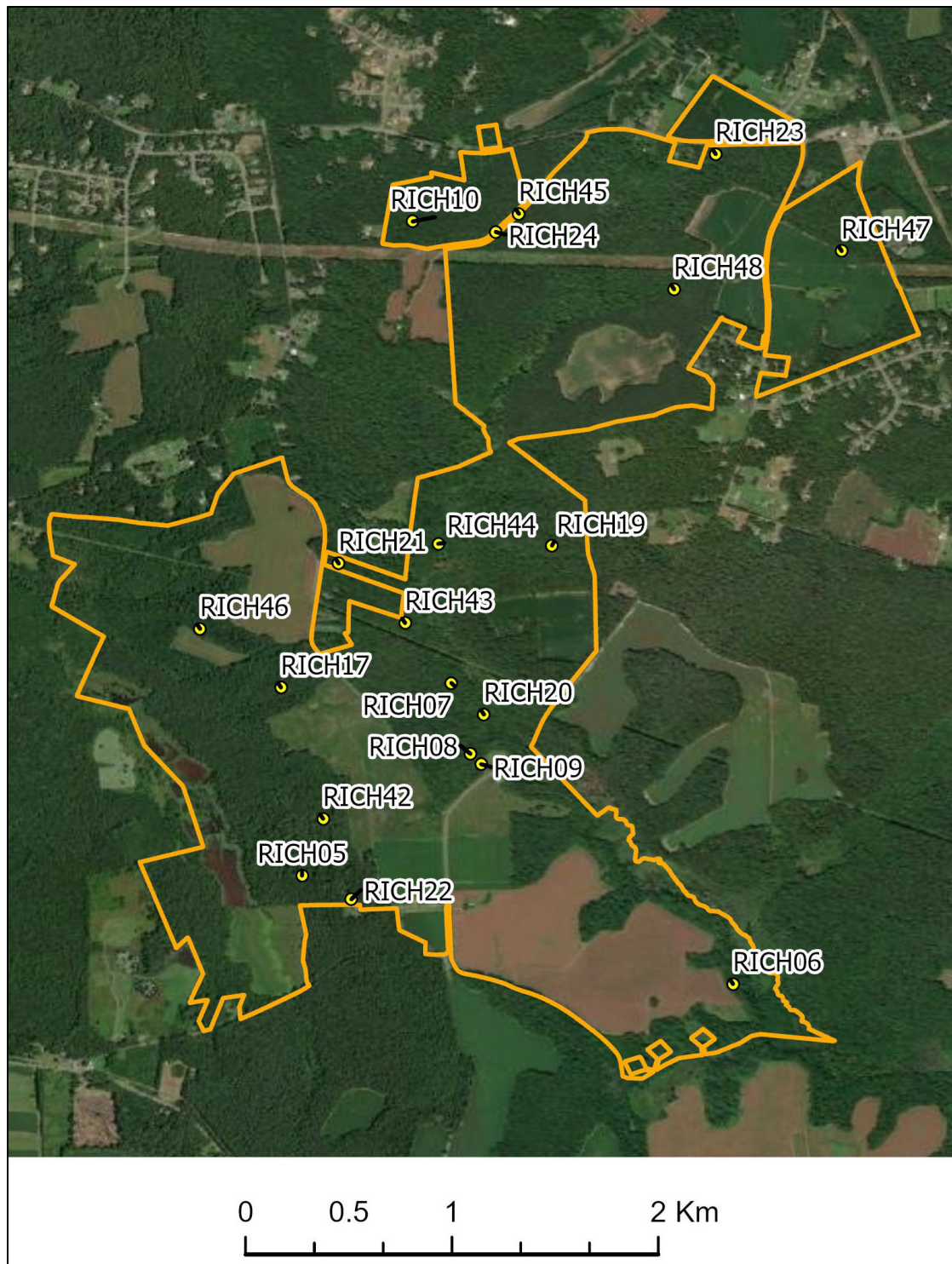


Figure 2. Bat summer acoustic detector sites from 2016–2020 at Richmond National Battlefield Park, Virginia, units Glendale and Malvern Hill.

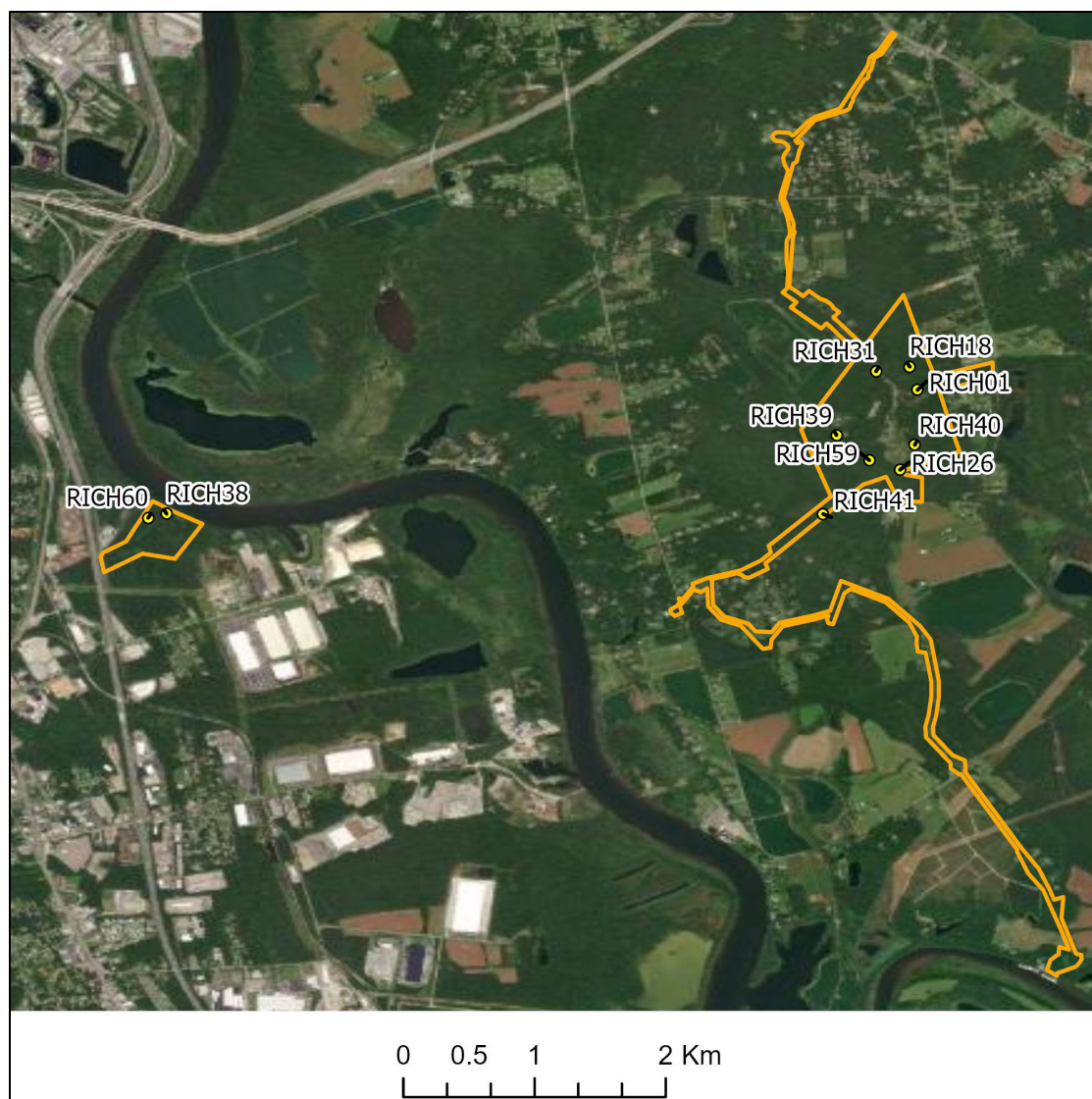


Figure 3. Bat summer acoustic detector sites from 2016–2020 at Richmond National Battlefield Park, Virginia, units Fort Harrison (right) and Drewry's Bluff (left).

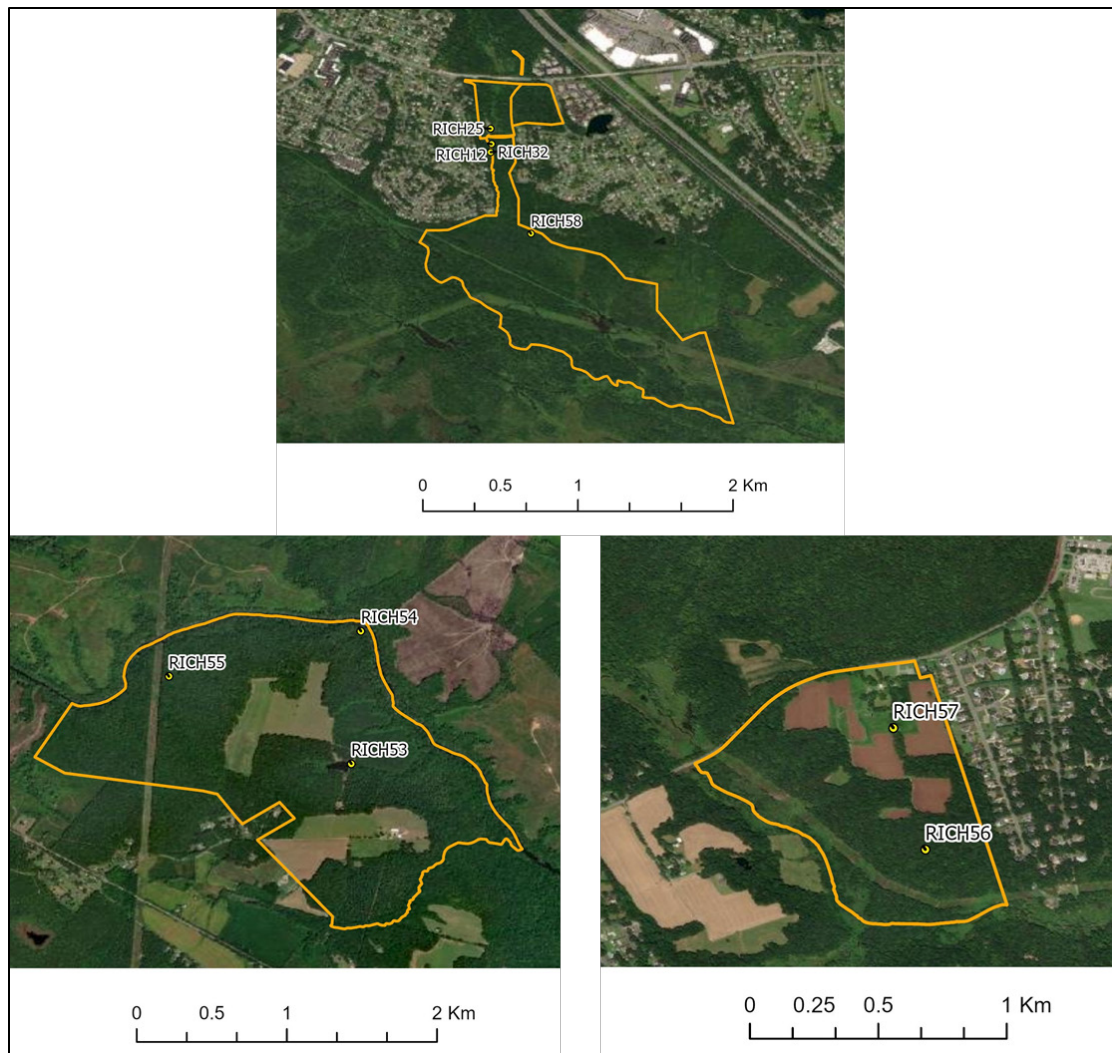


Figure 4. Bat summer acoustic detector sites from 2016–2020 at Richmond National Battlefield Park, Virginia, units Beaverdam Creek (above), North Anna (lower left), and Totopotomoy Creek (lower right).

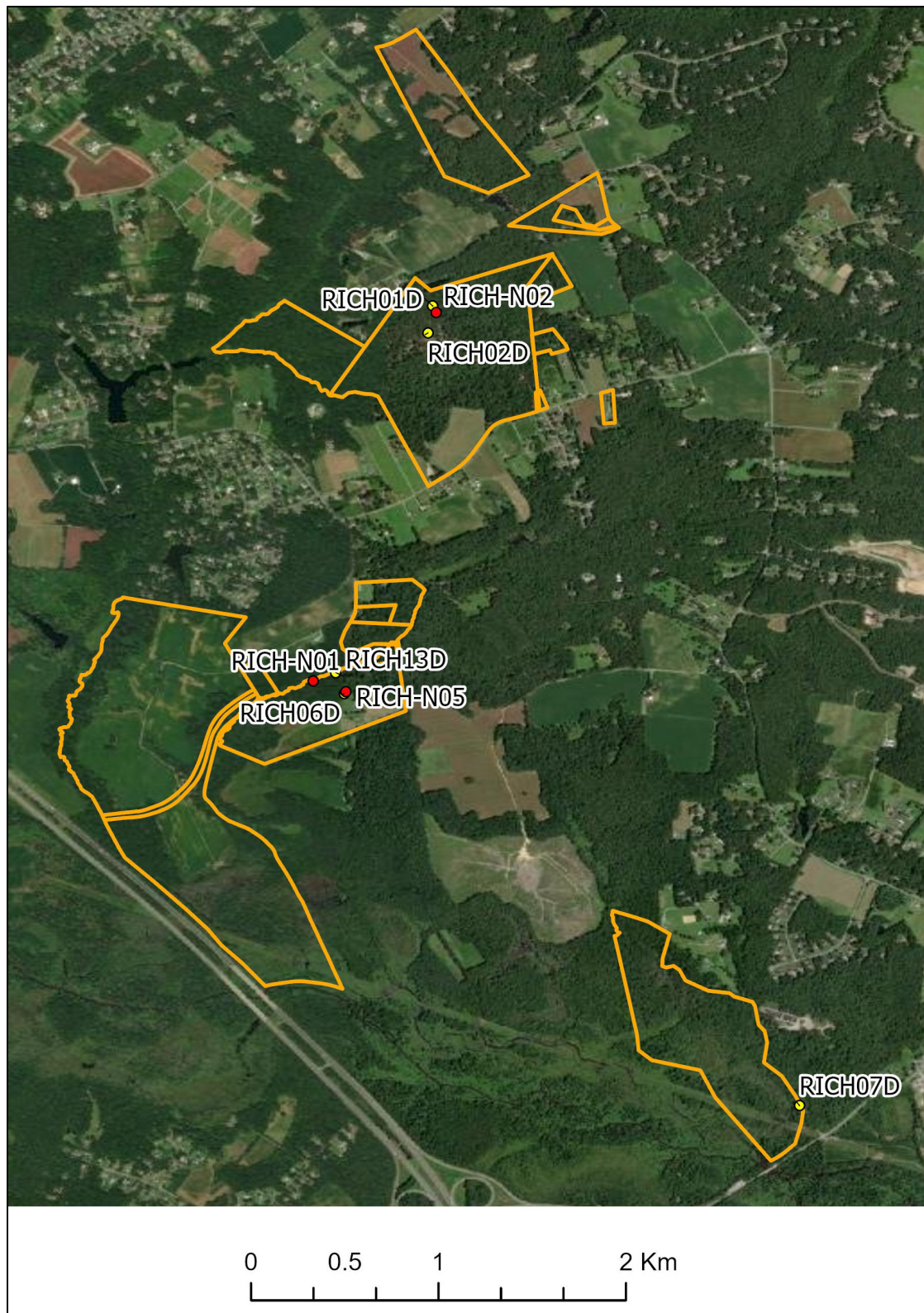


Figure 5. Bat capture sites (red) and dormant season acoustic sites (yellow) from 2016–2021 at Richmond National Battlefield Park, Virginia, units Cold Harbor (above), Gaines’ Mill, and Turkey Hill.

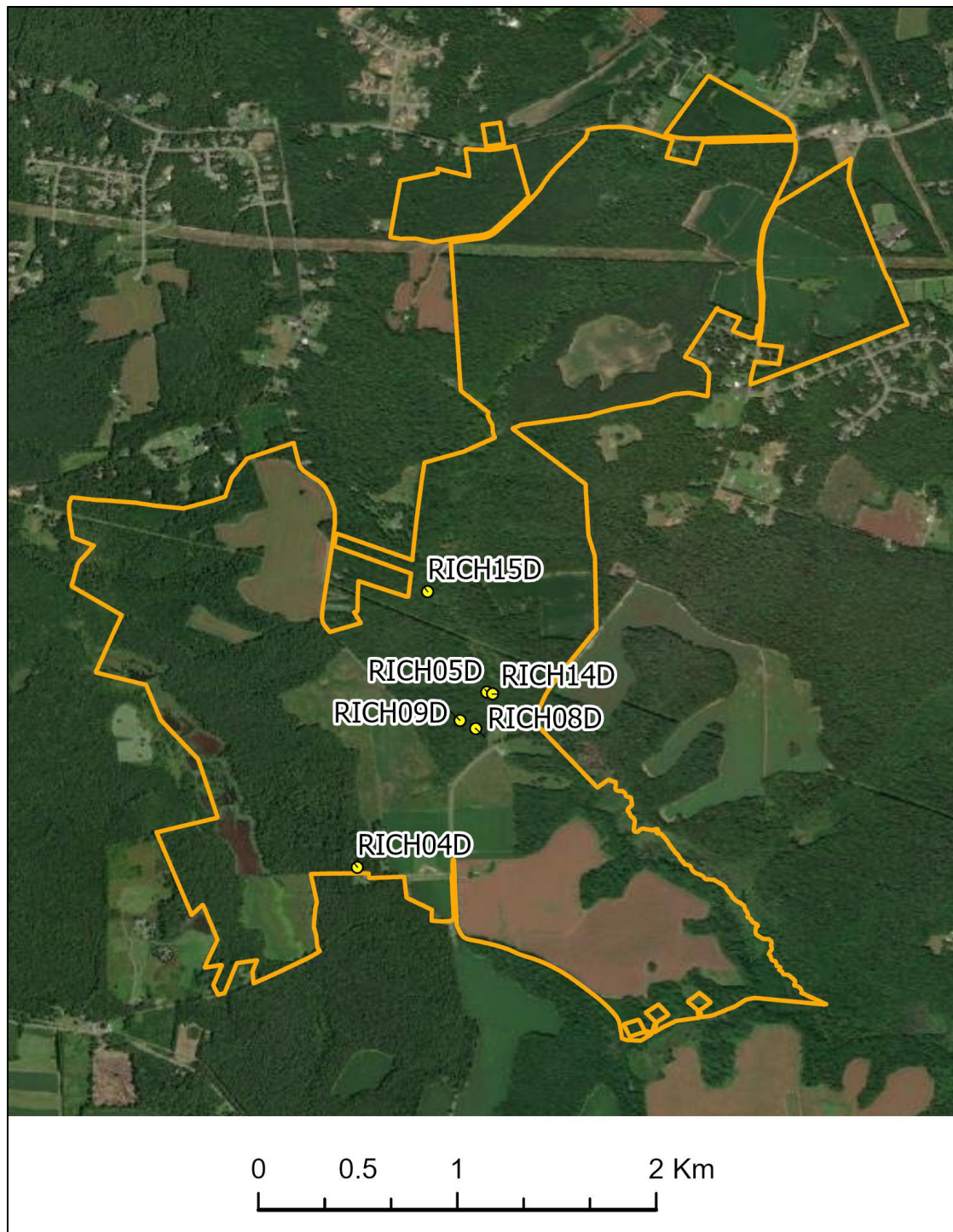


Figure 6. Bat dormant season acoustic sites from 2016–2021 at Richmond National Battlefield Park, Virginia, units Glendale and Malvern Hill.

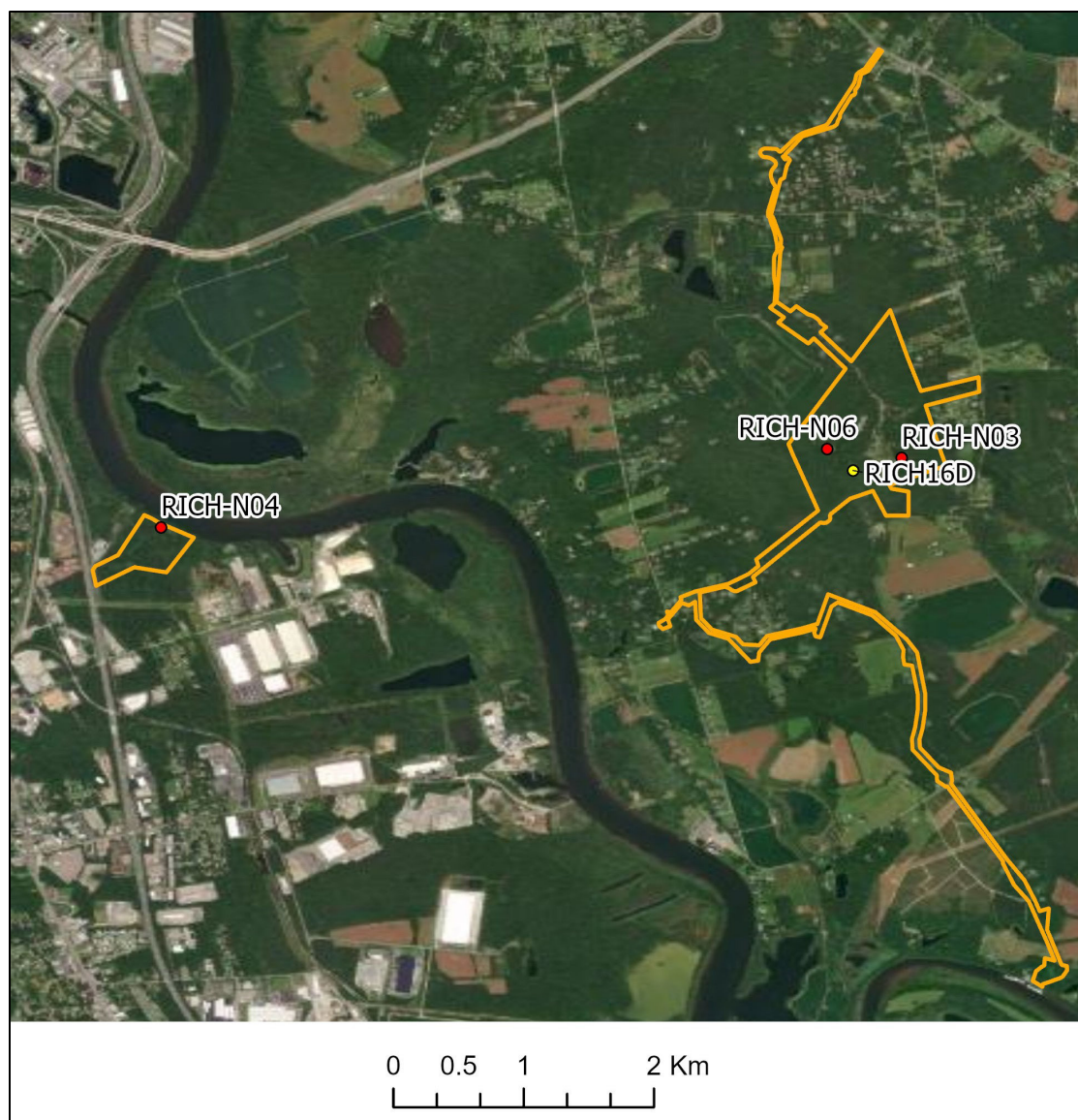


Figure 7. Bat capture sites (red) and dormant season acoustic sites (yellow) from 2016–2021 at Richmond National Battlefield Park, Virginia, units Cold Harbor, Gaines' Mill, and Turkey Hill.

