



Bats of Petersburg National Battlefield Following White-nose Syndrome

Natural Resource Report NPS/PETE/NRR—2023/2513



ON THE COVER

Little brown bat (*Myotis lucifugus*) captured at Five Forks, Petersburg National Battlefield
NPS/NICHOLAS KALEN

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Natural Resource Report NPS/PETE/NRR—2023/2513

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Abstract

I conducted bat surveys at Petersburg National Battlefield Park (PETE) 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*), the federally-endangered northern long-eared bat (*Myotis septentrionalis*) and Indiana bat (*Myotis sodalis*) (USFWS 2007, USFWS 2022a), as well as the tricolored bat (*Perimyotis subflavus*), which has been proposed for endangered status (USFWS 2022b). I sampled sites with acoustic bat detectors from the summer of 2016 through fall 2021 and conducted capture surveys using mist nets from 2016-2019 to characterize seasonal occurrence of bat species with a focus on documenting WNS-imperiled species. Surveys also sought to document potential over-wintering of bats at PETE, especially northern long-eared bats, which have recently been discovered wintering in the Coastal Plain of North Carolina. Acoustic results identified the presence of nine 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, Indiana bat, evening bat (*Nycticeius humeralis*), tricolored bat, and Mexican free-tailed bat (*Tadarida brasiliensis*). Northern long-eared bats were identified acoustically by software, but identifications were invalidated by visual review. Acoustic misidentifications also occurred for little brown and Indiana bats, but diagnostic calls were confirmed. Capture surveys documented big brown bats, eastern red bats, evening bats, and a single little brown bat. 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, hoary, silver-haired, and Mexican free-tailed bats was highest in open habitats. Little brown and eastern red bats were most associated with mixed forest habitats. Evening bat activity was highest in deciduous forests. Habitat type was not a significant predictor of activity for Indiana and tricolored bat activity. 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, tricolored, and evening bats was highest during summer. Activity identified as Indiana bats was very low overall but was also highest in the summer. Activity of tree bat species hoary, silver-haired, and Mexican free-tailed bat was highest during the dormant season and peak activity appeared associated with migration. Dormant season results suggest some winter activity for most bat species identified as present in the park.

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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. Tim Blumenschine, National Park Service Natural Resource Manager, provided invaluable assistance 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, reclassified it as endangered (Federal Register § 81:1900-1922, USFWS 2022a). The Indiana bat has been federally endangered since 1967 in response to declines associated with disturbances in hibernacula (USFWS 2007). Tricolored bats have recently been proposed for endangered species listing (USFWS 2022b). 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 Petersburg National Battlefield 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. Petersburg National Battlefield Park (PETE) may constitute significant high-quality bat habitat in a rapidly urbanizing portion of southeastern Virginia and likely supports a diverse bat community, including several species most-imperiled by WNS. Investigating summer occurrences and, potentially, reproduction of imperiled bat species at localities such as PETE is essential to bat conservation following WNS. Furthermore, potential year-round occurrence of northern long-eared bats requires investigation. To evaluate bat species community composition at PETE, 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

Petersburg National Battlefield (PETE) has two main units: Eastern Front and Five Forks that total approximately 1,050 hectares (Figure 1 through Figure 4). The Eastern Front falls within the city limits of the densely developed City of Petersburg that lies to the west and has an eastern portion in Prince George County that is bordered by Fort Lee, a U.S. Army post of over 2,000 hectares. Eastern Front is roughly 90% forest with mid- to late successional mixed oak-loblolly pine, oak-poplar, and oak-hickory comprising the most common forest types. The other approximately 10% is managed grassland and shrubland. Five Forks is located in the Piedmont in Dinwiddie County and is surrounded by forested and agricultural use areas. It is also roughly 90% forest with the majority being early to mid-successional loblolly pine plantation along with some oak-hickory and oak-poplar forest in its southeastern portion. About 10% of Five Forks is managed open grassland. Both units are located within the James River Basin and include several branching streams with the Eastern Front including the Branch, Harrison, and Poor Creeks.



Figure 1. Bat summer acoustic detector sites from 2016-2020 at the Eastern Front unit, Petersburg National Battlefield, Virginia.

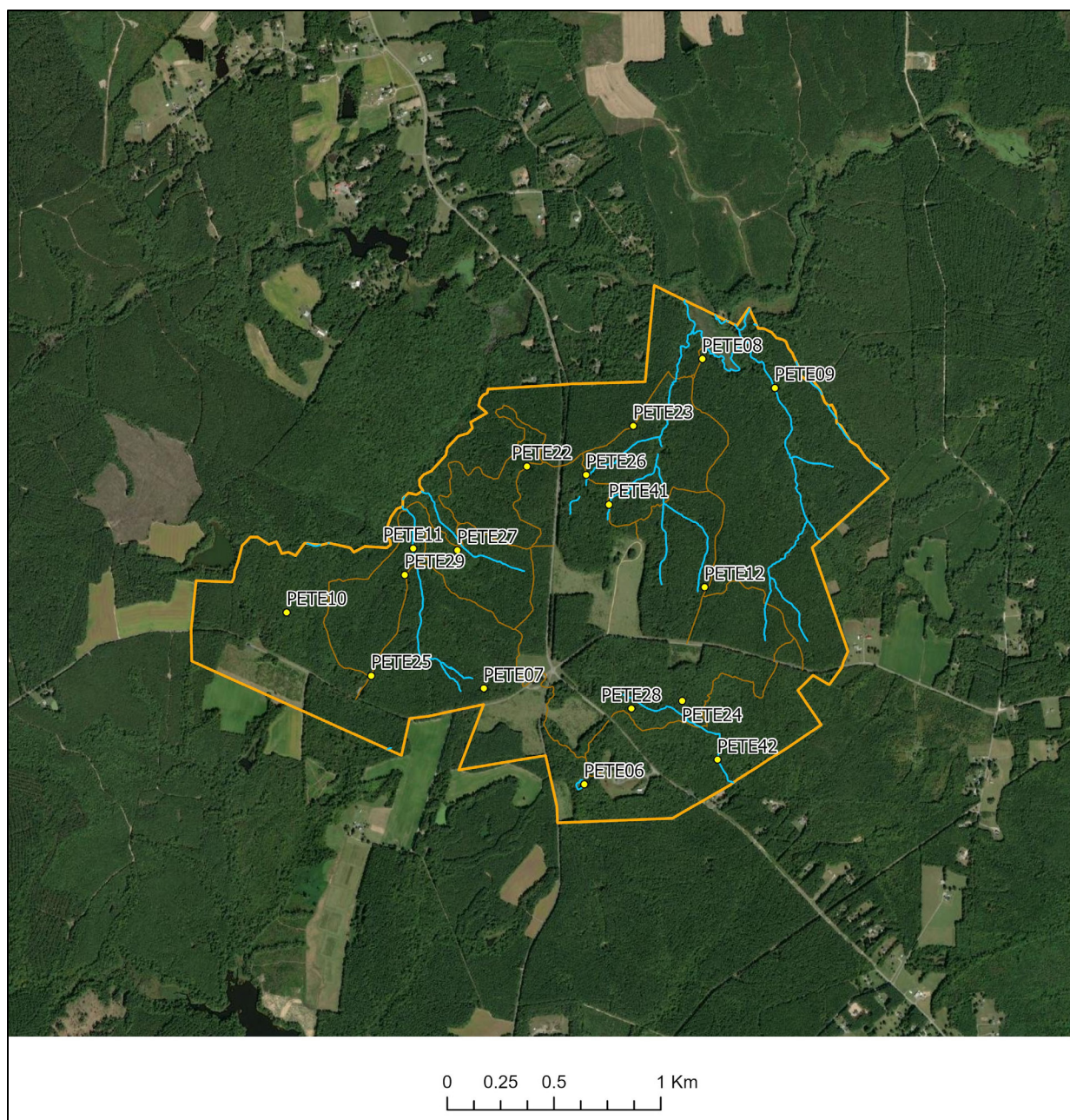


Figure 2. Bat summer acoustic detector sites from 2016-2020 at the Five Forks unit, Petersburg National Battlefield, Virginia.