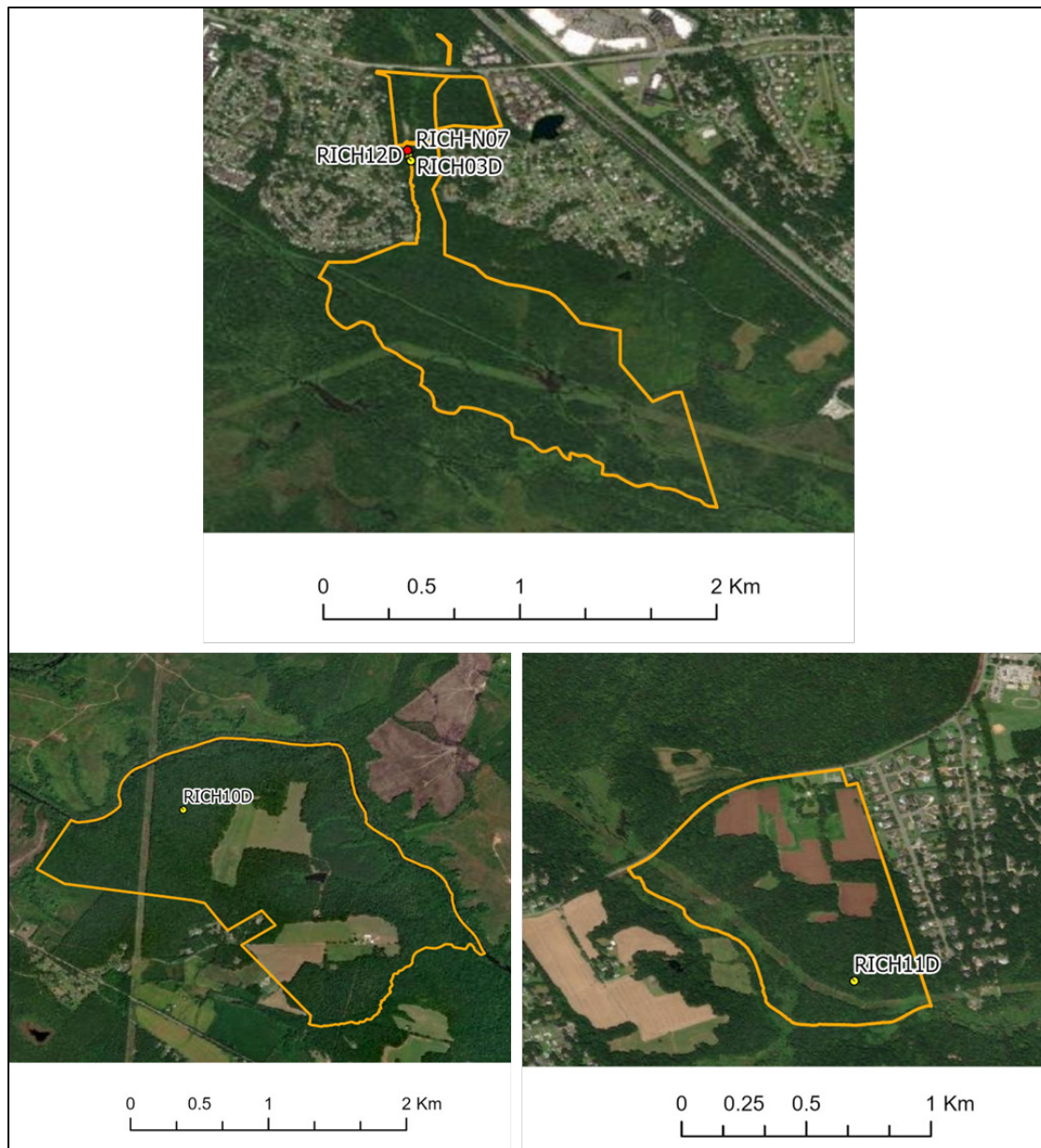


Figure 8. Bat capture sites (red) and dormant season acoustic detector sites (yellow) from 2016–2021 at Richmond National Battlefield Park, Virginia, units Beaverdam Creek (upper), North Anna (bottom left), and Totopotomoy Creek (bottom right).

Methods

I conducted acoustic and mist-netting surveys at RICH with the objectives of assessing bat species communities and documenting locations where WNS-imperiled species occur with specific emphasis on the federally endangered northern long-eared bat. Work began in 2016 in conjunction with several other NPS parks in Virginia with acoustic and capture surveys during the summer season. In the fall of 2017, I began non-reproductive, or dormant, season acoustic sampling from fall through spring, expanding work to examine over-wintering bat communities with specific focus on identifying if northern long-eared bats occurred year-round. In addition to serving as the first sample approximation, I used data from acoustic sampling to guide subsequent mist-netting efforts to increase the likelihood of northern long-eared bat capture.

Acoustic Survey

For acoustic survey, I deployed zero-crossing, frequency division bat detectors (Wildlife Acoustics, Concord, MA) at sites to sample for bat echolocation calls. All acoustic sampling occurred at passive acoustic sites (i.e., stationary) with detectors and microphones affixed to trees via cable lock (Figure 9). Acoustic bat detectors were set to record ultrasonic echolocation calls from dusk until dawn. Sampling methodology during the summer period, when bat activity is generally high, consisted of deploying detectors at many, non-repeating sites throughout the nine largest units of RICH (Figure 1 through Figure 8). Most summer acoustic sampling took place from May 15-August 15 to coincide with bat reproductive period (i.e., formation of maternity colonies through juvenile volancy) as defined the USFWS Indiana and northern long-eared bat survey guidelines (USFWS 2022b). However, for the purpose of presenting seasonal results, I extended this summer period to April 15–September 16 to better reflect activity patterns at RICH. Initially, sample periods consisted of 10–14 nights, but there were several instances in which sample periods were abbreviated as a result of equipment failure, battery depletion, or equipment disturbance. In 2018 and 2020, summer deployment periods were approximately 20 nights. Beginning in 2017, I included long-term deployments that ran through the non-reproductive or dormant season (September 16–April 15). During this period, I utilized long-term deployments of detectors at fewer locations that I considered to be optimal sites (e.g. drinking sites or commuting corridors) to record bat activity during traditionally low activity times of year. In many cases, I used summer sampling to guide dormant season sampling, such that dormant sites were in the same locations as summer sites where high activity of *Myotis* spp. was observed (e.g. RICH34 and RICH01D; RICH29 and RICH06D). Several dormant season sites were repeated over consecutive years. I sampled in dormant seasons from fall 2017 through spring 2021.



Figure 9. Representative acoustic detector deployment in 2016 at Richmond National Battlefield Park, Virginia.

I selected individual acoustic sites to encompass a variety of habitat types and correspond with bat ecology. I targeted forest trails, riparian corridors, ponds, vernal pools, field edges, and interior forest gaps that represented suitable habitat for the foraging, commuting, drinking, and roosting behavior of eastern bats (Coleman et al. 2014a, Kunz and Kurta 1988, Murray et al. 1999, Silvis et al. 2016).

I used United States Fish and Wildlife Service and United States Geological Survey-approved software Kaleidoscope 5.3.9 (Wildlife Acoustics, Concord, MA) using 5.2.0 species classifiers to identify bat species activity by echolocation call classification. I chose species candidates for call identification analysis based on known distribution and recent and historic capture records that corresponded with the park location. Bat species considered for identification included cave bat species: big brown bat, little brown bat, northern long-eared bat, Indiana bat, and tricolored bat; and tree bat species eastern red bat, hoary bat, silver-haired bat, evening bat (*Nycticeius humeralis*), and Mexican free-tailed bat (*Tadarida brasiliensis*). I used a maximum-likelihood estimator (MLE) p -value of 0.05 or less to qualify identification of bat species calls on a nightly basis to reduce reporting of misidentified bat calls. Kaleidoscope generates this MLE p -value for each sample night based on number of calls identified along with a confusion matrix of species error rates observed in test data. I performed visual validation on selected calls identified as northern long-eared bats, Indiana bats, and little brown bats to further evaluate identification accuracy.

I tabulated mean nightly activity of species by summing total number of MLE-qualifying identified echolocation passes and dividing this by number of nights sampled. Results were tabulated seasonally over years for spring (March 1–April 15), summer (April 16–September 15), fall (September 16–November 30), and winter (December 1–February 28) with seasonal periods based on a generalized cave bat annual life cycle (Silvis et al. 2016).

Acoustic Data Modeling

Generalized Linear Mixed Model (GLMM)

To interpret bat activity relative to broadscale landscape and weather variables, I modeled summer nightly bat echolocation pass results by covariates: habitat type, distance to water, nightly precipitation, and minimum temperature (Barr et al. 2021, Muthersbaugh et al. 2019, True et al. 2021). I classified habitat type at each acoustic site as: coniferous forest, deciduous forest, open, and wetland by grouping delineation classifications made by the Virginia Department of Conservation and Recreation (Patterson 2008, Taverna 2022, Appendix A). Coniferous forest included both pine dominant and mixed forest types (i.e., pine and deciduous trees). Deciduous forest included all non-wetland deciduous dominant forest types. Open comprised grassland, agricultural fields, and shrubland habitats. Wetlands included open wetlands, riparian-zone forest, swamps, and bottomland hardwood swamps. I calculated distance to water source by calculating distance from acoustic sites to streams and ponds in ArcGIS Pro 2.5.0 (Environmental Systems Research Institute, Inc., Redlands, CA) using US Geological Survey National Hydrology Dataset (USGS 2019). I obtained nightly weather data total rainfall and minimum temperature from the National Oceanic and Atmospheric Administration National Centers for Environmental Information (NOAA 2022). Bat acoustic nightly activity data (passes/night) is often zero-inflated (i.e., datasets contain many zeros because many site-nights do not record species passes) and has very high variance because passes per night usually vary considerably by site and night. Accordingly, I modeled activity with zero-inflated Generalized Linear Mixed Models (GLMMs) using a negative binomial distribution with the package *glmmTMB* in Program R (Brooks et al. 2017, R Core Team 2017). I used backwards stepwise selection to remove non-significant predictors, requiring a *p*-value of 0.10 or less for model inclusion. Resulting models varied by individual species and included all predictors that exceeded this significance threshold. I used models to predict fixed effects of each significant covariate on bat species activity using the *glmmTMB* package (Brooks et al. 2017).

Generalized Additive Model (GAM)

To evaluate seasonal fluctuations in bat activity, I used zero-inflated, negative binomial distribution Generalized Additive Models (GAMs) using package *mgcv* (Wood 2011) to predict species activity by Julian day in Program R (Guisan et al. 2002).

Capture Survey

I captured bats using 38 mm low-bag mist nets (Avinet Inc. Portland, Maine) of varying widths (4, 6, 9 and 12 m) and stacking configurations. Majority of sampling included multiple net stations with mist nets set across forest corridors, such as trails and unimproved roads, as well as, across streams and standing water where foliar clutter was such that it would surround mist nets to prevent free-flying bats from avoiding capture (Kunz and Kurta 1988, Kunz and Parsons 2009, Silvis et al. 2012).

I used acoustic survey results to guide selection of mist-netting sites to improve the likelihood of captures, with specific regard to capturing WNS-imperiled species. However, suitable and accessible mist-netting sites were limited due to the overall open nature of many park units, which limited the number of capture survey sites. I only mist-netted for bats on nights with optimal weather conditions, avoiding sampling during periods of high winds, substantial rain, or lightning (Loeb et al. 2015).

From captured bats, I recorded species, sex, age, reproductive condition, mass, and forearm length (Menzel et al. 2002a, Silvis et al. 2012). Age (i.e., adult or juvenile) was determined by backlighting the metacarpal phalangeal joint to evaluate joint fusion (Kunz 1973). I determined reproductive condition in females by palpating the abdomen to detect pregnancy and examined mammary glands to detect lactation and post-lactation (Kunz 1973). I released all bats near the site of capture and all handling adhered to the guidelines of National Park Service and Virginia Tech Institutional Animal Care and Use Committee protocols, NNCR.NER_MultipleParks_Ford_Bats_2018.A2, 16–240, and 19–227, respectively.

Results

Acoustic Survey

I sampled for 4,065 detector-nights, 1,603 of which occurred during the summer period. Summer sampling included 60 summer sites in 2016, 2017, 2018, and 2020, as well as seven dormant sites that recorded during the summer period in 2020 (Table 1). Dormant season sampling occurred at 16 sites, from 2017-2021, with many sites being resampled over this period (Table 2 through Table 4). Kaleidoscope software identified all ten bat species considered for presence at qualifying MLE thresholds ($p \leq 0.05$, Appendix B). Total numbers of bat passes identified by species were: big brown bat ($n = 76,516$), eastern red bat ($n = 47,134$), hoary bat ($n = 6,747$), silver-haired bat ($n = 6,298$), little brown bat ($n = 39,421$), northern long-eared bat ($n = 2,851$), Indiana bat ($n = 1,190$), evening bat ($n = 25,803$), tricolored bat ($n = 16,800$), and Mexican free-tailed ($n = 8,562$). Bat species GLMM and GAM parameter estimates are presented in Appendix C.

Table 1. Mean nightly activity in number of echolocation passes per night of bat species at Richmond National Battlefield Park, Virginia during the summers (April 16–September 15) of 2016, 2017, 2018, and 2020. Sites ending in “D” were dormant season sampling locations that recorded during summer 2020.

Site	Unit ¹	Year	All	EPFU ²	LABO ²	LACI ²	LANO ²	MYLU ²	MYSE ²	MYSO ²	NYHU ²	PESU ²	TABR ²
RICH01	FH	2016	35.67	0.25	10.75	0.00	0.00	16.50	0.17	1.50	0.00	6.50	0.00
RICH02	TH	2016	11.08	1.31	0.31	0.38	0.31	3.08	0.00	0.00	1.46	0.00	4.23
RICH03	CH	2016	122.31	106.23	1.62	0.69	0.00	0.38	0.00	0.00	13.38	0.00	0.00
RICH04	CH	2016	0.18	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH05	GMH	2016	1.00	0.00	0.00	0.00	0.00	0.00	0.82	0.00	0.00	0.18	0.00
RICH06	GMH	2016	1.83	0.00	0.83	0.33	0.25	0.42	0.00	0.00	0.00	0.00	0.00
RICH07	GMH	2016	9.64	3.82	0.00	0.27	0.00	1.27	2.45	0.27	0.00	1.55	0.00
RICH08	GMH	2016	0.50	0.00	0.00	0.17	0.00	0.17	0.00	0.00	0.00	0.17	0.00
RICH09	GMH	2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH10	GMH	2016	1.09	0.00	0.00	0.00	0.18	0.18	0.00	0.00	0.00	0.00	0.73
RICH11	GM	2016	80.92	64.00	7.75	0.00	0.00	0.83	1.25	0.92	6.17	0.00	0.00
RICH12	BD	2016	39.08	10.08	13.58	0.50	0.00	4.00	0.00	0.00	9.17	1.17	0.58
RICH13	GM	2016	219.67	199.17	0.00	0.00	0.00	1.83	0.00	0.17	14.83	0.33	3.33
RICH14	CH	2016	21.85	20.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23
RICH15	CH	2016	8.15	2.85	0.00	0.00	0.00	0.38	4.54	0.00	0.00	0.38	0.00
RICH16	CH	2016	324.54	244.08	34.31	2.92	0.00	0.00	0.92	0.62	28.54	13.15	0.00
RICH17	GMH	2016	5.31	0.00	1.92	0.00	0.00	0.00	0.00	0.00	1.77	1.62	0.00
RICH18	FH	2016	1.08	0.00	0.23	0.31	0.00	0.00	0.00	0.00	0.00	0.54	0.00
RICH19	GMH	2016	0.50	0.17	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
RICH20	GMH	2017	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

¹ BD = Beaver Dam Creek, CH = Cold Harbor, DB = Drewry’s Bluff, FH = Fort Harrison, GMH = Glendale/Malvern Hill, GM= Gaines’ Mill, MH = Malvern Hill, NA = North Anna, TC = Totopotomoy Creek, TH = Turkey Hill.

² EPFU = big brown bat (*Eptesicus fuscus*), LABO = eastern red bat (*Lasiurus borealis*), LACI = hoary bat (*Lasiurus cinereus*), LANO = silver-haired bat (*Lasionycteris noctivagans*), MYLU = little brown bat (*Myotis lucifugus*), MYSE = northern long-eared bat (*Myotis septentrionalis*), MYSO = Indiana bat (*Myotis sodalis*), NYHU = evening bat (*Nycticeius humeralis*), PESU = tricolored bat (*Perimyotis subflavus*), TABR = Mexican free-tailed bat (*Tadarida brasiliensis*).

Table 1 (continued). Mean nightly activity in number of echolocation passes per night of bat species at Richmond National Battlefield Park, Virginia during the summers (April 16–September 15) of 2016, 2017, 2018, and 2020. Sites ending in “D” were dormant season sampling locations that recorded during summer 2020.

Site	Unit ¹	Year	All	EPFU ²	LABO ²	LACI ²	LANO ²	MYLU ²	MYSE ²	MYSO ²	NYHU ²	PESU ²	TABR ²
RICH21	GMH	2017	5.91	0.82	2.18	0.00	0.00	2.91	0.00	0.00	0.00	0.00	0.00
RICH22	GMH	2017	35.18	11.55	2.45	0.00	0.00	15.09	1.55	0.00	0.00	3.27	1.27
RICH23	GMH	2017	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH24	GMH	2017	197.40	0.00	69.20	0.20	1.20	75.90	2.30	18.10	0.00	29.40	1.10
RICH25	BD	2017	189.18	117.00	0.00	0.00	0.00	0.00	0.91	0.18	16.55	1.64	52.91
RICH26	FH	2017	768.00	648.30	13.80	0.00	0.00	11.60	1.00	0.00	75.90	2.50	14.90
RICH27	CH	2017	2.00	0.80	0.40	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00
RICH28	GM	2017	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27
RICH29	GM	2017	591.91	32.00	241.82	0.00	0.00	286.18	0.00	0.00	0.00	31.91	0.00
RICH30	TH	2017	10.73	8.27	0.18	0.00	0.00	0.82	0.55	0.27	0.00	0.00	0.64
RICH31	FH	2017	54.50	7.60	18.20	2.40	0.00	6.50	0.00	0.00	17.60	0.00	2.20
RICH32	BD	2018	124.79	30.24	24.30	0.06	0.36	29.48	1.70	5.48	23.91	8.91	0.33
RICH33	CH	2018	82.64	67.77	3.64	0.00	3.14	0.27	0.00	0.00	0.68	0.00	7.14
RICH34	CH	2018	174.55	33.50	22.14	2.23	0.00	9.68	0.14	0.00	97.77	8.23	0.86
RICH35	CH	2018	21.29	7.14	7.71	1.86	0.00	4.29	0.00	0.00	0.00	0.00	0.29
RICH36	GM	2018	62.65	5.96	0.74	0.43	3.57	0.17	0.00	0.00	9.48	0.00	42.30
RICH37	GM	2018	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH38	DB	2018	106.00	8.33	24.62	0.00	0.00	3.81	0.57	0.00	0.00	68.05	0.62
RICH39	FH	2018	104.38	45.62	22.38	0.57	0.00	8.38	0.14	0.00	10.67	16.62	0.00
RICH40	FH	2018	26.83	0.00	6.83	0.50	0.00	19.50	0.00	0.00	0.00	0.00	0.00

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Table 1 (continued). Mean nightly activity in number of echolocation passes per night of bat species at Richmond National Battlefield Park, Virginia during the summers (April 16–September 15) of 2016, 2017, 2018, and 2020. Sites ending in “D” were dormant season sampling locations that recorded during summer 2020.

Site	Unit ¹	Year	All	EPFU ²	LABO ²	LACI ²	LANO ²	MYLU ²	MYSE ²	MYSO ²	NYHU ²	PESU ²	TABR ²
RICH41	FH	2018	17.80	6.00	9.60	0.80	0.00	0.00	0.00	0.00	1.40	0.00	0.00
RICH42	GMH	2018	6.29	0.10	0.52	3.24	0.00	0.33	0.19	1.29	0.00	0.00	0.62
RICH43	GMH	2018	0.22	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00
RICH44	GMH	2018	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH45	GMH	2018	206.33	10.05	75.86	0.14	0.00	86.05	0.00	8.76	0.00	24.76	0.71
RICH46	GMH	2020	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68
RICH47	GMH	2020	88.86	3.10	27.24	3.05	0.00	10.86	0.10	1.29	28.95	0.62	13.67
RICH48	GMH	2020	1.45	0.25	0.55	0.00	0.00	0.00	0.40	0.25	0.00	0.00	0.00
RICH49	TH	2020	0.62	0.24	0.00	0.00	0.00	0.10	0.29	0.00	0.00	0.00	0.00
RICH50	CH	2020	27.19	3.67	3.81	0.00	0.00	4.10	0.29	0.62	10.43	0.90	3.38
RICH51	GM	2020	0.13	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00
RICH52	GM	2020	9.65	3.25	0.00	0.00	0.00	0.00	0.00	0.00	5.10	0.00	1.30
RICH53	NA	2020	211.40	4.00	23.35	0.00	0.65	7.00	0.00	0.00	6.50	168.10	1.80
RICH54	NA	2020	64.71	15.14	33.95	0.48	0.24	7.05	1.90	0.62	1.19	4.00	0.14
RICH55	NA	2020	213.60	0.45	123.85	0.50	0.00	87.35	1.45	0.00	0.00	0.00	0.00
RICH56	TC	2020	333.00	71.80	92.60	0.00	0.00	158.90	9.70	0.00	0.00	0.00	0.00
RICH57	TC	2020	34.85	0.55	6.60	0.20	0.00	24.30	0.00	0.00	0.00	3.05	0.15
RICH58	BD	2020	23.20	5.80	1.15	0.00	0.00	9.55	6.70	0.00	0.00	0.00	0.00
RICH59	FH	2020	313.31	227.44	29.56	0.00	0.00	19.81	0.00	0.00	2.63	33.88	0.00
RICH60	DB	2020	5.50	5.31	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00

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Table 1 (continued). Mean nightly activity in number of echolocation passes per night of bat species at Richmond National Battlefield Park, Virginia during the summers (April 16–September 15) of 2016, 2017, 2018, and 2020. Sites ending in “D” were dormant season sampling locations that recorded during summer 2020.

Site	Unit ¹	Year	All	EPFU ²	LABO ²	LACI ²	LANO ²	MYLU ²	MYSE ²	MYSO ²	NYHU ²	PESU ²	TABR ²
RICH01D	CH	2020	117.89	40.88	16.85	4.32	0.00	8.91	0.23	0.00	41.42	3.80	1.49
RICH02D	CH	2020	381.25	150.00	114.75	1.10	0.00	0.27	0.19	0.27	109.63	1.08	3.96
RICH03D	BD	2020	161.53	83.20	6.95	0.00	0.00	14.27	3.80	0.98	19.83	32.50	0.00
RICH04D	GMH	2020	12.03	1.96	4.31	0.99	1.03	2.48	0.43	0.07	0.08	0.02	0.66
RICH06D	GM	2020	361.30	61.74	137.80	43.94	4.53	103.19	0.00	0.06	4.23	0.00	5.80
RICH07D	TH	2020	109.64	13.86	18.05	0.03	0.03	19.71	0.33	0.00	28.36	29.26	0.00
RICH09D	GMH	2020	9.33	2.01	2.26	0.24	0.00	2.89	0.25	0.53	0.00	1.08	0.07

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Table 2. Mean nightly activity of bat species at Richmond National Battlefield Park, Virginia during fall from September 16–November 30 in echolocation passes per night.

Site	Unit ¹	All	EPFU ²	LABO ²	LACI ²	LANO ²	MYLU ²	MYSE ²	MYSO ²	NYHU ²	PESU ²	TABR ²
RICH01D	CH	10.61	3.63	0.44	1.03	0.07	0.55	0.03	0.00	0.83	0.27	3.79
RICH02D	CH	60.66	58.39	0.73	0.05	0.00	0.11	0.05	0.02	0.95	0.16	0.20
RICH03D	BD	45.71	28.69	1.03	0.09	0.56	6.34	4.04	0.44	3.67	0.51	0.33
RICH04D	GMH	2.16	0.04	0.08	0.31	0.26	0.06	0.80	0.00	0.03	0.03	0.56
RICH05D	GMH	1.15	0.00	0.00	0.63	0.00	0.00	0.37	0.00	0.00	0.00	0.15
RICH06D	GM	10.37	0.55	2.27	0.04	1.56	4.33	0.00	0.27	0.12	0.11	1.11
RICH07D	TH	22.89	0.17	0.67	0.30	1.86	1.63	0.08	0.38	4.30	12.83	0.67
RICH08D	GMH	33.16	0.00	0.00	1.78	0.00	0.00	0.00	0.00	0.00	0.00	31.38
RICH09D	GMH	1.38	0.00	0.00	0.31	0.00	0.38	0.00	0.00	0.00	0.00	0.69
RICH10D	NA	11.92	1.44	0.00	0.12	0.08	5.52	4.32	0.44	0.00	0.00	0.00
RICH11D	TC	12.00	2.50	0.29	0.00	0.00	2.58	6.50	0.00	0.13	0.00	0.00
RICH12D	BD	1.08	0.15	0.15	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.00
RICH13D	GM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH14D	GMH	0.35	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.00
RICH15D	GMH	11.72	0.00	2.88	2.52	0.68	2.52	0.00	0.00	1.32	1.08	0.72
RICH16D	FH	10.61	3.63	0.44	1.03	0.07	0.55	0.03	0.00	0.83	0.27	3.79
RICH01D	CH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH02D	CH	3.22	0.41	0.58	0.37	0.04	0.16	0.12	0.00	0.44	0.84	0.27
RICH03D	BD	17.63	13.68	0.05	0.02	0.02	0.56	0.43	0.17	2.52	0.02	0.15
RICH04D	GMH	1.64	0.00	0.00	0.31	0.69	0.00	0.18	0.00	0.00	0.00	0.46
RICH05D	GMH	0.85	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.55
RICH06D	GM	30.26	0.00	9.80	0.43	0.49	14.14	0.00	0.00	1.86	3.40	0.14

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Table 2 (continued). Mean nightly activity of bat species at Richmond National Battlefield Park, Virginia during fall from September 16–November 30 in echolocation passes per night.

Site	Unit ¹	All	EPFU ²	LABO ²	LACI ²	LANO ²	MYLU ²	MYSE ²	MYSO ²	NYHU ²	PESU ²	TABR ²
RICH07D	TH	0.33	0.00	0.00	0.10	0.00	0.24	0.00	0.00	0.00	0.00	0.00
RICH08D	GMH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH09D	GMH	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13
RICH10D	NA	0.15	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH11D	TC	3.55	0.11	0.06	0.21	0.00	0.77	2.40	0.00	0.00	0.00	0.00
RICH12D	BD	3.46	2.46	0.08	0.04	0.04	0.25	0.44	0.06	0.08	0.00	0.00
RICH13D	GM	0.10	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
RICH14D	GMH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH15D	GMH	0.11	0.00	0.00	0.00	0.06	0.00	0.06	0.00	0.00	0.00	0.00
RICH16D	FH	5.06	0.08	1.39	0.39	0.00	2.96	0.00	0.00	0.00	0.20	0.04

¹ BD = Beaver Dam Creek, CH = Cold Harbor, DB = Drewry's Bluff, FH = Fort Harrison, GMH = Glendale/Malvern Hill, GM= Gaines' Mill, MH = Malvern Hill, NA = North Anna, TC = Totopotomoy Creek, TH = Turkey Hill.

² EPFU = big brown bat (*Eptesicus fuscus*), LABO = eastern red bat (*Lasiurus borealis*), LACI = hoary bat (*Lasiurus cinereus*), LANO = silver-haired bat (*Lasionycteris noctivagans*), MYLU = little brown bat (*Myotis lucifugus*), MYSE = northern long-eared bat (*Myotis septentrionalis*), MYSO = Indiana bat (*Myotis sodalis*), NYHU = evening bat (*Nycticeius humeralis*), PESU = tricolored bat (*Perimyotis subflavus*), TABR = Mexican free-tailed bat (*Tadarida brasiliensis*).

Table 4. Mean nightly activity of bat species at Richmond National Battlefield Park, Virginia during spring from March 1–April 14 in echolocation passes per night.

Site	Unit ¹	All	EPFU ²	LABO ²	LACI ²	LANO ²	MYLU ²	MYSE ²	MYSO ²	NYHU ²	PESU ²	TABR ²
RICH01D	CH	30.82	12.57	4.47	0.55	0.42	5.45	0.08	0.04	2.14	4.33	0.77
RICH02D	CH	51.54	31.08	3.89	1.84	5.81	0.15	0.29	0.00	5.68	0.47	2.33
RICH03D	BD	65.46	32.44	2.79	0.13	0.13	5.53	1.80	0.20	20.65	0.74	1.04
RICH04D	GMH	23.08	0.53	0.79	0.13	13.44	0.10	0.13	0.05	5.67	0.13	2.10
RICH05D	GMH	0.14	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH06D	GM	148.06	9.45	41.72	1.03	33.37	38.65	0.00	0.16	10.30	0.54	12.83
RICH07D	TH	32.60	7.91	3.92	10.10	0.82	4.61	0.07	0.29	0.17	1.22	3.49
RICH08D	GMH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RICH09D	GMH	12.37	0.51	2.72	0.47	0.65	5.14	1.23	1.33	0.00	0.33	0.00
RICH10D	NA	3.17	0.07	0.22	0.00	0.00	1.88	0.51	0.44	0.00	0.05	0.00
RICH11D	TC	6.28	1.52	1.09	0.20	0.00	2.43	0.00	0.00	0.00	0.96	0.09
RICH12D	BD	22.78	12.16	1.71	0.07	0.49	3.42	0.38	0.00	3.44	0.09	1.02
RICH13D	GM	1.00	0.61	0.00	0.00	0.28	0.00	0.06	0.00	0.00	0.00	0.06
RICH14D	GMH	0.53	0.06	0.15	0.00	0.09	0.18	0.06	0.00	0.00	0.00	0.00
RICH15D	GMH	1.66	0.32	0.00	0.29	0.61	0.00	0.00	0.00	0.00	0.00	0.44
RICH16D	FH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

¹ BD = Beaver Dam Creek, CH = Cold Harbor, DB = Drewry's Bluff, FH = Fort Harrison, GMH = Glendale/Malvern Hill, GM= Gaines' Mill, MH = Malvern Hill, NA = North Anna, TC = Totopotomoy Creek, TH = Turkey Hill.

² EPFU = big brown bat (*Eptesicus fuscus*), LABO = eastern red bat (*Lasiurus borealis*), LACI = hoary bat (*Lasiurus cinereus*), LANO = silver-haired bat (*Lasionycteris noctivagans*), MYLU = little brown bat (*Myotis lucifugus*), MYSE = northern long-eared bat (*Myotis septentrionalis*), MYSO = Indiana bat (*Myotis sodalis*), NYHU = evening bat (*Nycticeius humeralis*), PESU = tricolored bat (*Perimyotis subflavus*), TABR = Mexican free-tailed bat (*Tadarida brasiliensis*)..

Big brown bat

Big brown bat activity was highest of species identified at RICH and prevalent among most sample locations (Table 1). Activity was extremely high at several locations at Fort Harrison (RICH26 and RICH59), Cold Harbor (RICH16, RICH03, RICH02D), and Gaines' Mill (RICH13) where mean passes per night exceeded 100 during the summer. The GLMM of activity included significant predictors: habitat type, distance to water, and nightly precipitation. Seasonally, big brown bat activity increased sharply in early April, peaked in late July and declined through October into November (Figure 10). Big brown bat activity continued through the dormant season at lower levels, and in winter months from December through February, notable activity appeared limited to Beaver Dam Creek. Predicted activity by GLMM was highest among open areas, but was also high among deciduous dominated forest and wetland and riparian forest (Figure 11).

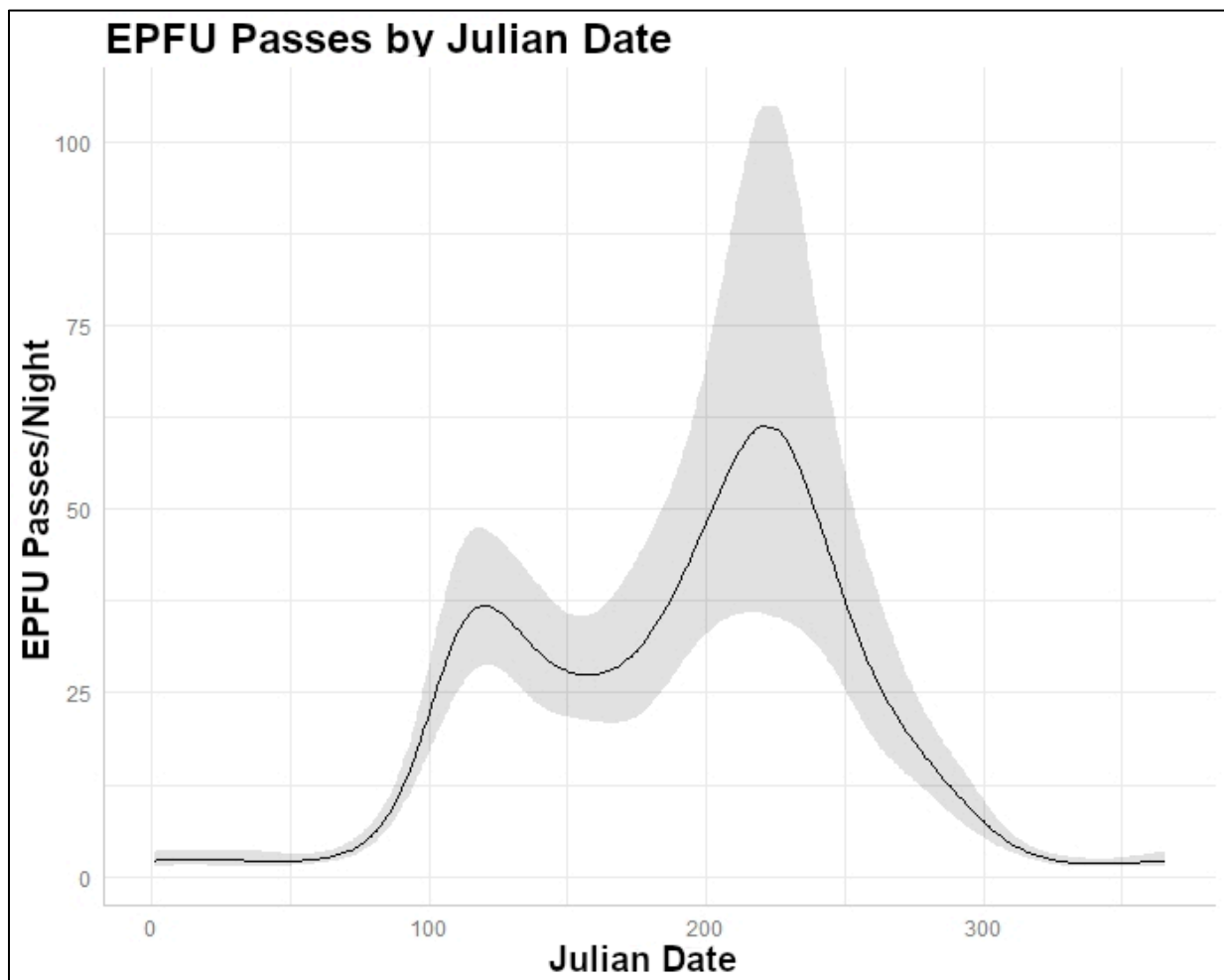


Figure 10. Big brown bat (*Eptesicus fuscus*) activity (mean passes/night and standard error) as predicted by a generalized additive model of activity by Julian date at Richmond National Battlefield Park, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

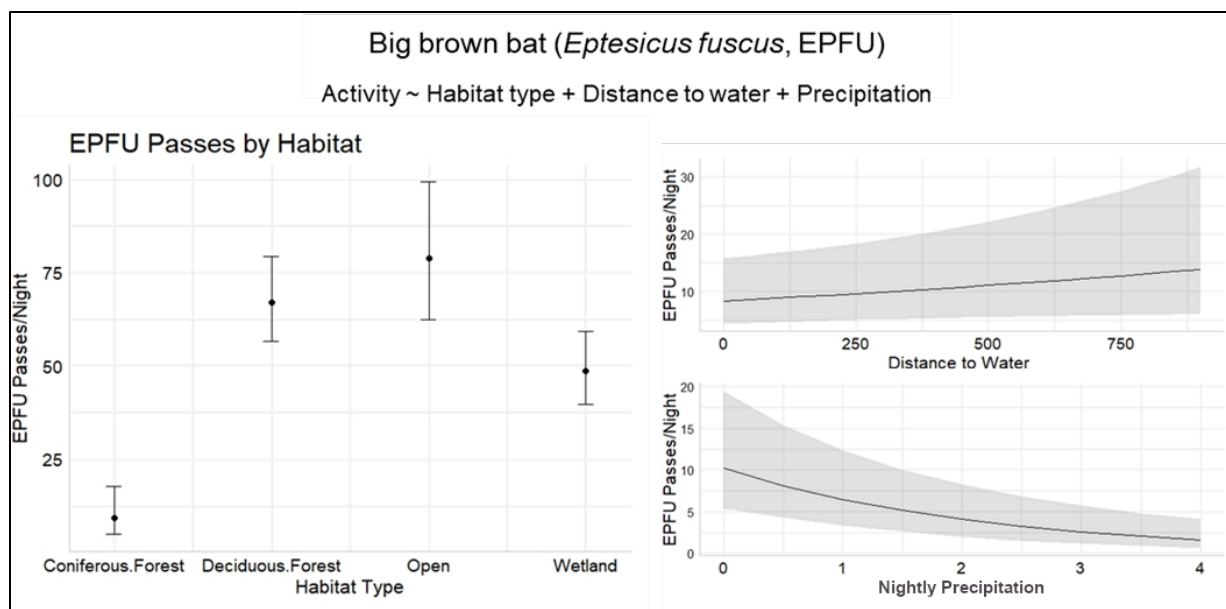


Figure 11. Predicted activity (mean passes per night and standard error) for big brown bats (*Eptesicus fuscus*, EPFU) by generalized linear mixed model during summer at Richmond National Battlefield Park, Virginia by covariates habitat, distance to water (m), and nightly precipitation (cm).

Little brown bat

Little brown bats were second most commonly identified among cave bats at RICH. Identified passes were widespread and occurred mostly at low to moderate levels. Several sites did record high levels of activity including: Glendale/Malvern Hill sites RICH24 and RICH45, Totopotomoy Creek RICH56, and especially Gaines' Mill RICH29 where mean calls/night was 286.1. However, visual validation of selected calls revealed many misidentifications. Overall trends of activity increased in early April, peaking in early July, then declining in late July (Figure 12). Notable winter activity was recorded at Gaines' Mill and Fort Harrison from December through February possibly indicative of overwintering near these sites. The GLMM showed predicted activity to be most associated with coniferous and mixed forest habitats and wetland/riparian forest (Figure 13).

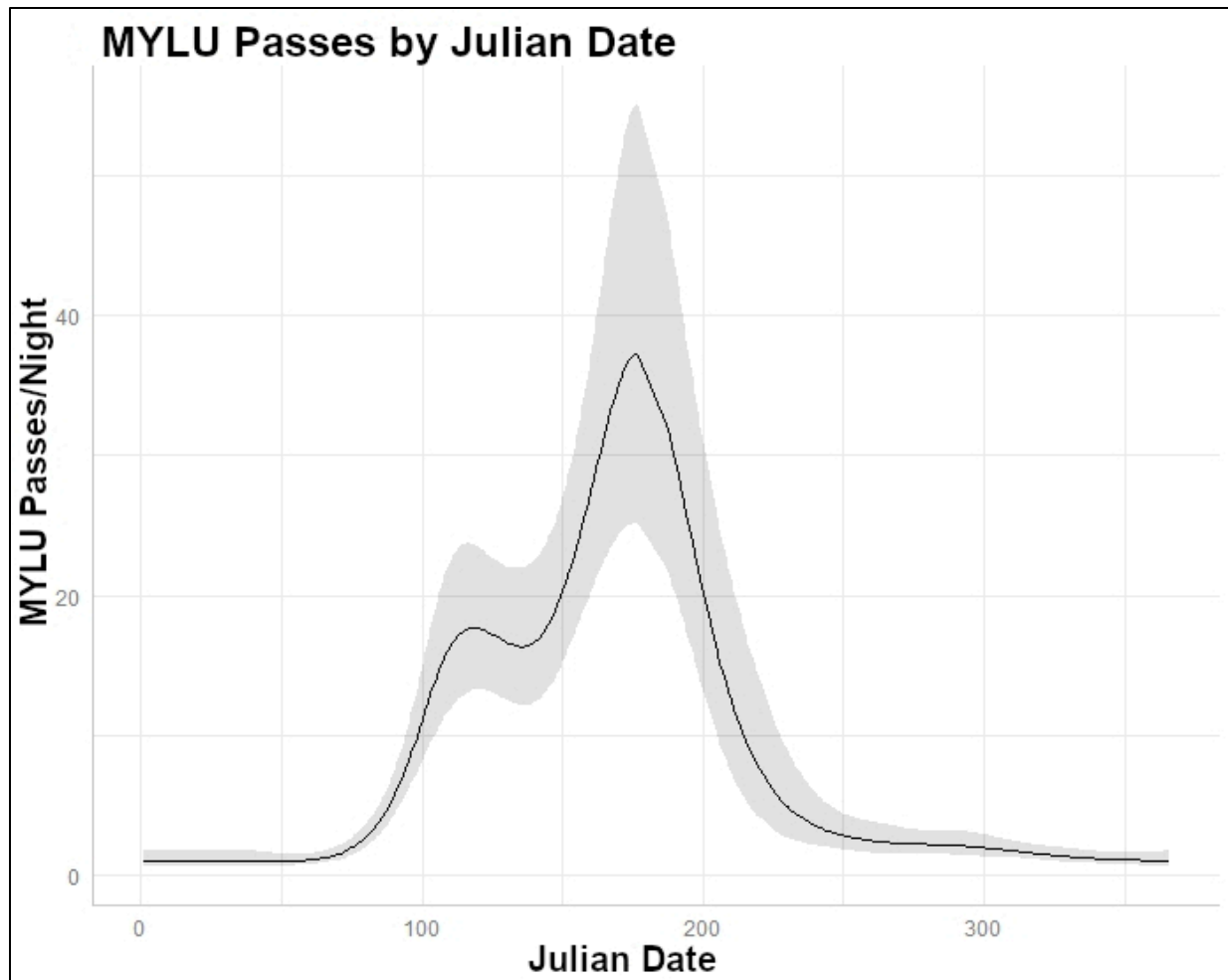


Figure 12. Little brown bat (*Myotis lucifugus*) activity (mean passes/night and standard error) as predicted by a generalized additive model of activity by Julian date at Richmond National Battlefield Park, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

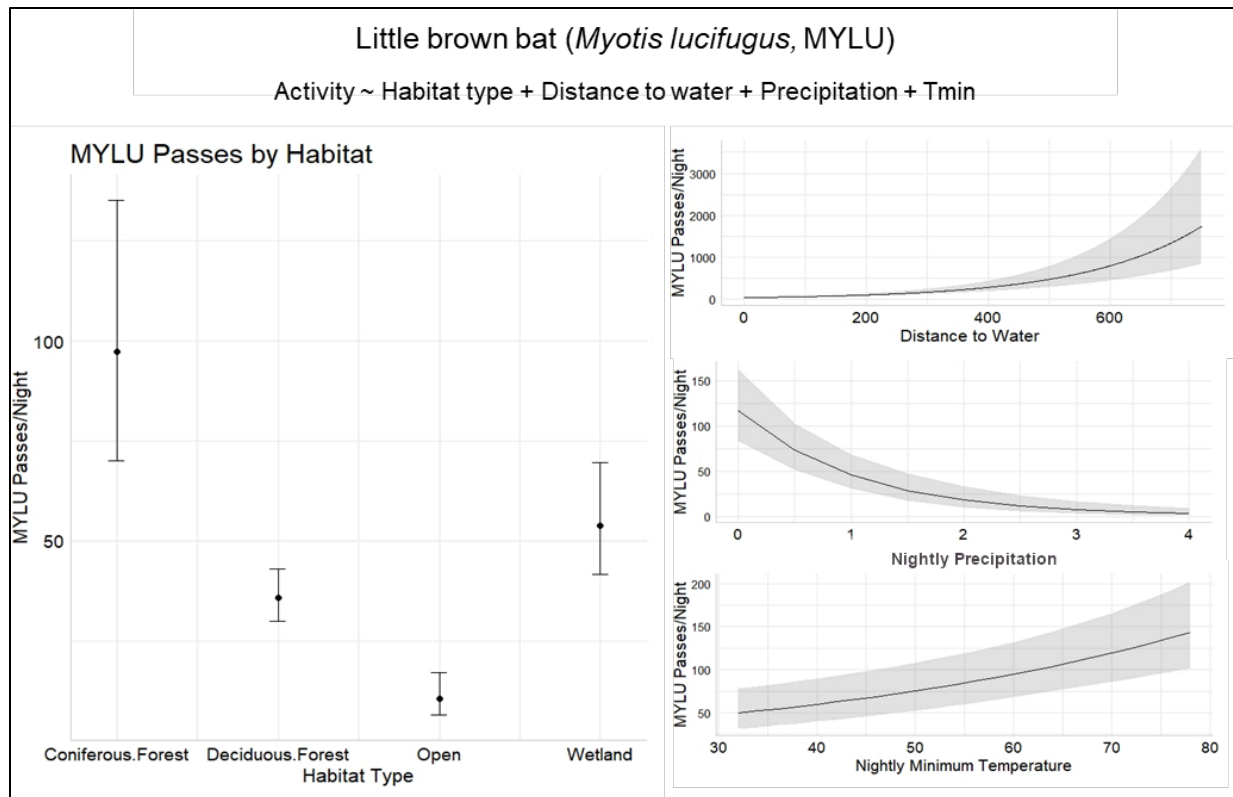


Figure 13. Predicted activity (mean passes per night and standard error) for little brown bats (*Myotis lucifugus*; MYLU) by generalized linear mixed model during summer at Richmond National Battlefield Park, Virginia by covariates: habitat, distance to water (m), nightly precipitation (cm), and minimum nightly temperature (°F).

Northern long-eared bat

Northern long-eared bat calls were identified at approximately half of sites that were sampled during the summer. Site passes per night were very low with few exceptions. During summer, Totopotomoy Creek site RICH56 recorded the most identified calls followed by Beaver Dam Creek site RICH58, and RICH15 at Cold Harbor. During winter, significant activity was identified at Totopotomoy Creek site RICH11D. Visual examination of identified calls from several sites found many to be software misidentifications of eastern red bats, however a portion of calls did appear to be correctly identified as northern long-eared bats, including some recorded during the winter period. Although overall activity was low, predicted activity from the GAM depicted peaks in early July and late October (Figure 14). The GLMM found activity to be highest in coniferous and mixed forest habitats (Figure 15).

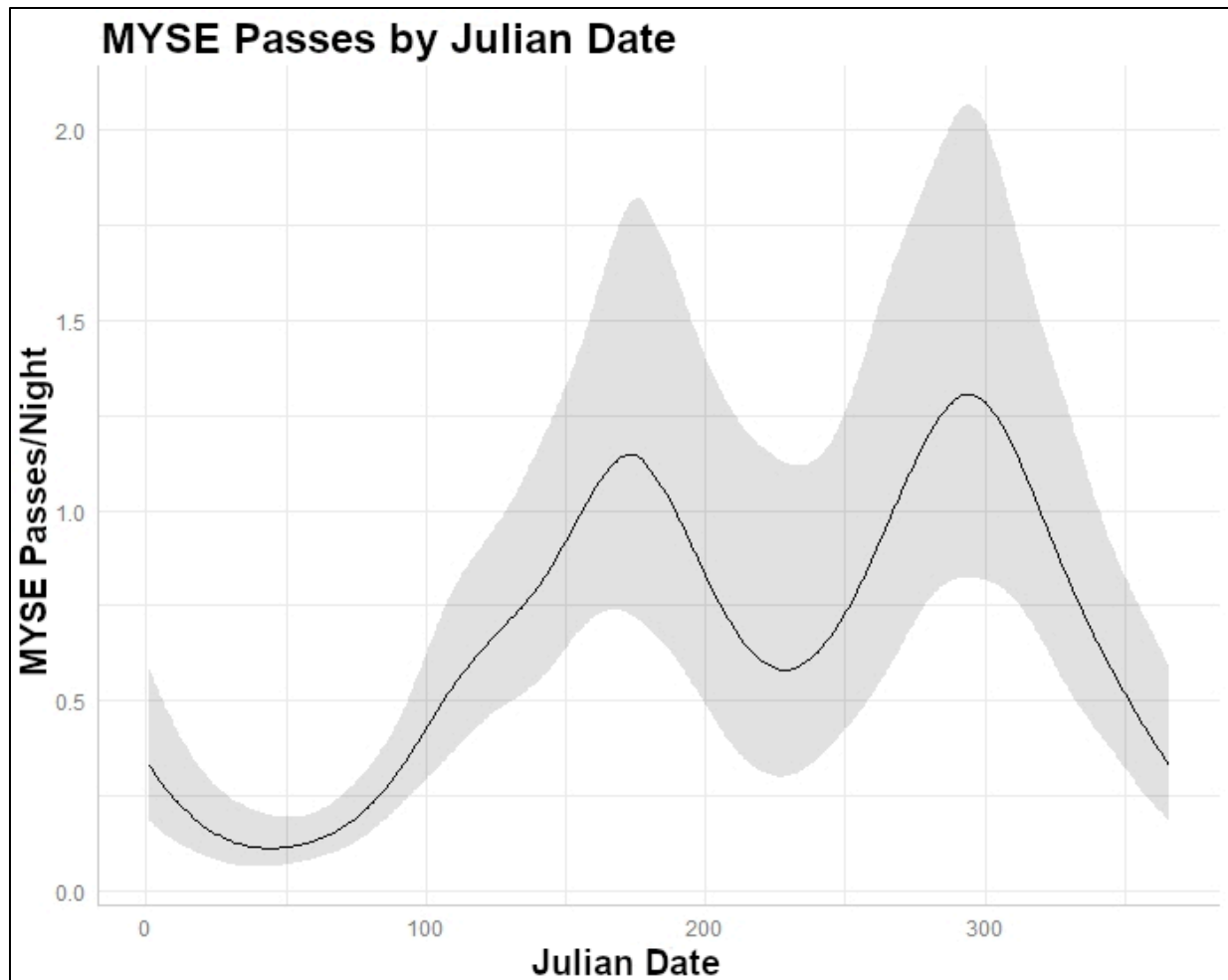


Figure 14. Northern long-eared bat (*Myotis septentrionalis*) activity (mean passes/night and standard error) as predicted by a generalized additive model of activity by Julian date at Richmond National Battlefield Park, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

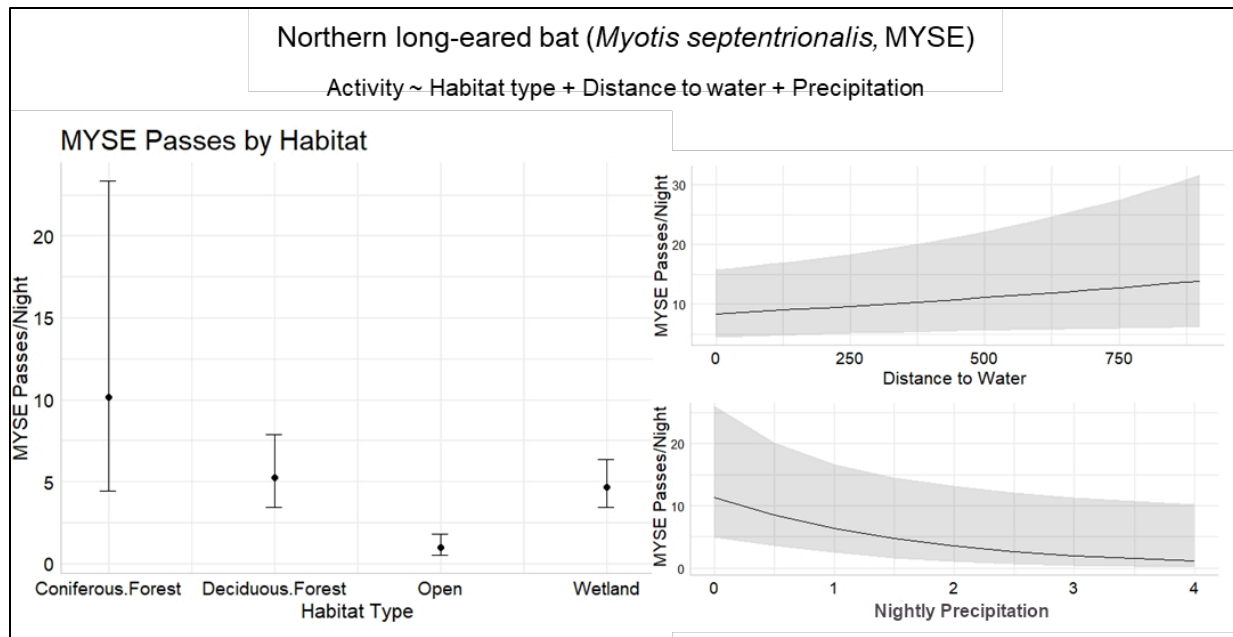


Figure 15. Predicted activity (mean passes per night and standard error) for northern long-eared bats (*Myotis septentrionalis*, MYSE) by generalized linear mixed model during summer at Richmond National Battlefield Park, Virginia by covariates habitat, distance to water (m), and nightly precipitation (cm).

Indiana bat

Indiana bats were identified at 21 of 67 sites that were sampled during the summer. Passes per night were very low at all but three sites: Glendale/Malvern Hill sites RICH24 and RICH45 and Beaver Dam Creek site RICH32. During the dormant season very few calls were identified. Visual authentication of identified Indiana bat calls found most to be misidentifications (i.e., eastern red bats), however, there were several identifications that could not be ruled out. No calls from the winter appeared to be plausible identifications. The GAM showed predicted activity was increased from April through early October (Figure 16). Predicted activity from the GLMM was more associated with coniferous and mixed forest (Figure 17).

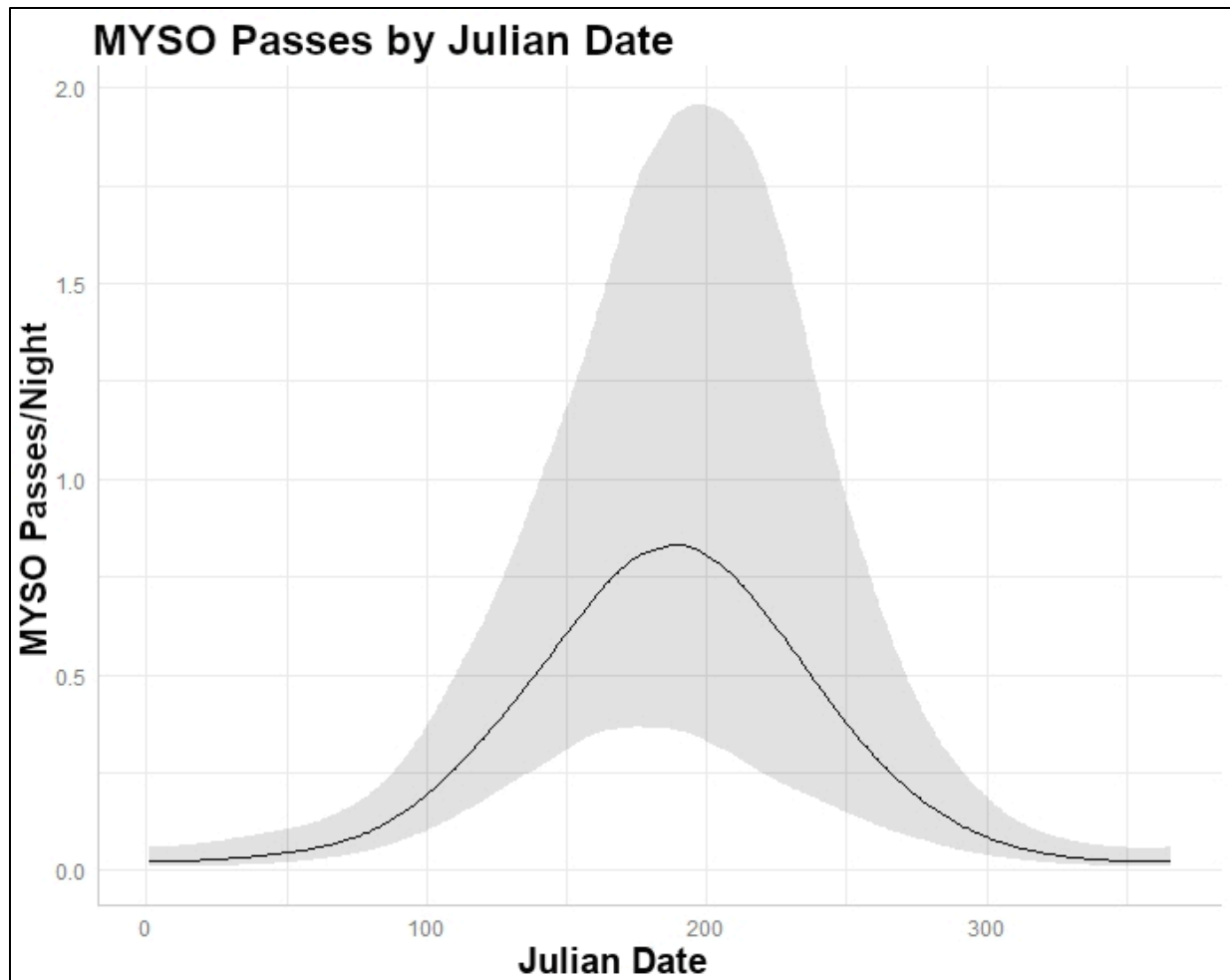


Figure 16. Indiana bat (*Myotis sodalis*) activity (mean passes/night and standard error) at Richmond National Battlefield Park, Virginia as predicted by a generalized additive model of activity by Julian date. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

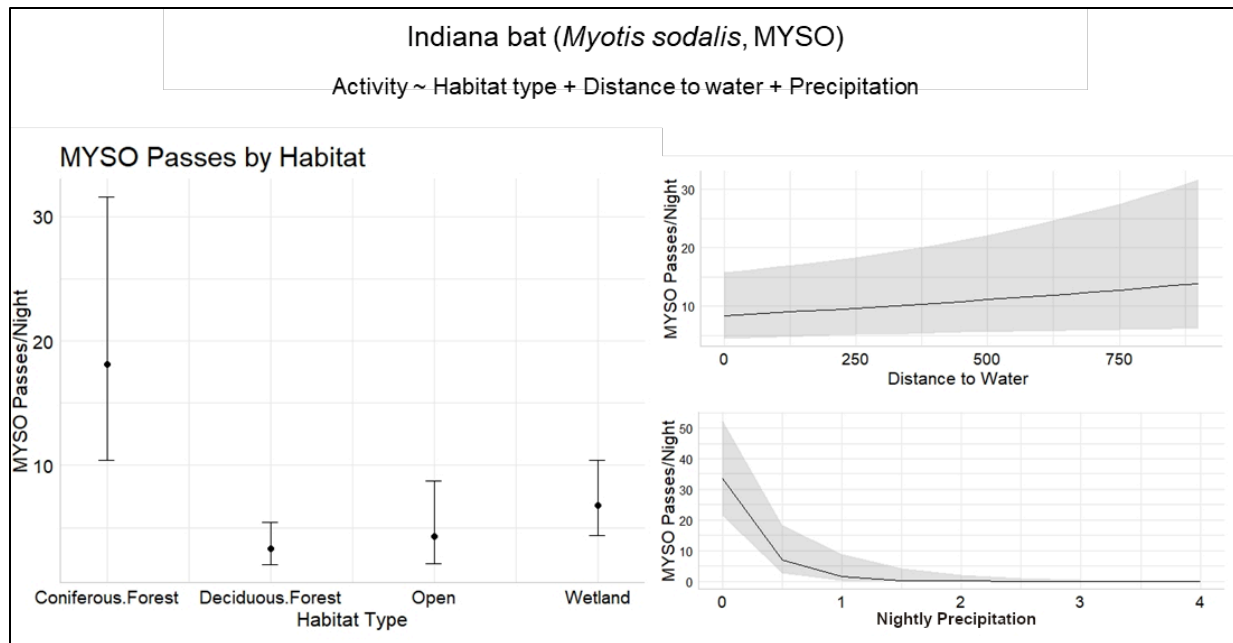


Figure 17. Predicted activity (mean passes per night and standard error) for Indiana bats (*Myotis sodalis*, MYSO) by generalized linear mixed model during summer at Richmond National Battlefield Park, Virginia by covariates habitat, distance to water (m), and nightly precipitation (cm).

Tricolored bat

Tricolored bats were identified at just under half of summer sites with activity varying greatly by location. North Anna pond site RICH53 had very high activity, recording several hundred passes per night on several nights. Drewry's Bluff site RICH38 recorded high activity and Beaver Dam Creek RICH03D, Glendale/Malvern Hill RICH24, Gaines' Mill RICH29, Turkey Hill RICH07D, and Fort Harrison site RICH59 all recorded moderate levels of activity of tricolored bats. During the dormant season, activity was low but passes were identified at Cold Harbor RICH01D and at RICH06D in Gaines' Mill during winter (Figure 18). The GLMM of tricolored bat activity included habitat and minimum temperature as significant predictors, and activity was most associated with wetland and riparian habitats (Figure 19). The GAM showed a sharp increase in activity starting in late April, peaking in early June and in early September.

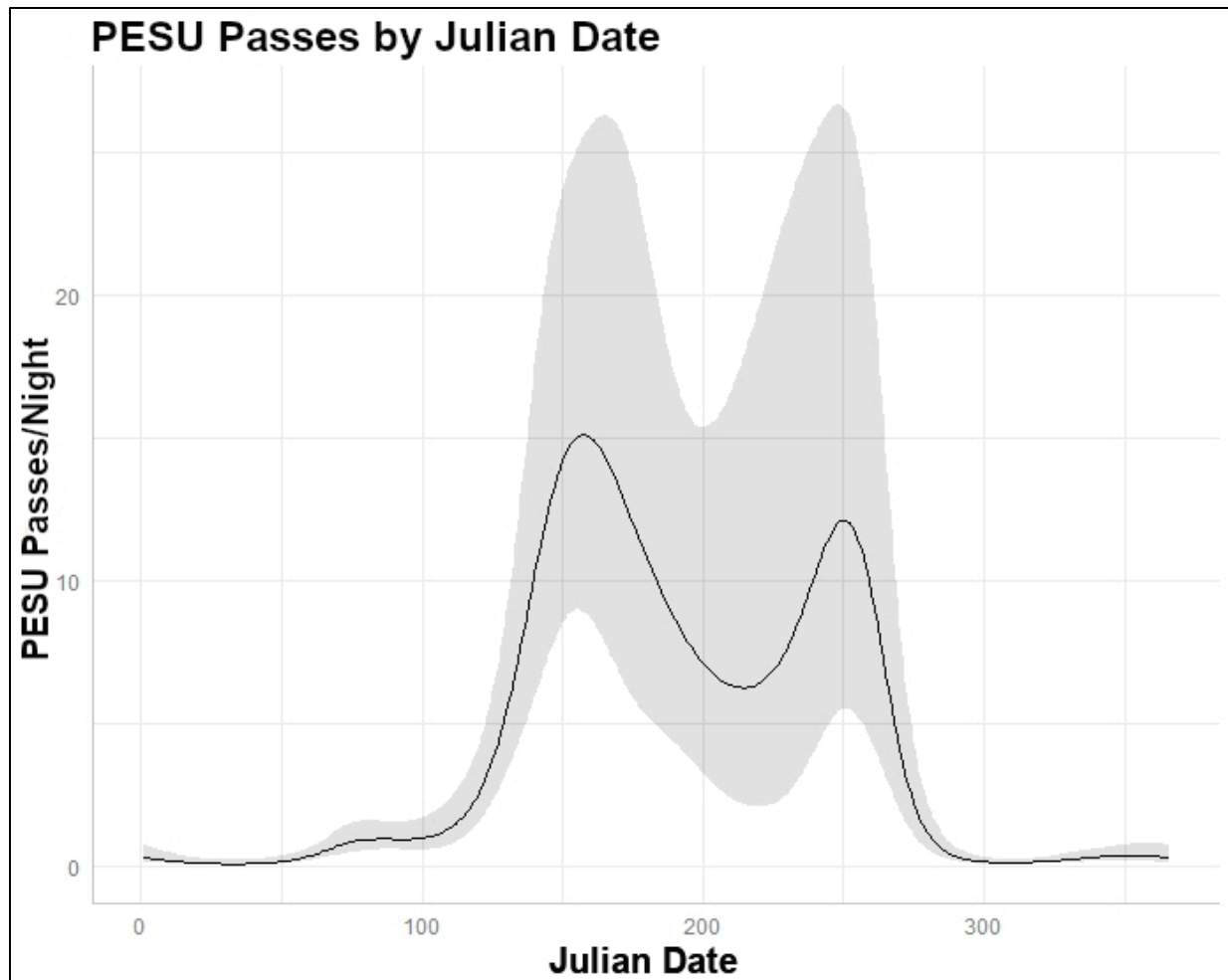


Figure 18. Tricolored bat (*Perimyotis subflavus*) activity (mean passes/night and standard error) as predicted by a generalized additive model of activity by Julian date at Richmond National Battlefield Park, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

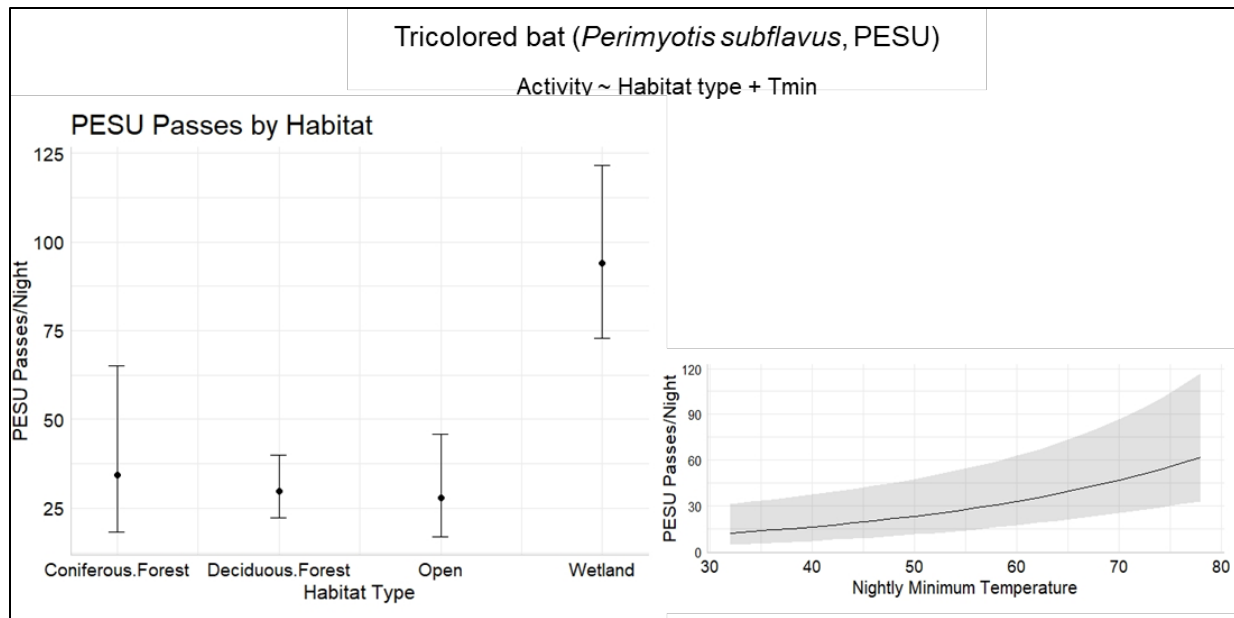


Figure 19. Predicted activity (mean passes per night and standard error) for tricolored bats (*Perimyotis subflavus*, PESU) by generalized linear mixed model during summer at Richmond National Battlefield Park, Virginia by covariates habitat and minimum nightly temperature (°F).

Eastern red bat

Activity of eastern red bats was second highest overall and they were identified at the majority of sample locations. High levels of summer activity were recorded at Gaines' Mill (RICH29/RICH06D), North Anna (RICH55), Totopotomoy Creek (RICH56), Cold Harbor (RICH02D), and Glendale/Malvern Hill (RICH45). Following summer, activity decreased but remained widespread through the dormant season. In winter, activity was recorded sporadically at many sites and Gaines' Mill site RICH06D recorded moderate levels of activity. The GAM showed activity sharply increasing in early April, peaking in late June, and then declining in early July (Figure 20). The GLMM of eastern red bats only included habitat type and precipitation as significant predictors. Activity was most associated with open as well as coniferous and mixed forest habitats (Figure 21).

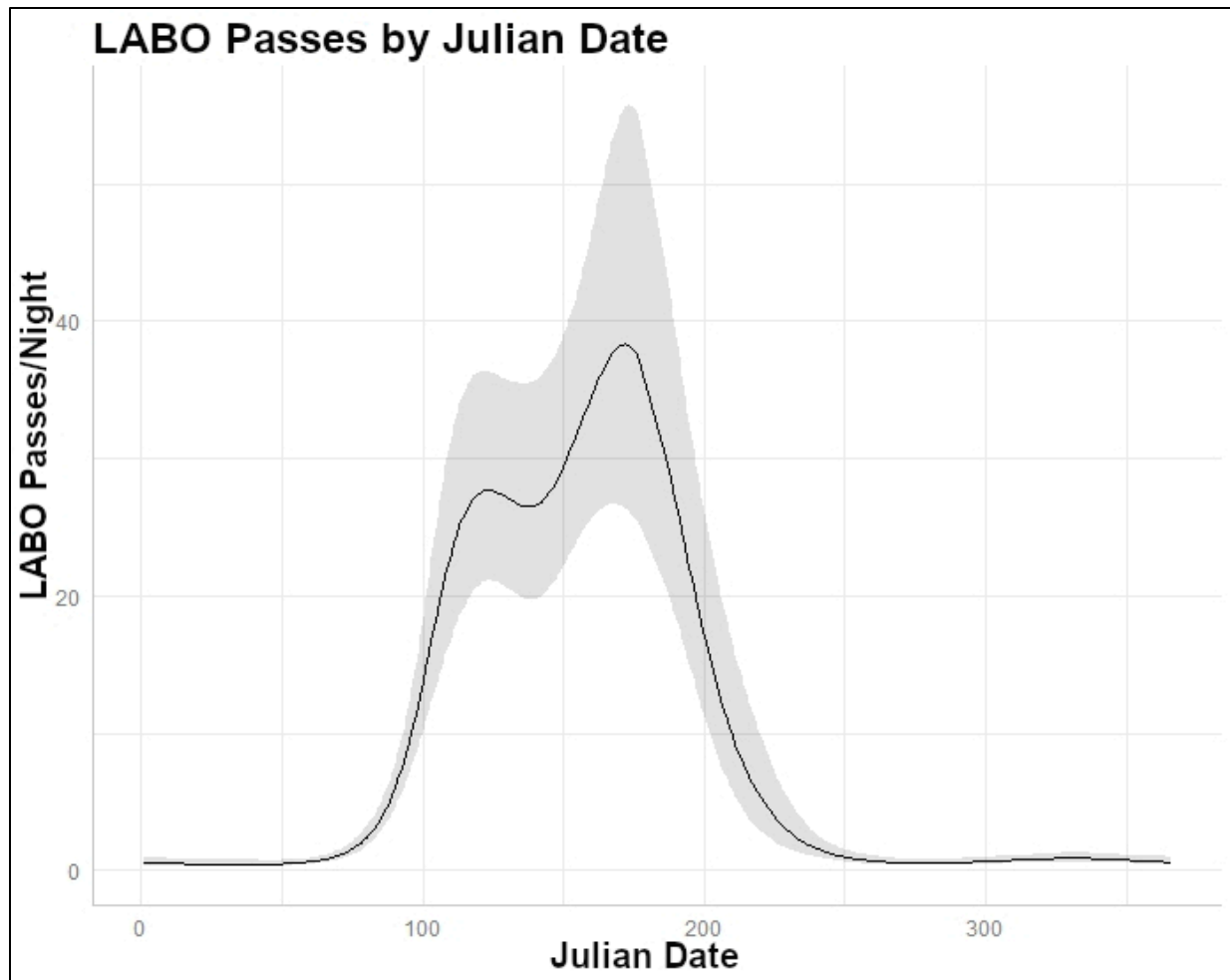


Figure 20. Eastern red bat (*Lasiurus borealis*) activity (mean passes/night and standard error) as predicted by a generalized additive model of activity by Julian date at Richmond National Battlefield Park, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

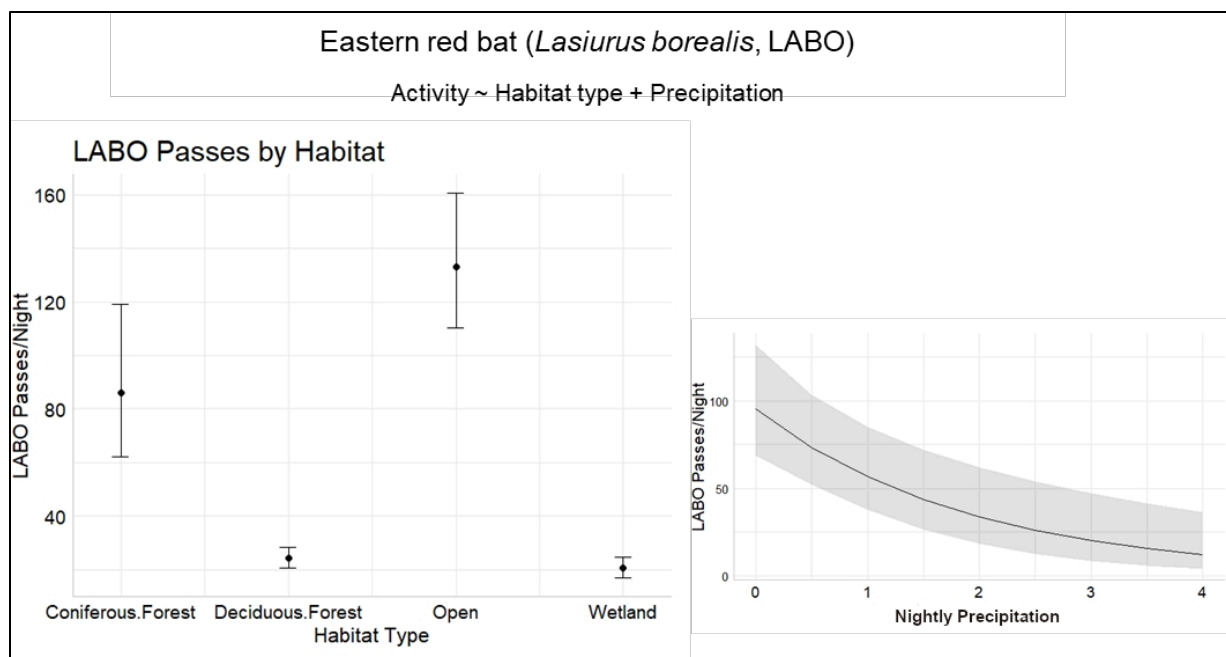


Figure 21. Predicted activity (mean passes per night and standard error) for eastern red bats (*Lasiurus borealis*) by generalized linear mixed model during summer at Richmond National Battlefield Park, Virginia by covariates habitat type and nightly precipitation (cm).

Hoary bat

Hoary bat passes were identified at 29 summer sample sites at low levels except Gaines' Mill site RICH06D where high activity was recorded in late May 2020, including one night in which over 2,300 passes were recorded. Turkey Hill site RICH07D recorded two nights in late March with high activity, one of which recorded over 600 passes. During the dormant season, activity persisted at very low levels in many locations through winter. The GAM showed activity was highest in early May followed by a decline through early July, with a slight increase in late October (Figure 22). The GLMM of activity only included habitat as a significant predictor and activity was strongly associated with open habitats (Figure 23).

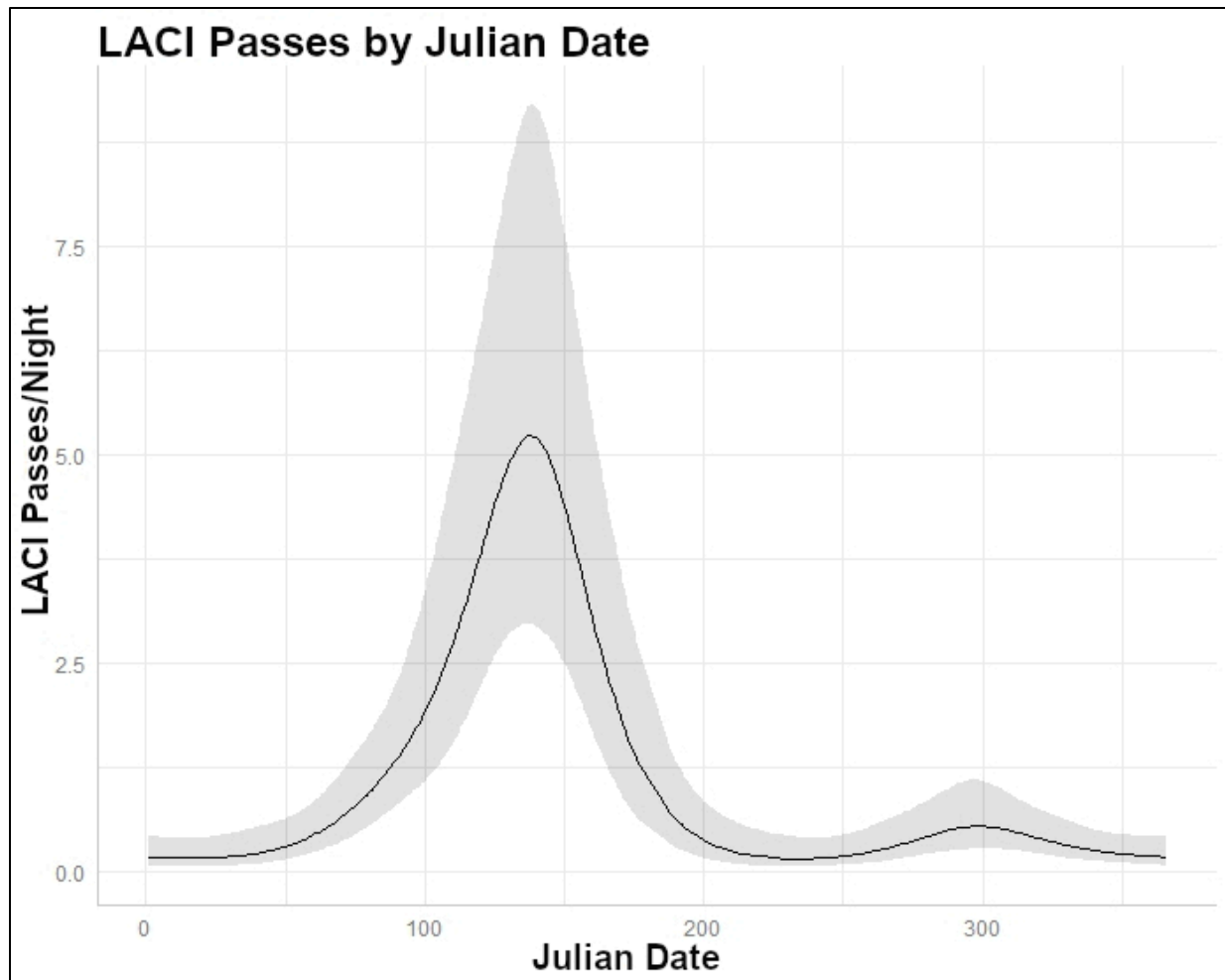


Figure 22. Hoary bat (*Lasiurus cinereus*) activity (mean passes/night and standard error) as predicted by a generalized additive model of activity by Julian date at Richmond National Battlefield Park, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

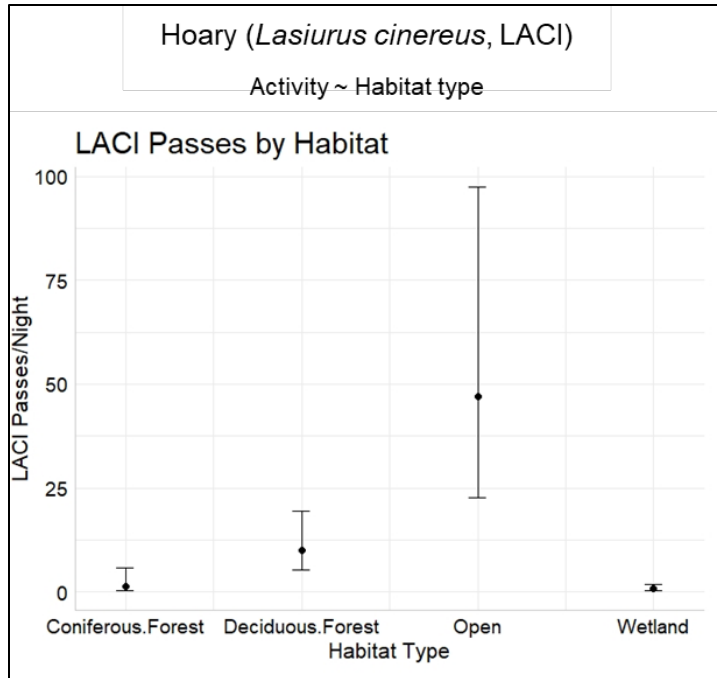


Figure 23. Predicted activity (mean passes per night and standard error) for hoary bats (*Lasiurus cinereus*, LACI) by generalized linear mixed model during summer at Richmond National Battlefield Park, Virginia by covariate habitat type.

Silver-haired bat

Silver-haired bats were identified at 12 of 67 summer sample sites. Activity levels were generally very low through the summer with a few exceptions. Highest activity was recorded at Gaines' Mill (RICH06D) in late March and early April when hundreds of calls were observed on several nights with heightened activity continuing periodically through early June. Increased activity was also documented at Glendale/Malvern Hill (RICH04D) in early March. The GAM predicted activity being highest from late March to early April, then low through the summer, with a slight increase in mid-October (Figure 24). The GLMM showed activity occurred in all habitat types and was highly variable, but was highest among deciduous forest sites (Figure 25).

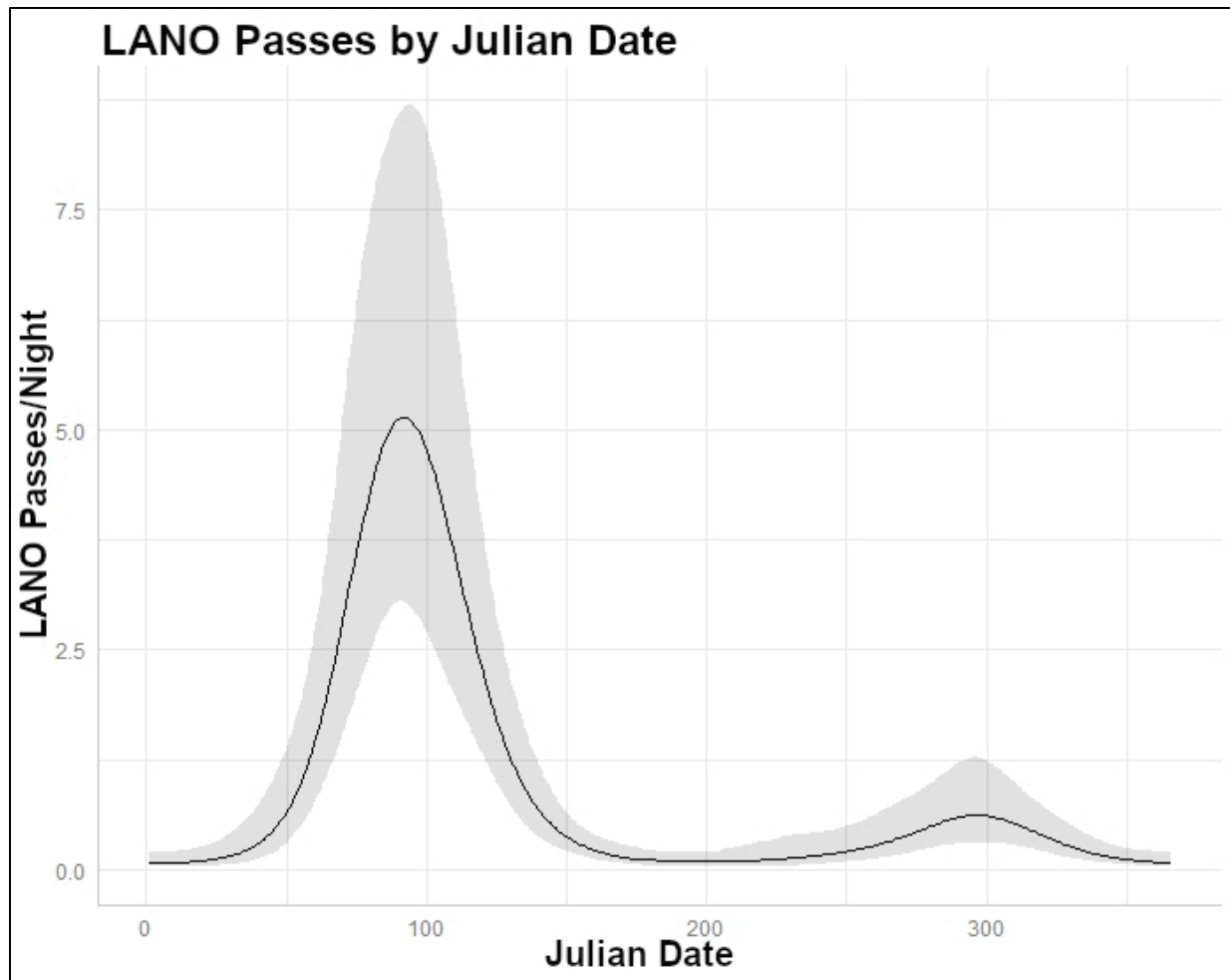


Figure 24. Silver-haired bat (*Lasionycteris noctivagans*) activity (mean passes/night and standard error) as predicted by a generalized additive model of activity by Julian date at Richmond National Battlefield Park, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

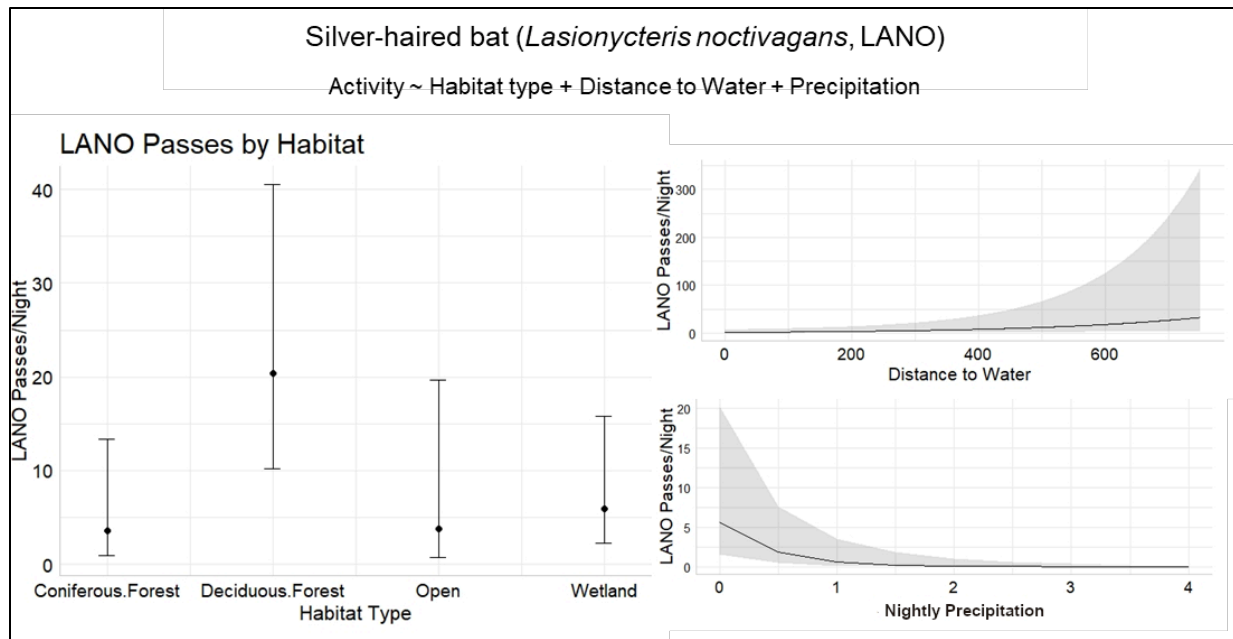


Figure 25. Predicted activity (mean passes per night and standard error) for silver-haired bats (*Lasionycteris noctivagans*, LANO) by generalized linear mixed model during summer at Richmond National Battlefield Park, Virginia by covariates: habitat type, distance to water (m), and nightly precipitation (cm).

Evening bat

Evening bats were identified at just under half of summer sites. Sites with highest activity were at Cold Harbor (RICH34, RICH02D) and Fort Harrison (RICH26). Activity was highest in May but was prevalent through August, after which it declined through October (Figure 26). Evening bats were observed at low levels through fall and during winter at Beaver Dam Creek (RICH03D) and Gaines' Mill with some passes at Cold Harbor. The GLMM showed activity was highest in open and non-riparian forest habitats (Figure 27).

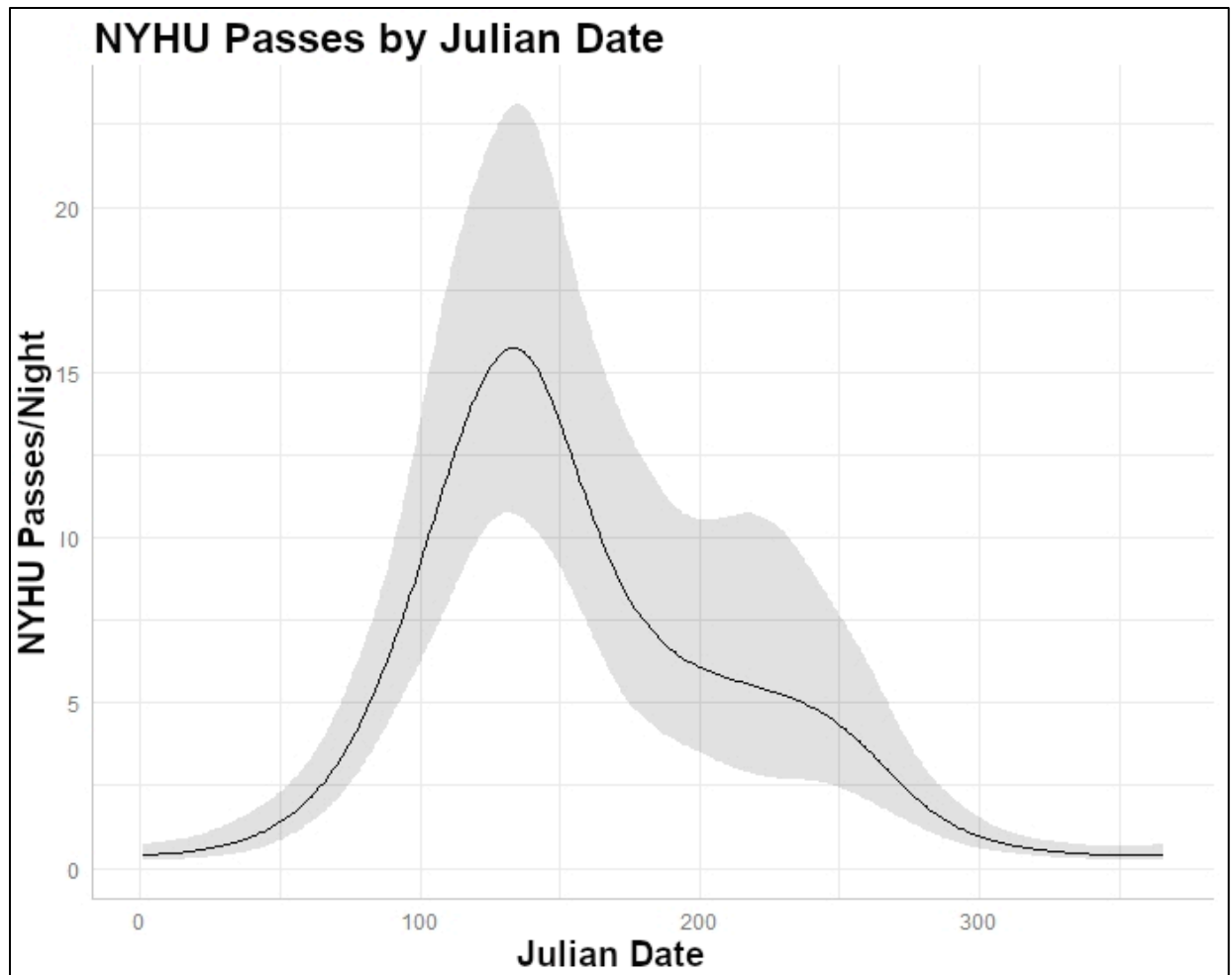


Figure 26. Evening bat (*Nycticeius humeralis*) activity (mean passes/night and standard error) predicted by a generalized additive model of activity by Julian date at Richmond National Battlefield Park, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

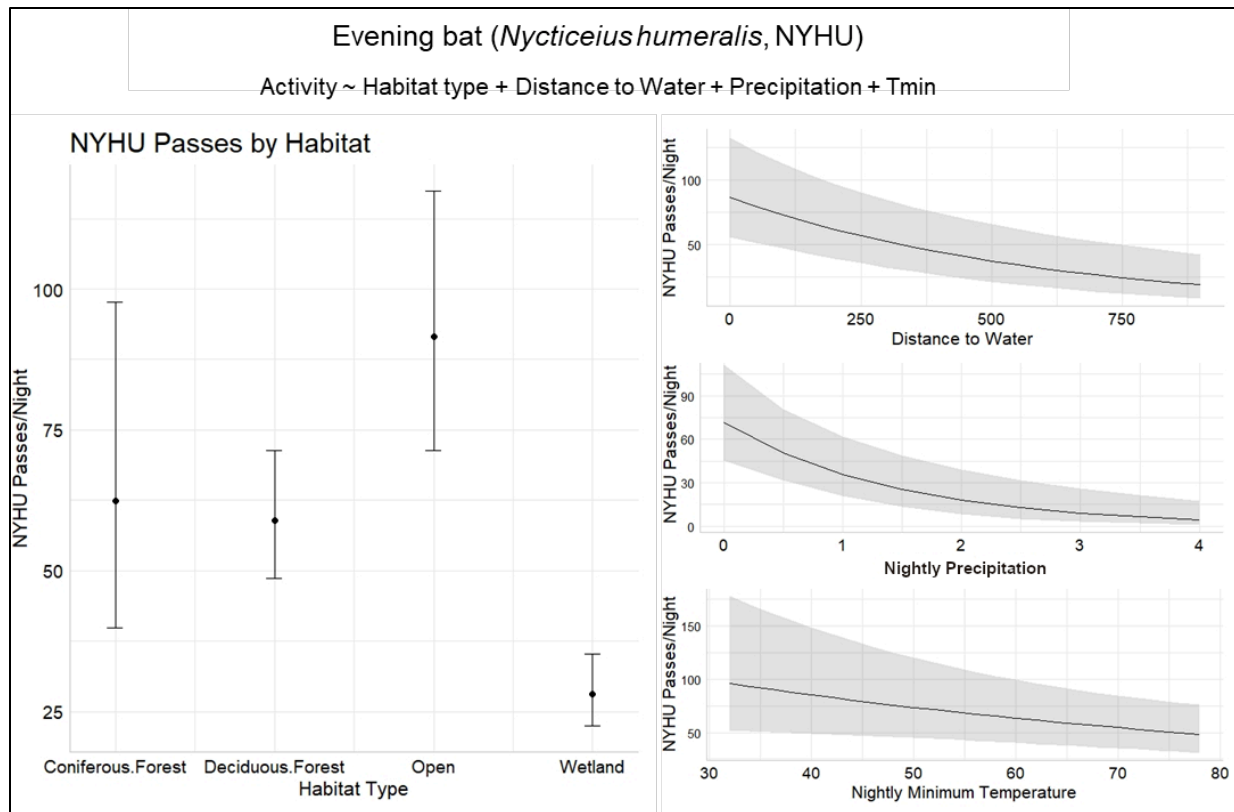


Figure 27. Predicted activity (mean passes per night and standard error) for evening bats (*Nycticeius humeralis*, NYHU) by generalized linear mixed model during summer at Richmond National Battlefield Park, Virginia by covariates: habitat type, distance to water (m), nightly precipitation (cm), and minimum nightly temperature (°F).

Mexican free-tailed bat

Mexican free-tailed bats were identified at approximately half of sites during the summer at low levels except for sites at Beaver Dam Creek (RICH25) and Gaines' Mill (RICH36) where activity was high. Non-summer activity was greatest during early April at Gaines' Mill (RICH06D) and in late October at Glendale/Malvern Hill (RICH09D) where there were three nights in which over 2000 passes were recorded. The GAM predicted activity with corresponding spring, summer, and fall peaks (Figure 28). Some winter activity was identified including detections at Glendale/Malvern Hill. The GLMM showed activity was highest in open habitats and deciduous forest (Figure 29).

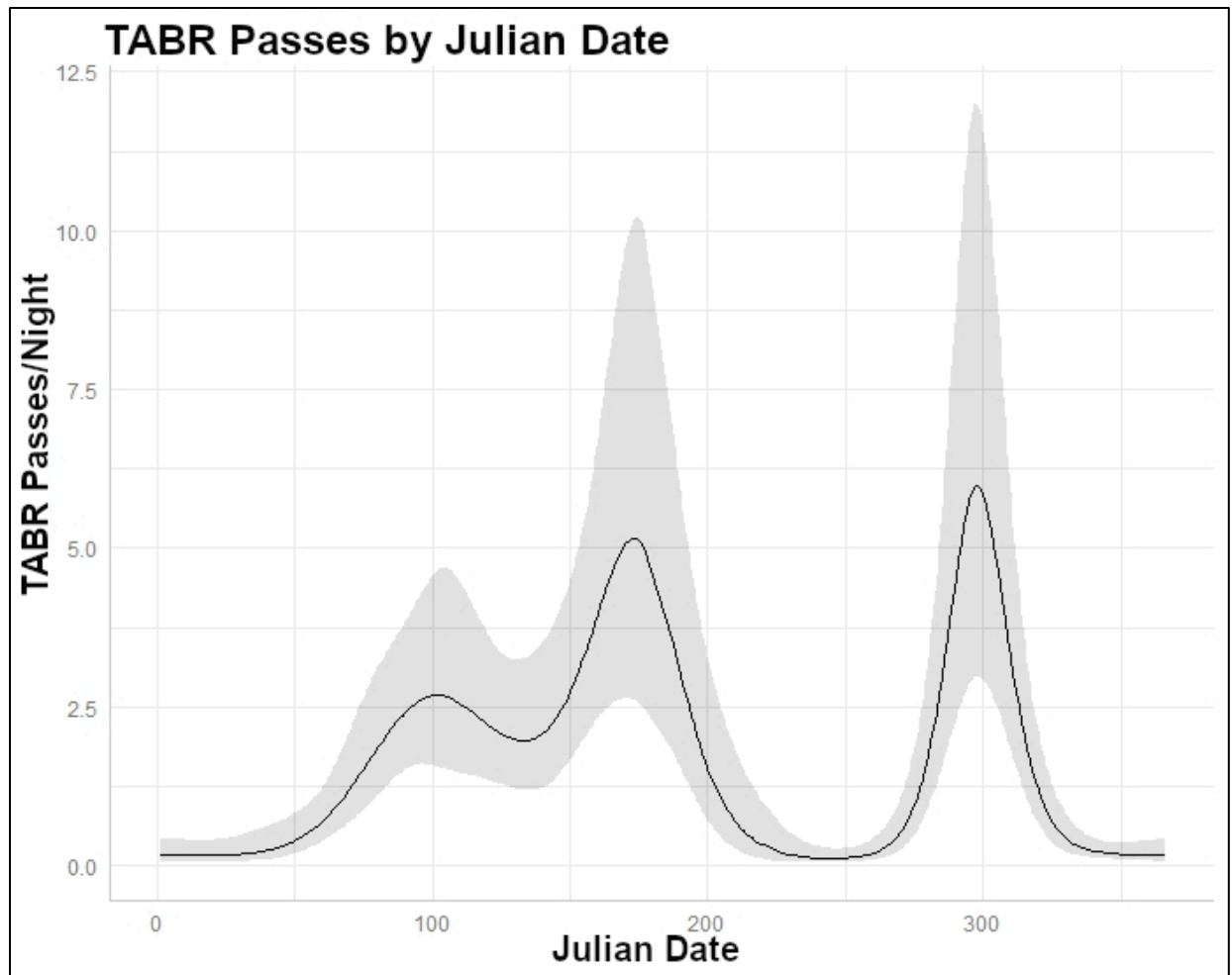


Figure 28. Mexican free-tailed bat (*Tadarida brasiliensis*) activity (mean passes/night and standard error) predicted by a generalized additive model of activity by Julian date at Richmond National Battlefield Park, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

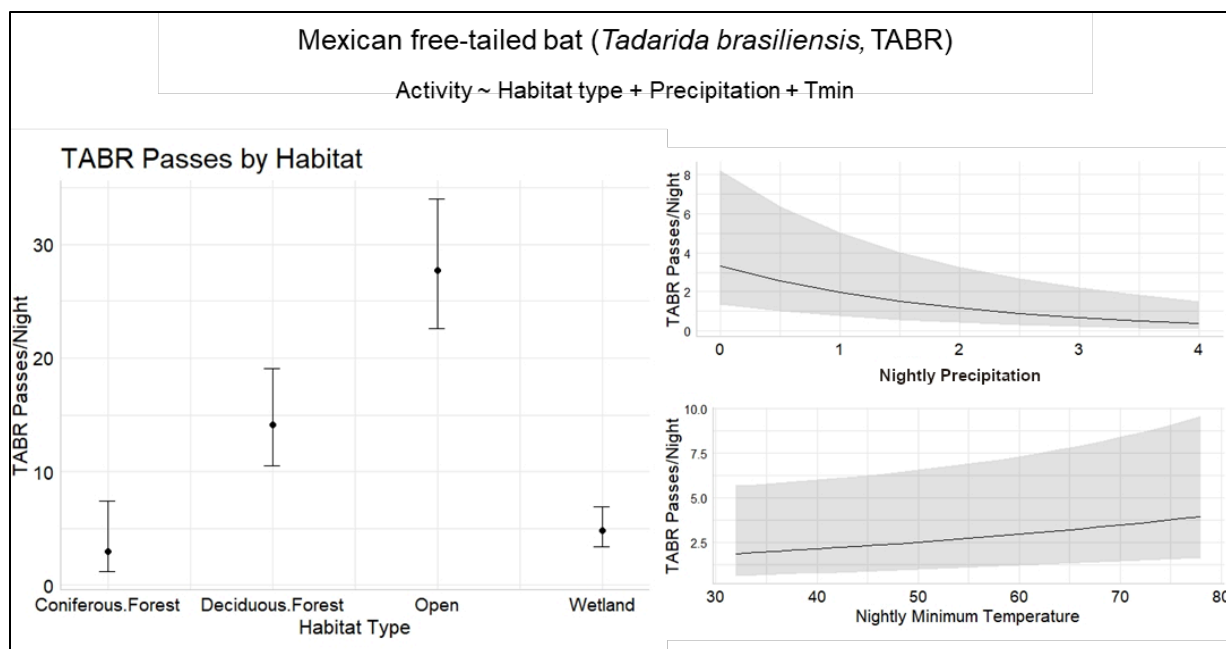


Figure 29. Predicted activity (mean passes per night and standard error) for Mexican free-tailed bat (*Tadarida brasiliensis*, TABR) by generalized linear mixed model during summer at Richmond National Battlefield Park, Virginia by covariates: habitat type, nightly precipitation, and minimum nightly temperature (°F).

Capture Survey

I captured four bat species during capture surveys: big brown, eastern red, evening, and silver-haired bats (Table 5; Appendix D). I conducted capture surveys on 17 nights at seven sites from 2016–2019. Capture surveys could not be completed in 2020 due to a national moratorium on bat capture to prevent potential transmission of COVID-19 to native bats. I targeted locations where higher levels of acoustic activity of *Myotis* species (i.e. little brown, Indiana, and northern long-eared bats) were documented when possible. However, the overall open nature of the park’s forests and lack of sufficient mid- and understory foliage made many locations unsuitable for mist-netting. Where possible, I sampled suitable sites on several occasions attempting to confirm presence of *Myotis* species identified in acoustic surveys, but was not successful capturing any *Myotis* species.

I captured big brown (n = 43) and eastern red bats (n = 28) on most occasions. Evening bats were also commonly captured (n = 23). Three silver-haired bats were captured in April of 2019. Higher capture nights included at one night at Cold Harbor (RICH-N02) and one night at Beaver Dam Creek (RICH-N07). At Cold Harbor on July 17, 2017, I captured nine big brown bats, including one lactating and three pregnant females; three eastern red bats, including one juvenile female; and two evening bats. At Beaver Dam Creek, I captured 12 evening bats, including eight pregnant females; eight big brown bats, including three pregnant females; and one eastern red bat on April 4, 2019. I also captured pregnant big brown bats at Gaines’ Mill and Drewry’s Bluff. Reproduction of eastern red bats was similarly documented at Gaines’ Mill in addition to Cold Harbor and Beaver Dam Creek.

Table 5. Bat capture results during mist-netting at Richmond National Battlefield Park, Virginia from 2016–2019 by species, sex, and reproductive condition.

Mist Net Site	Parcel ¹	Date	EPFU ²		LABO ²		LANO ²		NYHU ²	
			# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³
RICH-N01	GM	7/19/2016	1	JM, NR	0	–	0	–	0	–
	GM	8/3/2016	2	AF, PL	0	–	0	–	0	–
	GM	8/3/2016	1	AM, NR	0	–	0	–	0	–
RICH-N02	CH	7/6/2017	3	AF, L	0	–	0	–	1	AM, NR
	CH	7/6/2017	1	AF, NR	0	–	0	–	0	–
	CH	7/6/2017	1	AM, NR	0	–	0	–	0	–
	CH	7/17/2017	3	AF, P	2	JM, NR	0	–	2	AM, NR
	CH	7/17/2017	2	AF, L	1	JF, NR	0	–	0	–
	CH	7/17/2017	2	AM, NR	0	–	0	–	0	–
	CH	7/17/2017	2	JF, NR	0	–	0	–	0	–
RICH-N01	GM	7/18/2017	0	–	1	AF, PL	0	–	0	–
RICH-N03	FH	5/15/2018	0	–	1	AF, U	0	–	0	–
	FH	5/15/2018	0	–	1	AM, NR	0	–	0	–
RICH-N04	DB	6/4/2018	1	AF, P	3	AM, NR	0	–	0	–
	DB	6/4/2018	1	AF, NR	0	–	0	–	0	–

¹ BD = Beaver Dam Creek, CH = Cold Harbor, DB = Drewry's Bluff, FH = Fort Harrison, GMH = Glendale/Malvern Hill, GM= Gaines' Mill, MH = Malvern Hill, NA = North Anna, TC = Totopotomoy Creek, TH = Turkey Hill.

² EPFU = big brown bat (*Eptesicus fuscus*), LABO = eastern red bat (*Lasiurus borealis*), LANO = silver-haired bat (*Lasionycteris noctivagans*), NYHU = evening bat (*Nycticeius humeralis*);

³ Age and sex: AM = adult male, AF = adult male, JM = juvenile male, JF = juvenile female; Reproductive condition: NR= non-reproductive, D= descended testes, P= pregnant, L= lactating, PL= post-lactating, and U=unknown; Units: BD = Beaver Dam Creek, CH = Cold Harbor, DB = Drewry's Bluff, FH = Fort Harrison, GM= Gaines' Mill.

Table 5 (continued). Bat capture results during mist-netting at Richmond National Battlefield Park, Virginia from 2016–2019 by species, sex, and reproductive condition.

Mist Net Site	Parcel ¹	Date	EPFU ²		LABO ²		LANO ²		NYHU ²	
			# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³
RICH-N04	DB	6/4/2018	1	AM, NR	0	–	0	–	0	–
RICH-N05	GM	6/5/2018	3	AF, P	1	AF, P	0	–	0	–
	GM	6/5/2018	0	–	1	AF, U	0	–	0	–
RICH-N06	FH	8/8/2018	1	AF, U	0	–	0	–	0	–
	FH	8/8/2018	2	AM, NR	0	–	0	–	0	–
RICH-N02	CH	4/4/2019	0	–	2	AM, NR	1	AF, U	1	AF, U
	CH	4/4/2019	0	–	1	AF, NR	0	–	0	–
	CH	4/5/2019	2	AF, U	3	AM, NR	0	–	1	AF, U
	CH	4/5/2019	1	AM, NR	0	–	0	–	0	–
	CH	4/22/2019	3	AF, U	2	AF, U	2	AM, NR	1	AM, NR
	CH	4/22/2019	1	AM, NR	0	–	0	–	0	–
RICH-N05	GM	4/23/2019	2	AM, NR	2	AF, U	0	–	0	–
	GM	4/23/2019	0	–	1	AM, NR	0	–	0	–
RICH-N07	BC	4/24/2019	5	AM, NR	1	AF, NR	0	–	8	AF, P
	BC	4/24/2019	3	AF, U	0	–	0	–	3	AF, U

¹ BD = Beaver Dam Creek, CH = Cold Harbor, DB = Drewry's Bluff, FH = Fort Harrison, GMH = Glendale/Malvern Hill, GM= Gaines' Mill, MH = Malvern Hill, NA = North Anna, TC = Totopotomoy Creek, TH = Turkey Hill.

² EPFU = big brown bat (*Eptesicus fuscus*), LABO = eastern red bat (*Lasiurus borealis*), LANO = silver-haired bat (*Lasionycteris noctivagans*), NYHU = evening bat (*Nycticeius humeralis*);

³ Age and sex: AM = adult male, AF = adult female, JM = juvenile male, JF = juvenile female; Reproductive condition: NR= non-reproductive, D= descended testes, P= pregnant, L= lactating, PL= post-lactating, and U=unknown; Units: BD = Beaver Dam Creek, CH = Cold Harbor, DB = Drewry's Bluff, FH = Fort Harrison, GM= Gaines' Mill.

Table 5 (continued). Bat capture results during mist-netting at Richmond National Battlefield Park, Virginia from 2016–2019 by species, sex, and reproductive condition.

Mist Net Site	Parcel ¹	Date	EPFU ²		LABO ²		LANO ²		NYHU ²	
			# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³
RICH-N07	BC	4/24/2019	0	–	0	–	0	–	1	AM, NR
RICH-N02	CH	8/12/2019	1	AF, NR	2	AF, NR	0	–	2	AF, NR
	CH	8/12/2019	0	–	1	JF, NR	0	–	3	AM, NR
	CH	8/12/2019	0	–	2	AM, NR	0	–	0	–
RICH-N05	GM	10/14/2019	0	–	0	–	0	–	0	–
	GM	10/16/2019	0	–	0	–	0	–	0	–

¹ Parcel: BD = Beaver Dam Creek, CH = Cold Harbor, DB = Drewry's Bluff, FH = Fort Harrison, GMH = Glendale/Malvern Hill, GM= Gaines' Mill, MH = Malvern Hill, NA = North Anna, TC = Totopotomoy Creek, TH = Turkey Hill.

² Species: EPFU = big brown bat (*Eptesicus fuscus*), LABO = eastern red bat (*Lasiurus borealis*), LANO = silver-haired bat (*Lasionycteris noctivagans*), NYHU = evening bat (*Nycticeius humeralis*);

³ Age and sex: AM = adult male, AF = adult female, JM = juvenile male, JF = juvenile female; Reproductive condition: NR= non-reproductive, D= descended testes, P= pregnant, L= lactating, PL= post-lactating, and U=unknown; Units: BD = Beaver Dam Creek, CH = Cold Harbor, DB = Drewry's Bluff, FH = Fort Harrison, GM= Gaines' Mill.

Discussion

Acoustic results identified a community of ten species of bats that occur at RICH. Generally, cave bat species big brown, little brown, and tricolored bats had increasing activity in March and April, highest activity in June or July, which is generally associated with reproduction (Deeley et al. 2022), then declines in activity in August–October. For migratory species hoary bats, silver-haired bats, and Mexican free-tailed bats, highest nightly activity was observed in the spring and/or fall, indicating RICH may be more important as a migratory stopover rather than for summer maternity habitat for these species. Eastern red bats and evening bats exhibited highest activity during the summer. Interestingly, all species except for Indiana bats appeared to occur in small numbers in January through February with consistency over sample years indicating some individuals are wintering locally. Winter occurrences of big brown, eastern red, hoary, silver-haired, northern long-eared, evening, and tricolored bats at RICH are supported by findings of by Grider *et al* (2016), who observed all of these species wintering south of RICH in the Coastal Plain of northeastern North Carolina. Tree bat species eastern red, hoary, and silver-haired bat have historically been documented during the winter in the Coastal Plain of Virginia in museum records (Cryan 2003). These tree bat species are known to roost among foliage or leaf litter during the winter (Jorge et al. 2021a). Other species may be winter-roosting in bottomland hardwood swamps as northern long-eared bats have been documented using these habitat types for winter day-roosts in eastern North Carolina (Jordan 2020). Winter occurrences may also be linked to use of anthropogenic structures (e.g. houses, bridges, abandoned mines). There are also many legacy coal mines in the northwest and western Richmond area that could be supporting hibernating bats (VA Department of Energy 2022).

Although activity in passes per night is often used as an indication of abundance, it is not a direct measure of abundance by species and habitat type (Ford et al. 2011). Bat occurrence should not be considered limited to sites of acoustic detections because nightly home ranges of bats are large and can exceed the area of individual RICH units (Coleman et al. 2014b, Menzel et al. 2005, Morris et al. 2011, Owen et al. 2003). Also, acoustic detections are not necessarily reflective of bat day-roosting sites but rather resource use by active bats.

Acoustic survey results were highly variable by night, site, and even within broad habitat categories. Despite extremely high variance in the dataset, species GLMMs provided interpretable associations among habitat types. Several species associations were consistent with a general morphology and foraging ecology trend in which larger, and higher wing-loaded bats big brown, eastern red, hoary, and Mexican free-tailed bats were more associated with open habitats and smaller, more maneuverable and clutter-adapted bats little brown and northern long-eared bats were more and associated with forested habitats (Barr et al. 2021, Ford et al. 2005). When distance to water was a significant covariate in species models, its inclusion improved model fit because it was representative of trends in results at RICH. Positive relationships between species activity and distance to water should not necessarily be interpreted as behavioral avoidance of streams and riparian habitats altogether because a small number of sites that recorded very high activity away from a water course can overrepresent the relationship of activity and distance to water in such a highly variable dataset. Minimum nightly temperature acted as a seasonal temporal smoother when it was significant by

offering improved fit when highest activity occurred during warmer nights of the summer (Muthersbaugh et al. 2019, True et al. 2021a). When nightly precipitation was significant, it was representative of finer scale nightly variance that correlated with rain events, which are known to reduce bat activity (Gorman et al. 2021).

Cave bats

Big brown bat

Big brown bats are a cave-hibernating species also known to overwinter in man-made structures and are commonly associated with urbanized environments (Boyles et al. 2006, Johnson et al. 2008, Kurta and Baker 1990). Big brown bats are the largest among cave-hibernating species present with adult total length ranging from 87–138 mm, wingspan averaging 330 mm, and weight ranging from 11–23 g (Kurta and Baker 1990). Their diet includes a range of insects, but they specialize in preying on beetles (Agosta 2002). Big brown bats will naturally day-roost in tree cavities and under sloughing bark, but they are largely now associated with an array of anthropogenic structures as day-roosts in current environments (Agosta 2002, Whitaker and Gummer 1992). Tree roost studies have observed them using silver maple (*Acer saccharinum*), black locust (*Robinia pseudoacacia*), and oaks in Missouri and Maryland (Agosta 2002, Timpone et al. 2006).

Prevalence and abundance of acoustic detections and captures throughout RICH indicate their populations have not been severely impacted by WNS, although comparative data of pre-WNS detection rates at RICH are lacking. This corresponds with findings throughout the East in which WNS mortality of big brown bats have been low compared to other species and acoustic and capture surveys indicate stable and even increasing populations (Barr et al. 2021, Deeley et al. 2021, Ford et al. 2011, Frank et al. 2014). Big brown bats appear to exhibit resistance to the effects of WNS that are thought to be attributable to amassing greater percentages of body fat before hibernation and undergoing shorter bouts of torpor than other species (Frank et al. 2014).

Spatially, the GLMM of activity found it to be greatest in open habitats, suggesting pastures and agricultural fields are being used as foraging habitat which corresponds to their reputation as an open-adapted foraging species (Barr et al. 2021, Duchamp et al. 2004, Ford et al. 2005). However, it is also considered a habitat generalist overall, and activity was also associated with deciduous forest as well as wetland and riparian forest habitats (Agosta 2002, Duchamp et al. 2004).

Sharp increases in activity in April suggest the end of their hibernation period and increased activity by local residents and regional migrants. Sustained dormant season activity through winter months suggests at least some individuals remain nearby and utilize areas of the park, especially Beaver Dam Creek, through the winter. Big brown bats are known to hibernate in anthropogenic structures so winter occurrences at Beaver Dam Creek where surroundings are urbanized may indicate they are wintering in buildings or other anthropogenic structures (Agosta 2002, Boyles et al. 2006). Alternatively, they could be hibernating in nearby abandoned mines (Virginia Department of Energy 2022). Peak activity in summer in late July is likely related to reproduction based on capture results (Deeley et al. 2022), however, interestingly, timing of reproductive phases was highly variable based

on captures. I captured pregnant, lactating, and volant juvenile big brown bats on the same night of July 17, 2017.

Big brown bats were the most commonly captured species during capture surveys and were documented on most netting occasions. Captures of reproductive females indicate maternity colonies with active recruitment at or nearby locations in Beaver Dam Creek, Cold Harbor, Gaines' Mill, and Drewry's Bluff. Results suggest big brown bats are maintaining abundant populations following WNS, and that they utilize RICH habitats year-round.

Little brown bat

Little brown bats are also a hibernating species and are known to primarily use caves and mines forming clusters along ceilings (Fenton and Barclay 1980). They are a smaller-bodied bat with adult total length averaging between 80-95 mm, weight ranging from 4 to 9 grams, and wingspan typically ranges from 220–270 mm (Harvey et al. 2011). This highly maneuverable species is considered a generalist in regard to habitat, but has been most associated with foraging in both open and forested riparian habitats feeding on a variety of small-bodied insects (Fenton and Barclay 1980). During summer, for day-roosts, they primarily use anthropogenic structures (e.g. attics, barns) but also roost in tree cavities and emergent rocks (Bergeson et al. 2015, Fenton and Barclay 1980). In Indiana, little brown bats were found to roost in cavities and under exfoliating bark in oaks, maples (*Acer* spp.), and hickories (*Carya* spp.; Bergeson et al. 2015).

Previously one of the most abundant bat species in the eastern United States, little brown bats have experienced a 90% population decline based on winter hibernacula counts (Turner et al. 2011). Little brown bats are not currently federally protected but are under review for potential federal listing and are considered state endangered in Virginia (Straw et al. 2022, VDGIF 2016). Acoustic survey results included high levels of identified little brown bat activity suggestive of high abundance at RICH, however, visual validation of selected calls showed a significant portion of identified activity was misidentified. Unfortunately, this high level of misidentification imparts significant inaccuracy to results and analysis so I suggest strong caution in interpreting results for little brown bats.

Furthermore, lack of captures of little brown bats despite targeted mist-netting to document them suggests their abundance is likely much lower than suggested by acoustic results. Specifically, validation of calls found most misidentifications to actually be calls of eastern red bats, in particular “feeding buzzes,” whereby bats display higher frequency, high slope, and high rate pulses as they approach and consume prey that, in red bats, mimic the normal search phase echolocation pulses of *Myotis* bat species. I did document some diagnostic little brown bat echolocation calls, so they likely do occur at RICH but at low levels of abundance. Glendale/Malvern Hill, Totopotomoy Creek, and Gaines' Mill should still be considered areas of use from a conservation perspective, and winter occurrence of little brown bats at Fort Harrison and Gaines' Mill is possible. Additional evidence of summer presence of little brown bats is supported by a single capture of a little brown bat in June of 2018 at Petersburg National Battlefield approximately 30 miles south of RICH (Kalen 2019). Similarly, I documented high levels of identified little brown bat activity there. Little brown bats have not been observed wintering in bottomland forests in the Coastal Plain as have northern long-eared bats (Jordan 2020), so it is more likely that they would be hibernating in abandoned mines that

have openings in western Richmond (VA Department of Energy 2022). Further investigation of wintering little brown bats is warranted.

Analysis of identified passes of little brown bats by GLMM found them to be more associated with coniferous and mixed forests and riparian habitats during summer. Forest and riparian habitat associations correspond with previous observations of little brown bats (Fenton and Barclay 1980, Ford et al. 2005). The GLMM also predicted a slightly positive relationship in distance to water that increased to very high levels after 500 m. This relationship is the result of several sites that were distant from water recording very high levels of identified activity and was not representative of results in relation to water in the data as a whole. Temporally, increase in activity in early April suggests arrival of migrants whether local or from karst landscapes in western Virginia. The peak in early July is likely associated with reproduction, and declines through September suggests departure of migrants (Francel et al. 2012).

Northern long-eared bat

Northern long-eared bats are a small-bodied, cave hibernating bat similar in morphology to little brown bats. Adult body length is typically 85–95 mm, weight is between 5–8 g, and wingspan is 230–260 mm (Barbor and Davis 1969, Caceres and Barclay 2000). Highly maneuverable and capable of hawking (i.e., aerial capture) and gleaning (i.e., capturing from leaves) prey, northern long-eared bats are known to predate moths, flies, and beetles (Lee and McCracken 2004). They most commonly hibernate in caves and mines individually or in small groups, usually in deep crevices (Caceres and Barclay 2000). During summer, they day-roost in cavities and sloughing bark in a wide variety tree species, but have shown preference for black locust, red maples (*Acer rubrum*), and oaks in the Mid-Atlantic and commonly use dead and dying trees, often with high solar exposure (Kalen et al. 2022, Silvis et al. 2016). Though uncommon in the Mid-Atlantic, they may day-roost in anthropogenic structures (Caceres and Barclay 2000, Silvis et al. 2016). However, they have been found to readily use “rocket-box” style bat houses in in the upper Ohio Valley of West Virginia and Ohio (De La Cruz et al. 2018).

Northern long-eared bats were very common in the East prior to WNS, and similar to little brown bats, they have suffered extreme population declines following the disease, with regional mortality estimates > 90% and are facing potential extirpation (Frick et al. 2015, Reynolds et al. 2016, Turner et al. 2011). Recent discoveries of northern long-eared bats wintering along the coast of North Carolina have increased interest in investigating potential winter occurrence, as these anomalous coastal wintering populations do not appear to show signs or impacts from WNS (Jordan 2020). Recent findings suggest genetic similarities between northern long-eared bats captured at Rock Creek Park in Washington DC and the North Carolina coast, indicating they may be linked (Hoff et al. 2022). Exploring potential winter occurrences of northern long-eared bats at RICH was an important objective in this study.

Northern long-eared bat activity was identified at low to moderate levels, yet similar to their congener little brown bat, visual validation revealed many identifications to be misidentifications of eastern red bats, especially feeding buzz calls. Therefore, results for northern long-eared bats should

be interpreted with caution. Still, I did find calls that appeared to be from northern long-eared bats, or at least could not be invalidated as such.

Spatially, northern long-eared bat activity was more associated with coniferous and mixed forests, deciduous forests, and, to a lesser extent, riparian habitats, whereas very few passes were identified in open sites. This corresponds with them being a clutter-adapted species that prefers foraging within forest cover and along small streams (Barr et al. 2021, Caceres and Barclay 2000, Ford et al. 2005, Gorman et al. 2022, Menzel et al. 2002a).

Seasonally, GAM predicted activity was low overall but did show peaks in early July, which aligns with the timing of the juvenile volancy previously observed in the Mid-Atlantic (Francel et al. 2012), as well as in mid-October, which could be associated with fall migration, potentially movement of bats from DC to winter in North Carolina (Hoff et al. 2022).

High rates of misidentifications and lack of captures indicates presence and distribution of northern long-eared bats at RICH remains somewhat equivocal. Although I was unable to capture them with targeted effort at RICH, northern long-eared bats have proven difficult to capture following WNS, even where they are known to be present (Kalen et al. 2022). Northern long-eared bats most likely occur sporadically at low abundances during the summer, and they may occur during winter months at Totopotomoy Creek where winter calls passed validation. Northern long-eared bats have been documented post-WNS in Virginia by capture and maternity colonies were observed in concurrent surveys at Rock Creek Park in the District of Columbia, Prince William Forest Park to the north of RICH, and Shenandoah National Park to the west of RICH (Deeley et al. 2021, Kalen et al. 2022). In the fall of 2021, a northern long-eared bat was captured in Sussex County, VA approximately 50 miles southeast of Richmond (J. L. De La Cruz, Virginia Tech, personal communication).

Indiana bat

Indiana bats are similar in size and ecology to northern long-eared bats and little brown bats, with a typical adult Indiana bat total body length measuring around 85 mm, wingspan measuring 240–270 mm, and weighing 6–9 g (Thomson 1982). They have a similar diet to northern long-eared bats, preferring moths (Lee and McCracken 2004). They hibernate in caves and mines in clusters along ceilings in the winter (Silvis et al. 2016). In the summer, Indiana bats day-roost in a variety of tree/snag species and have shown preference for roosting under exfoliating bark in positions with high solar exposure (St. Germain et al. 2017, Silvis et al. 2016). Tree species summer day roost use is diverse and includes selection for pine snags including loblolly pine (*Pinus taeda*) in the Mid-Atlantic Coastal Plain (St. Germain et al. 2017) and hickories, maples, and ash (*Fraxinus* spp.) in the Appalachians (Silvis et al. 2016).

Although Indiana bats were much less common than northern long-eared and little brown bats in the Mid-Atlantic prior to WNS, they have also experienced significant population declines following WNS (Silvis et al. 2016). Already a federally endangered species prior to WNS, high additive mortality from the disease threatens them with extirpation over portions of their range (Thogmartin et al. 2013).

Indiana bats had the lowest number of identified calls of any species at RICH. Unfortunately, as with little brown and northern long-eared bats, authenticity of call identification was questionable. Visual validations of calls found both misidentifications of eastern red bats and what appeared to be little brown bat calls on many occasions. Nonetheless, several calls did seem authentic and could not be attributed to other species. Indiana and little brown bat calls are the most similar of the bat community at RICH and are difficult to distinguish, making confident identification of Indiana bats through acoustic survey extremely difficult where they are sympatric. Indiana bats may occur at RICH at low numbers during the summer but likely do not occur in the winter despite some MLE-qualifying identifications by Kaleidoscope. Indiana bats have been captured following WNS in Caroline County, VA approximately 40 miles north of Richmond, where an active maternity colony was identified, supporting its possible summer occurrence at RICH (St. Germain et al. 2017). Winter calls are attributable to misidentifications, however there is a possibility for occurrence if they are hibernating in abandoned mines or exhibiting aberrant day-roosting in forests in the winter.

Tricolored bat

Tricolored bats are considered a hibernating species that uses caves, but they are also known to overwinter and roost in tree cavities, foliage, and bridges in the southern portion of their range (Newman et al. 2021). They are the smallest bat present at RICH and are typically 77–89 mm long, weigh between 4–8 g, and have a wingspan of 210–260 mm (Fujita and Kunz 1984, Harvey et al. 2011). They generally hibernate singly or in smaller groups in caves, mines, and man-made structures (Fujita and Kunz 1984). During the summer they most often day-roost in tree foliage and, to a lesser extent, man-made structures (Silvis et al. 2016). Day-roost selection is not well understood, but tricolored bats have been observed roosting in oaks in Indiana, South Carolina, and Arkansas, as well as shortleaf pine (*Pinus echinate*) in Arkansas and sweetgum (*Liquidambar styraciflua*) in South Carolina (Shute et al. 2021, Silvis et al. 2016). They move by slow, fluttery flight and forage by hawking and gleaning a variety of small bodied insects including flies, beetles, aphids, leafhoppers, and moths (Fujita and Kunz 1984).

Tricolored bats were previously common throughout the East and have sustained significant declines from WNS that threaten extirpation over portions of their range, particularly where they engage in long-duration hibernation (Frick et al. 2015, Silvis et al. 2016). Tricolored bats have been proposed for federal endangered species status and listed as state endangered in Virginia (USFWS 2022b, VDGIF 2016).

Identification of tricolored bat calls by Kaleidoscope is generally highly accurate, so results and analysis are more reliable for this species. High levels of activity identified in several locations during the summer indicate RICH is important summer habitat for the species and indicate populations persist in the region. High nightly activity levels exceeding hundreds of passes per night at North Anna pond site RICH53 and Drewry's Bluff site RICH38 in June and late May, respectively, suggest maternity colonies were present or nearby. Notable activity at Beaver Dam Creek, Glendale/Malvern Hill, Gaines' Mill, Turkey Hill, and Fort Harrison indicate these are important foraging habitats to tricolored bats.

The GLMM showed activity was most associated with wetland and riparian habitats, which is consistent with previously observed preference for foraging over waterways and ponds (Ford et al. 2005, Fujita and Kunz 1984). A similar post-WNS study at NPS parks Catoclin Mountain and Harper's Ferry also found strong associations between tricolored bat activity and stream and pond acoustic sites (Kalen et al. 2015).

The GAM predicted a sharp rise in activity in late April which correlates with formation of maternity colonies (Silvis et al. 2016). The activity peak in June is likely associated with reproduction, specifically either increased foraging during lactation or increased abundance due to juvenile volancy (Fujita and Kunz 1984). The second peak in early September could be associated with fall migration either moving south or towards hibernacula where they have been found arriving in late September through mid-October (Silvis et al. 2016). During the fall and winter, activity appeared low and sporadic. Passes recorded from December through February at Cold Harbor and Gaines' Mill suggest some individuals are wintering nearby. Tricolored bats are known to hibernate in a variety of anthropogenic structures and have been observed wintering in Caroline County, VA approximately 40 miles north of Richmond in an abandoned concrete culvert (W. M. Ford, USGS, personal communication, Silvis et al. 2016).

Tree bats

Eastern red bat

Eastern red bats are a migratory tree bat species that generally migrate to southern or coastal portions of their range to winter in tree foliage or in leaf litter, entering torpor in cold temperatures and periodically emerging in warm temperatures (Cryan 2003, Mormann and Robbins 2005, Shump and Shump 1982a). They are a medium-sized bat generally measuring 100–130 mm long, weighing 7–15 g, with wingspan of 280–330 mm (Harvey et al. 2011, Shump and Shump 1982a). They have relatively long, pointed wings adapted for fast flight and moderate maneuverability (Shump and Shump 1982a). They prey on a variety of insects including moths, beetles, flies, and crickets (Shump and Shump 1982a). During the summer they disperse throughout their range and day-roost in tree foliage, shrubs (Mormann and Robbins 2007, Shump and Shump 1982a). Red bats have been reported roosting in a variety of tree species including oaks, pines, red maple, tulip poplar (*Liriodendron tulipifera*), sweetgum, and blackgum (*Nyssa sylvatica*) in Maryland, South Carolina, and Florida (Jorge et al. 2021a, Limpert et al. 2005, Menzel et al. 2002b). They appear to roost and raise young individually but often congregate to forage and migrate (Mormann and Robbins 2007, Shump and Shump 1982a).

They were the second most commonly documented species in acoustic surveys and were the second most commonly captured species during capture surveys. Acoustic results for eastern red bats are underrepresented because of misidentifications of *Myotis* spp. by Kaleidoscope. Results suggest red bats are abundant at all units during the summer. We captured reproductive females at Cold Harbor and Gaines' Mill and a juvenile at Cold Harbor showing active recruitment at these sites. Parturition appears to occur in mid-June based on timing of capture of pregnant females in early June and post-lactating females and volant juvenile males in mid-July.

The GLMM for eastern red bats showed activity was highest in open habitats and coniferous and mixed forests. Preference for foraging in moderately cluttered to open habitats is consistent with other observations of eastern red bats and its fast-flight morphology (Ford et al. 2005, Shump and Shump 1982a). Seasonally, the GAM showed activity rose sharply in early April and peaked in late June and early July, which aligns with the later stages of lactation when foraging activity is high based on capture results (Deeley et al. 2022). GAM predicted activity decreased greatly after late July, which followed timing of juvenile volancy, and suggests some summer residents emigrated during this time. Fall, winter, and spring activity indicated some individuals wintered locally, especially at Gaines' Mill, which is consistent with previous observation of eastern red bats wintering in coastal Virginia (Cryan 2003).

Hoary bat

Hoary bats are the largest bat species at RICH and are a migratory tree bat that winters in tree foliage along the Atlantic and Gulf coasts in the East (Cryan 2003, Jorge et al. 2021a, Shump and Shump 1982b). Though overall migratory habits are poorly understood, they appear to vary regionally and by sex, with females more likely to migrate greater distances (Cryan 2003). They are believed to be generally solitary but migrate long distances in large flocks to summer locations where they day-roost in foliage of a variety of tree species (Cryan 2003, Shump and Shump 1982b). Day-roosting observations include use of oaks and pines in Arkansas and Florida (Jorge et al. 2021a, Perry and Thill 2007), eastern hemlock (*Tsuga canadensis*) in New Hampshire (Veilleux et al. 2009), and white spruce (*Picea glauca*) in Saskatchewan (Willis et al. 2005). Adults are typically 130–150 mm long, weigh 20-35 g, and have a wingspan of approximately 430 mm (Harvey et al. 2011, Shump and Shump 1982b). They have long, high-loaded wings adapted for fast flying, facilitating efficient migration and open and above canopy foraging (Menzel et al. 2005, Shump and Shump 1982b). They predate moths, beetles, flies, grasshoppers, dragonflies, and wasps (Shump and Shump 1982b).

Activity of hoary bats was generally very low except for some nights in late March and late May that recorded very high activity levels at Gaines' Mill and Turkey Hill. These nights of isolated high activity are indicative of large, passing migratory groups (Cryan 2003, Shump and Shump 1982b). Some activity persisted at lower levels through the spring and summer showing that some hoary bats remain at RICH through the summer and occur at all units to some degree. Activity was also recorded through the fall and winter indicating some individuals winter locally, which corresponds to previous records in coastal Virginia (Cryan 2003). Hoary bats often fly high above forest canopies and open areas, which may contribute to low levels of acoustic detection and lack of captures (Menzel et al. 2005). Additionally, hoary bats have been found to use “micro” echolocation pulses that are undetectable by ultrasonic bat detectors and even navigate without using echolocation in some instances, which could potentially contribute to underrepresentation in acoustic results (Corcoran and Weller 2018).

Habitat type was the only significant predictor in the GLMM, and they were strongly associated with open habitats, which is consistent with their ecology (Ford et al. 2005). Temporally, the GAM showed predicted activity peaking during mid-May, which reflects instances of very high activity in both late March and late May that were likely associated with passing migratory groups. There was

also an increase in activity in October that is representative of fall migration. High activity of migratory hoary bats in spring and fall is consistent with acoustic observations from the southern and central Appalachians, as well coastal Virginia (Diggins et al. in press, True et al. 2021a).

Silver-haired bat

Silver-haired bats are a migratory tree species that are believed to overwinter in the Mid-Atlantic, but their migratory habits and distribution are not well understood (Cryan 2003, Kunz 1982). They are medium-bodied with an approximate total length of 90-155 mm, wingspan of 270–310 mm, and weight of 8–11 grams (Harvey et al. 2011, Kunz 1982). They are known to roost in tree cavities and are considered a solitary species but do form maternity colonies (Harvey et al. 2011). They have been observed roosting in shortleaf pine, blackgum, and oaks in Arkansas (Perry et al. 2010). They are a slower flying species adapted for consuming smaller insects (Kunz 1982).

Similar to hoary bats, incidences of high activity in spring and fall are likely the result of passing migrants in both seasons (Cryan 2003). Lack of significant activity during the summer suggests very few individuals remain locally through the reproductive season (Diggins et al. in press, True et al. 2021a). Some summer calls identified as silver-haired bats may in fact be misidentifications of big brown bats (Austin et al. 2020). I did capture one male and two female silver-haired bats in April 2019 at Cold Harbor confirming their presence then. Their activity occurred at all habitat types and was highly variable but was highest overall in deciduous forest locations, where highest activity was recorded in spring and fall.

Evening bat

Evening bats are believed to be moderate to short distance migrants and year-round residents in much of their distribution (Watkins 1972). They are known to overwinter in trees and in buildings (Boyles et al. 2006). During the summer, they form maternity colonies and day-roost in a variety of trees and anthropogenic structures (Menzel et al. 2001, Watkins 1972). They were found to prefer longleaf pine (*Pinus palustris*) in South Carolina, loblolly pine in Georgia, and used silver maple, oaks, and hickories in Missouri but roost tree selection is otherwise poorly understood (Menzel et al. 2001, Miles et al. 2006, Timpone et al. 2006). They are a smaller-bodied bat with an approximate total length of 88–105 mm, wingspan of 260–280 mm, and weight of 8 g (Harvey et al. 2011, Watkins 1972). They prey on moths, beetles, leaf hoppers, and flies among other insects (Whitaker and Clem 1992).

Results indicate evening bats are present from early April through August and are abundant at Cold Harbor, Fort Harrison, and Beaver Dam Creek, where I documented eight pregnant females by capture in late April 2019. Declines in acoustic activity in the fall suggest most summer inhabitants migrate away from RICH to winter. However, sustained activity at Beaver Dam Creek and Gaines' Mill through February indicates some individuals winter near these sites. Similar to big brown bats, evening bats may be wintering in buildings near these urbanized locations (Boyles et al. 2006). The GLMM showed activity was fairly high among all habitat types and lowest in wetland and riparian forest habitats.

Mexican free-tailed bat

Mexican free-tailed bats are known to be long-distance migrants, but migration varies significantly by region (McCracken et al. 2018, Wilkins 1989). They generally move to warmer climates in winter and are not considered a true hibernator, though they may undergo torpor for short periods (Wilkins 1989). They are a medium-sized bat with an approximate length of 90–105 mm, wingspan of 290–350 mm, and weight of 9–15 g (Harvey et al. 2011, Wilkins 1989). They have long, narrow wings that enable fast flight and foraging (Wilkins 1989). They most commonly roost in a variety of anthropogenic structures, but can also roost trees (Wilkins 1989). Mexican free-tailed bats have recently expanded their range in to Virginia (McCracken et al. 2018).

Acoustic results indicate that Mexican free-tailed bats occur at mostly low levels, but that migratory groups pass through Richmond in April and October. Higher activity in late June implies some summer residence and potentially recruitment (McCracken et al. 2018). Winter passes were identified in a few locations including Glendale/Malvern Hill and suggest some Mexican free-tailed bats winter locally as well, which is supported by a record in February 2015 from Henrico County, Virginia (McCracken et al. 2018). Spatially, activity was most associated with open habitats, which corresponds with their morphology and acoustic results from Tennessee (McCracken et al. 2018, Wilkins 1989).

Conclusions

Big brown bats were the only species of those affected by WNS that were abundant at RICH. Although acoustic results included high levels of activity identified as little brown bats, high rates in misidentifications and lack of captures suggest this previously common species now occurs at low abundances at RICH. Acoustic misidentifications were also problematic for federally endangered northern long-eared bats and Indiana bats that were identified at much lower levels. Yet, validation could not rule out the presence of either species. Northern long-eared bats likely occur at low levels at RICH, which is consistent with acoustic results from other eastern Virginia locations including Petersburg National Battlefield, Colonial National Historical Park, and National Capitol Region parks (Deeley et al. 2021, Kalen 2018). At Rock Creek Park and Prince William Forest Park, northern long-eared bats were captured and confirmed in the summer (Deeley et al. 2021). Little brown bats likely occur at RICH as well considering echolocation calls passed validation. Presence of Indiana bats remains questionable, however, as very few calls passed validation and similarities with little brown bat calls prevent confident identification. Nevertheless, Indiana bats should be considered present from a conservation perspective because diagnostic calls were recorded. Tricolored bats seem to be somewhat common at RICH and summer peaks in activity are suggestive of maternity colonies near some sites. Northern long-eared bats appear to occur to some degree during the winter at RICH, but results do not suggest they winter locally to the extent that populations do in coastal North Carolina (Jordan 2020).

Considerations for future bat research should include continued effort to confirm or disprove the presence of little brown, northern long-eared, and Indiana bats at RICH. If captured, individuals should be radio-tagged and tracked to day-roosts. Additional species the southeastern myotis (*Myotis austroriparius*), the Seminole bat (*Lasiurus seminolus*), and Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) have potential to expand to RICH and should be considered in future surveys. The southeastern myotis and Seminole bat appear to be expanding their ranges northward coastally as the southeastern myotis has recently been captured in Colonial National Historical Park in Yorktown, Virginia (Kalen 2020), and the Seminole bat was recently captured in the Delmarva Peninsula (True et al. 2021b). Rafinesque's big-eared bats have been historically reported in the southeastern coast of Virginia and have potential to expand to RICH (VAFWIS 2022).

The forests and natural habitats preserved in RICH units are important bat habitats among otherwise rapidly urbanizing areas. Management practices should include consideration for bat species use of these diverse habitats. Deciduous and mixed forests appear to be important for foraging habitat of *Myotis* spp. and forests are requisite for the roosting of all bat species that occur. Open habitats and forest edges as foraging habitat are important for big brown, eastern red, hoary, and Mexican free-tailed bats. Riparian habitats and ponds are preferred foraging areas for tricolored bats. Standing snags should be retained where safe because many species, including federally protected northern long-eared and Indiana bats, have shown preference for roosting in dead and decaying trees (Silvis et al. 2016). Prescribed fire aids in creating and improving such roosts, as well as reducing forest clutter, which is beneficial to foraging (Austen et al. 2020, Jorge et al. 2021b, Ford et al. 2016). Tree-clearing should be avoided if possible from May 15–August 15 to prevent take of northern long-

eared and Indiana bats during the maternity season. Management practices during the dormant season should be considerate of potential dormant season and winter occurrences of bats. Due to potential overwinter forest use by northern long-eared and tricolored bats, tree removal activity outside of the maternity season should include assessment of tree species and condition and investigation for evidence of recent or current bat use including: inspecting cavities for guano, searching for inhabiting bats, watching for emerging bats at dusk, or acoustic surveys at the removal site prior to action.

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Appendix A: Crosswalk table for habitat classification

Table A-1. Crosswalk table for habitat classification, Richmond National Battlefield Park, Virginia.

U.S. National Vegetation Classification Habitat Class¹	General Habitat Class
Acidic Oak - Hickory Forest	Deciduous forest
Beaver Wetland Complex	Wetland
Coastal Plain / Piedmont Acidic Seepage Swamp	Wetland
Coastal Plain / Piedmont Small-Stream Floodplain Forest	Wetland
Coastal Plain Mixed Oak / Heath Forest	Deciduous forest
Cultural Meadow	Open
Forested Earthworks	Deciduous forest
Loblolly Pine - Hardwood Forest	Coniferous forest
Loblolly Pine Plantation	Coniferous forest
Mesic Mixed Hardwood Forest	Deciduous forest
Non-Riverine Saturated Forest	Wetland
Non-Riverine Saturated Forest (Pine Subtype)	Wetland
Open Earthworks	Open
Other Urban or Built-up Land	Open
Residential	Open
Successional Black Walnut Forest	Deciduous forest
Successional Mixed Scrub	Open
Successional Red-cedar Forest	Deciduous forest
Successional Shrub Swamp	Wetland
Successional Tuliptree Forest	Deciduous forest
Transportation, Communications, and Utilities	Open

¹ U.S. National Vegetation Classification Habitat Class used in Patterson 2008

Appendix B: Bat species acoustic activity summary table

Table B-1. Bat species acoustic activity summary table, Richmond National Battlefield Park, Virginia.

Species	Conservation Status	Peak Acoustic Activity	Spring*	Summer*	Fall*	Winter*	Acoustic Activity Habitat Association
Big brown bat (<i>Eptesicus fuscus</i>)	Federal: unprotected State: unprotected	late July	yes; BD, CH, DB, GM, GMH, NA, TC, TH	BD, CH, DB, FH, GM, GMH, NA, TC, TH	yes; BD, CH, GM, GMH, NA, TC, TH	Yes; BD, CH, FH, TC	Open and deciduous forests
Little brown bat (<i>Myotis lucifugus</i>)	Federal: unprotected (under review) State: endangered	late June	BD, CH, GM, GMH, NA, TC, TH	BD, CH, DB, FH, GM, GMH, NA, TC, TH	BD, CH, FH, GM, GMH, NA, TC, TH	BD, CH, FH, GM, TC, TH	Coniferous forest and wetland habitats
Northern long-eared bat (<i>Myotis septentrionalis</i>)	Federal: endangered State: endangered	early July, late October	BD, CH, GM, GMH, NA, TC, TH	BD, CH, DB, FH, GM, GMH, NA, TC, TH	BD, CH, FH, GMH, NA, TC, TH	BD, CH, GM, GMH, TC	Coniferous forest
Indiana bat (<i>Myotis sodalis</i>)	Federal: endangered State: endangered	early July	BD, CH, GMH, NA, TH	BD, CH, FH, GM, GMH, NA, TH	BD, CH, GM, NA, TH	BD	Coniferous forest
Tricolored bat (<i>Perimyotis subflavus</i>)	Federal: unprotected (proposed endangered) State: endangered	early June	BD, CH, GM, GMH, NA, TC, TH	BD, CH, DB, FH, GM, GMH, NA, TC, TH	BD, CH, FH, GM, GMH, TH	BD, CH, FH, GM	Wetland habitats
Eastern red bat (<i>Lasiurus borealis</i>)	Federal: unprotected State: unprotected	late June	BD, CH, GM, GMH, NA, TC, TH	BD, CH, DB, FH, GM, GMH, NA, TC, TH	BD, CH, FH, GM, GMH, TC, TH	BD, CH, FH, GM, NA, TC	Open and coniferous forest

*BD = Beaver Dam Creek, CH = Cold Harbor, DB = Drewry's Bluff, FH = Fort Harrison, GMH = Glendale/Malvern Hill, GM= Gaines' Mill, NA = North Anna, TC = Totopotomoy Creek, TH = Turkey Hill

Table B-1 (continued). Bat species acoustic activity summary table, Richmond National Battlefield Park, Virginia.

Species	Conservation Status	Peak Acoustic Activity	Spring*	Summer*	Fall*	Winter*	Acoustic Activity Habitat Association
Hoary bat (<i>Lasiurus cinereus</i>)	Federal: unprotected State: unprotected	late April	BD, CH, GM, GMH, TC, TH	BD, CH, FH, GM, GMH, NA, TC, TH	BD, CH, FH, GM, GMH, NA, TH	BD, CH, FH, GM, GMH, TC, TH	Open
Silver-haired bat (<i>Lasionycteris noctivagans</i>)	Federal: unprotected State: unprotected	late March	BD, CH, GM, GMH, TH	BD, CH, GM, GMH, NA, TH	BD, CH, FH, GM, GMH, NA, TH	BD, CH, GM, GMH	Deciduous forest
Evening bat (<i>Nycticeius humeralis</i>)	Federal: unprotected State: unprotected	early May	BD, CH, GM, GMH, TH	BD, CH, FH, GM, GMH, NA, TH	BD, CH, FH, GM, GMH, TC, TH	BD, CH, GM	Open and coniferous forest
Mexican free-tailed bat (<i>Tadarida brasiliensis</i>)	Federal: unprotected State: unprotected	late June, late October	BD, CH, GM, GMH, TC, TH	BD, CH, DB, FH, GM, GMH, NA, TC	BD, CH, FH, GM, GMH, TH	BD, CH, FH, GM, GMH	Open

*BD = Beaver Dam Creek, CH = Cold Harbor, DB = Drewry's Bluff, FH = Fort Harrison, GMH = Glendale/Malvern Hill, GM= Gaines' Mill, NA = North Anna, TC = Totopotomoy Creek, TH = Turkey Hill.

Appendix C: Bat species activity model parameters

Big brown bat (*Eptesicus fuscus*; EPFU)

Table C-1 and Table C-2 show the activity model parameters for big brown bat.

Table C-1. Generalized linear mixed model (GLMM) parameter estimates of big brown bat (*Eptesicus fuscus*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Coniferous/Mixed Forest)	2.2146	0.3248	6.819	< 0.0001
Habitat – Deciduous Forest	1.9704	0.3371	5.846	<0.0001
Habitat – Open	2.1314	0.3533	6.032	<0.0001
Habitat – Wetland	1.6739	0.3343	5.007	<0.0001
Distance to Water	0.0005	0.0003	1.764	0.0777
Precipitation	-0.4577	0.0911	-5.024	<0.0001

Table C-2. Generalized additive model (GAM) parameter estimate of big brown bat (*Eptesicus fuscus*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	2.3883	0.0549	43.51	< 0.0001

Little brown bat (*Myotis lucifugus*, MYLU)

Table C-3 and Table C-4 show the activity model parameters for little brown bat.

Table C-3. Generalized linear mixed model (GLMM) parameter estimates of little brown bat (*Myotis lucifugus*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Coniferous/Mixed Forest)	2.3347	0.3587	6.509	< 0.0001
Habitat – Deciduous Forest	-0.9995	0.1868	-5.351	<0.0001
Habitat – Open	-2.2208	0.3237	-6.861	<0.0001
Habitat – Wetland	-0.5916	0.1977	-2.993	0.0028
Distance to Water	0.0052	0.0005	9.587	<0.0001
Precipitation	-0.9368	0.0911	-5.024	<0.0001
Minimum Temperature	0.0230	0.0047	4.889	<0.0001

Table C-4. Generalized additive model (GAM) parameter estimate of little brown bat (*Myotis lucifugus*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	1.5669	0.0630	24.87	< 0.0001

Northern long-eared bat (*Myotis septentrionalis*, MYSE)

Table C-5 and Table C-6 show the activity model parameters for northern long-eared bat.

Table C-5. Generalized linear mixed model (GLMM) parameter estimates of northern long-eared bat (*Myotis septentrionalis*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Coniferous/Mixed Forest)	2.9171	0.4507	6.472	< 0.0001
Habitat – Deciduous Forest	-0.6667	0.4600	-1.449	0.1473
Habitat – Open	-2.3566	0.5125	-4.598	< 0.0001
Habitat – Wetland	-0.7822	0.4547	-1.721	0.0853
Distance to Water	-0.0025	0.0006	-3.811	0.0001
Precipitation	-0.5783	0.2652	-2.181	0.0292

Table C-6. Generalized additive model (GAM) parameter estimate of northern long-eared bat (*Myotis septentrionalis*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	-0.5857	0.0877	-6.676	< 0.0001

Indiana bat (*Myotis sodalis*, MYSO)

Table C-7 and Table C-8 show the activity model parameters for Indiana bat.

Table C-7. Generalized linear mixed model (GLMM) parameter estimates of Indiana bat (*Myotis sodalis*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Coniferous/Mixed Forest)	3.8016	0.2571	14.784	< 0.0001
Habitat – Deciduous Forest	-1.695	0.3160	-5.364	< 0.0001
Habitat – Open	-1.4487	0.3959	-3.659	0.0003
Habitat – Wetland	-0.9867	0.2951	-3.344	0.0008
Distance to Water	-0.0015	0.0007	-1.956	0.0504
Precipitation	-3.1446	0.9052	-3.474	0.0005

Table C-8. Generalized additive model (GAM) parameter estimate of Indiana bat (*Myotis sodalis*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	-1.8452	0.1908	-9.672	< 0.0001

Tricolored bat (*Perimyotis subflavus*, PESU)

Table C-9 and Table C-10 show the activity model parameters for tricolored bat.

Table C-9. Generalized linear mixed model (GLMM) parameter estimates of tricolored bat (*Perimyotis subflavus*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Coniferous/Mixed Forest)	1.406	0.7243	1.941	0.0523
Habitat – Deciduous Forest	-0.1455	0.3511	-0.414	0.6785
Habitat – Open	-0.2124	0.3935	-0.540	0.5894
Habitat – Wetland	1.004	0.3552	2.827	0.0047
Minimum Temperature	0.0349	0.0093	3.746	0.0002

Table C-10. Generalized additive model (GAM) parameter estimate of tricolored bat (*Perimyotis subflavus*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	0.325	0.1125	2.893	0.0038

Eastern red bat (*Lasiurus borealis*, LABO)

Table C-11 and Table C-12 show the activity model parameters for eastern red bat.

Table C-11. Generalized linear mixed model (GLMM) parameter estimates of eastern red bat (*Lasiurus borealis*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Coniferous/Mixed Forest)	4.5567	0.166	27.352	< 0.0001
Habitat – Deciduous Forest	-1.2704	0.1832	-6.936	< 0.0001
Habitat – Open	0.4348	0.1904	2.283	0.0224
Habitat – Wetland	-1.4358	0.1905	-7.538	< 0.0001
Precipitation	-0.5174	0.1400	-3.697	0.0002

Table C-12. Generalized additive model (GAM) parameter estimate of eastern red bat (*Lasiurus borealis*) at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	1.2916	0.0621	20.8	< 0.0001

Hoary bat (*Lasiurus cinereus*, LACI)

Table C-13 and Table C-14 show the activity model parameters for hoary bat.

Table C-13. Generalized linear mixed model (GLMM) parameter estimates of hoary bat (*Lasiurus cinereus*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Coniferous/Mixed Forest)	0.3448	0.7106	0.485	0.6275
Habitat – Deciduous Forest	1.9666	0.7379	2.665	0.0077
Habitat – Open	3.504	0.7682	4.562	< 0.0001
Habitat – Wetland	-0.6272	0.7729	-0.811	0.4171

Table C-14. Generalized additive model (GAM) parameter estimate of hoary bat (*Lasiurus cinereus*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	-0.1700	0.1332	-1.276	0.202

Silver-haired bat (*Lasionycteris noctivagans*, LANO)

Table C-15 and Table C-16 show the activity model parameters for silver-haired bat.

Table C-15. Generalized linear mixed model (GLMM) parameter estimates of silver-haired bat (*Lasionycteris noctivagans*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Coniferous/Mixed Forest)	0.9358	0.7352	1.273	0.2031
Habitat – Deciduous Forest	1.727	0.7342	2.352	0.0187
Habitat – Open	0.0548	1.0710	0.051	0.9592
Habitat – Wetland	0.5002	0.8051	0.621	0.5344
Distance to Water	0.0040	0.0018	2.257	0.0240
Precipitation	-2.2345	0.6267	-3.566	0.0004

Table C-16. Generalized additive model (GAM) parameter estimate of silver-haired bat (*Lasionycteris noctivagans*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	-0.4910	0.1286	-3.817	0.0001

Evening bat (*Nycticeius humeralis*, NYHU)

Table C-17 and Table C-18 show the activity model parameters for evening bat.

Table C-17. Generalized linear mixed model (GLMM) parameter estimates of evening bat (*Nycticeius humeralis*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Coniferous/Mixed Forest)	5.502	0.4513	12.190	< 0.0001
Habitat – Deciduous Forest	-0.0578	0.2400	-0.241	0.8097
Habitat – Open	0.3837	0.2767	1.386	0.1656
Habitat – Wetland	-0.7957	0.2432	-3.271	0.0011
Precipitation	-0.6866	0.1640	-4.186	< 0.0001
Minimum Temperature	-0.0149	0.0060	-2.480	0.0131

Table C-18. Generalized additive model (GAM) parameter estimate of evening bat (*Nycticeius humeralis*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	1.219	0.0948	12.87	< 0.0001

Mexican Free-tailed bat (*Tadarida brasiliensis*, TABR)

Table C-19 and Table C-20 show the activity model parameters for Mexican free-tailed bat.

Table C-19. Generalized linear mixed model (GLMM) parameter estimates of Mexican free-tailed bat (*Tadarida brasiliensis*) activity at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Coniferous/Mixed Forest)	0.2106	0.7539	0.279	0.780
Habitat – Deciduous Forest	1.550	0.4878	3.177	0.0015
Habitat – Open	2.223	0.4665	4.765	< 0.0001
Habitat – Wetland	0.4730	0.4907	4.765	< 0.0001
Precipitation	-0.5233	0.1199	-4.364	< 0.0001
Minimum Temperature	0.0162	0.0083	1.961	0.050

Table C-20. Generalized additive model (GAM) parameter estimate of Mexican free-tailed bat (*Tadarida brasiliensis*) at Richmond National Battlefield Park, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	0.2182	0.1084	2.013	0.044

Appendix D: Capture survey sites and net arrangements

Table D-1. Bat capture survey sites and net arrangements, Richmond National Battlefield Park, Virginia.

Date	Site	Unit	Description	# of Nets	Placement
7/19/2016	RICH-N01	Gaines' Mill	Forest trail	4	1 double 9m, 1 single 6m, and 2 single 4m across trails
8/3/2016	RICH-N01	Gaines' Mill	Forest trail with stream	4	1 triple 12m, 1 double 12m, and 1 single 6m across trail; 1 single 9m across stream
7/6/2017	RICH-N02	Cold Harbor	Forest trail adjacent managed savanna and road	4	2 triple 12m across road, 2 single 4m across trails
7/17/2017	RICH-N02	Cold Harbor	Forest trail adjacent managed savanna and road	4	2 triple 12m across road, 2 single 4m across trails
7/18/2017	RICH-N01	Gaines' Mill	Forest trail with stream	5	1 single 6m, 1 single 4m, and 1 single 9m across trail; 2 single 4m across stream
5/15/2018	RICH-N03	Fort Harrison	Forest trails adjacent open field	3	1 triple 6m, 1 double 9m, and 1 double 6m across trails
6/4/2018	RICH-N04	Drewry's Bluff	Forest trail and clearing adjacent river	3	1 double 9m and 1 single 4m across trail, 1 single 6m over puddle
6/5/2018	RICH-N05	Gaines' Mill	Open field adjacent forest trail	3	1 single 12m at open field edge, 1 single 6m and 1 single 9m across trail
8/8/2018	RICH-N06	Fort Harrison	Forest trail	1	1 triple 9m across trail
4/4/2019	RICH-N02	Cold Harbor	Forest trail adjacent managed savanna	2	1 triple 12m and 1 triple 9m across roads
4/5/2019	RICH-N02	Cold Harbor	Forest trail adjacent managed savanna	2	1 triple 12m and 1 triple 9m across roads
4/22/2019	RICH-N02	Cold Harbor	Forest trail adjacent managed savanna	2	1 triple 12m and 1 triple 9m across roads

Table D-1 (continued). Bat capture survey sites and net arrangements, Richmond National Battlefield Park, Virginia.

Date	Site	Unit	Description	# of Nets	Placement
4/23/2019	RICH-N05	Gaines' Mill	Open field adjacent forest trail, road	2	1 triple 9m open field edge, 1 triple 6m across road
4/24/2019	RICH-N07	Beaver Dam Creek	Stream and forest trail	2	1 triple 12m across stream, 1 double 9m across trail
8/12/2019	RICH-N02	Cold Harbor	Forest trail adjacent managed savanna and road	1	1 triple 12m across road
10/14/2019	RICH-N05	Gaines' Mill	Open field adjacent forest trail, road	1	1 triple 6m across road
10/16/2019	RICH-N05	Gaines' Mill	Open field adjacent forest trail, road	1	1 triple 18m open field edge

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
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