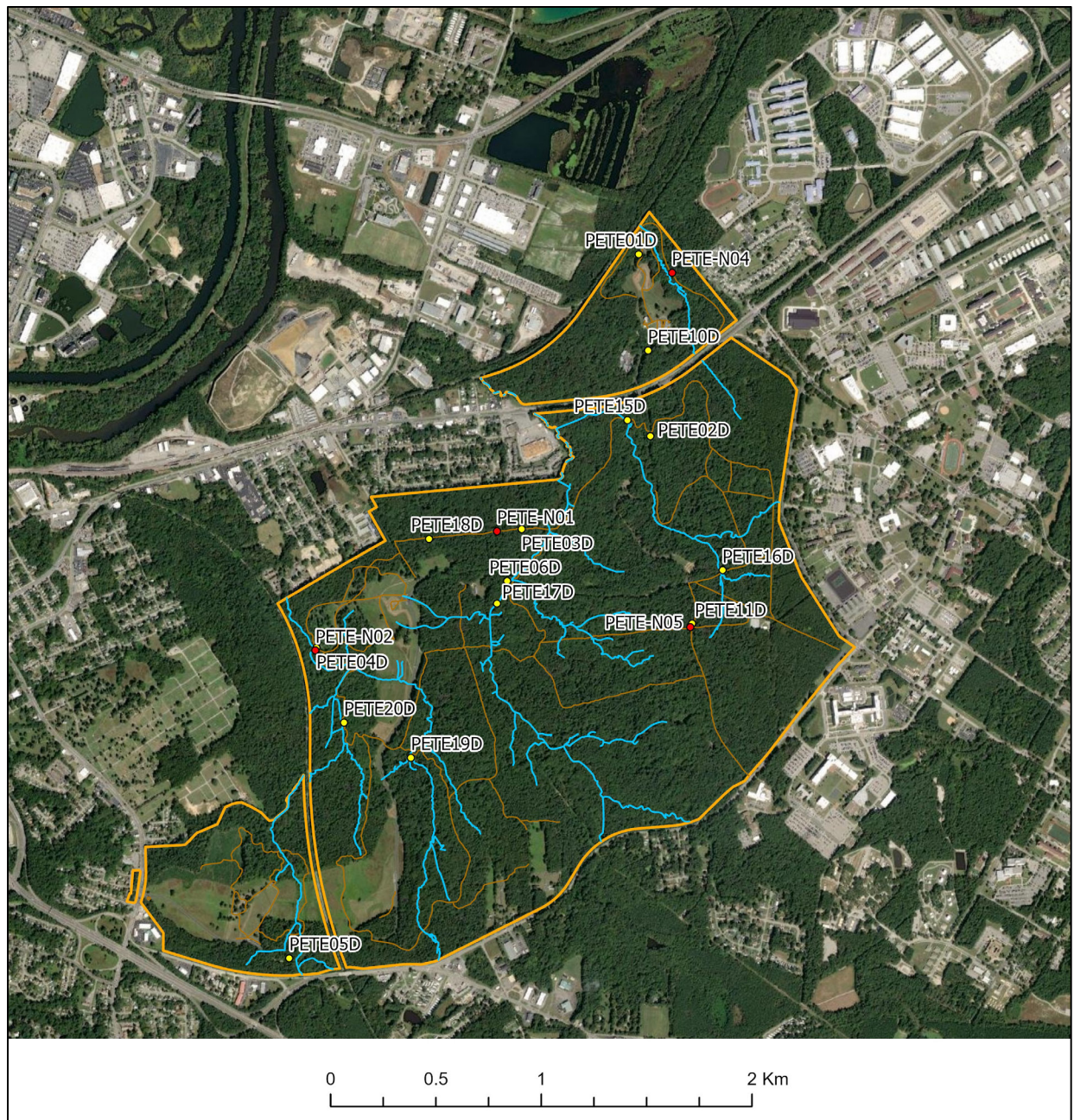


Figure 3. Bat dormant season acoustic detector sites and summer mist-netting sites from 2016-2020 at the Eastern Front unit, Petersburg National Battlefield, Virginia.

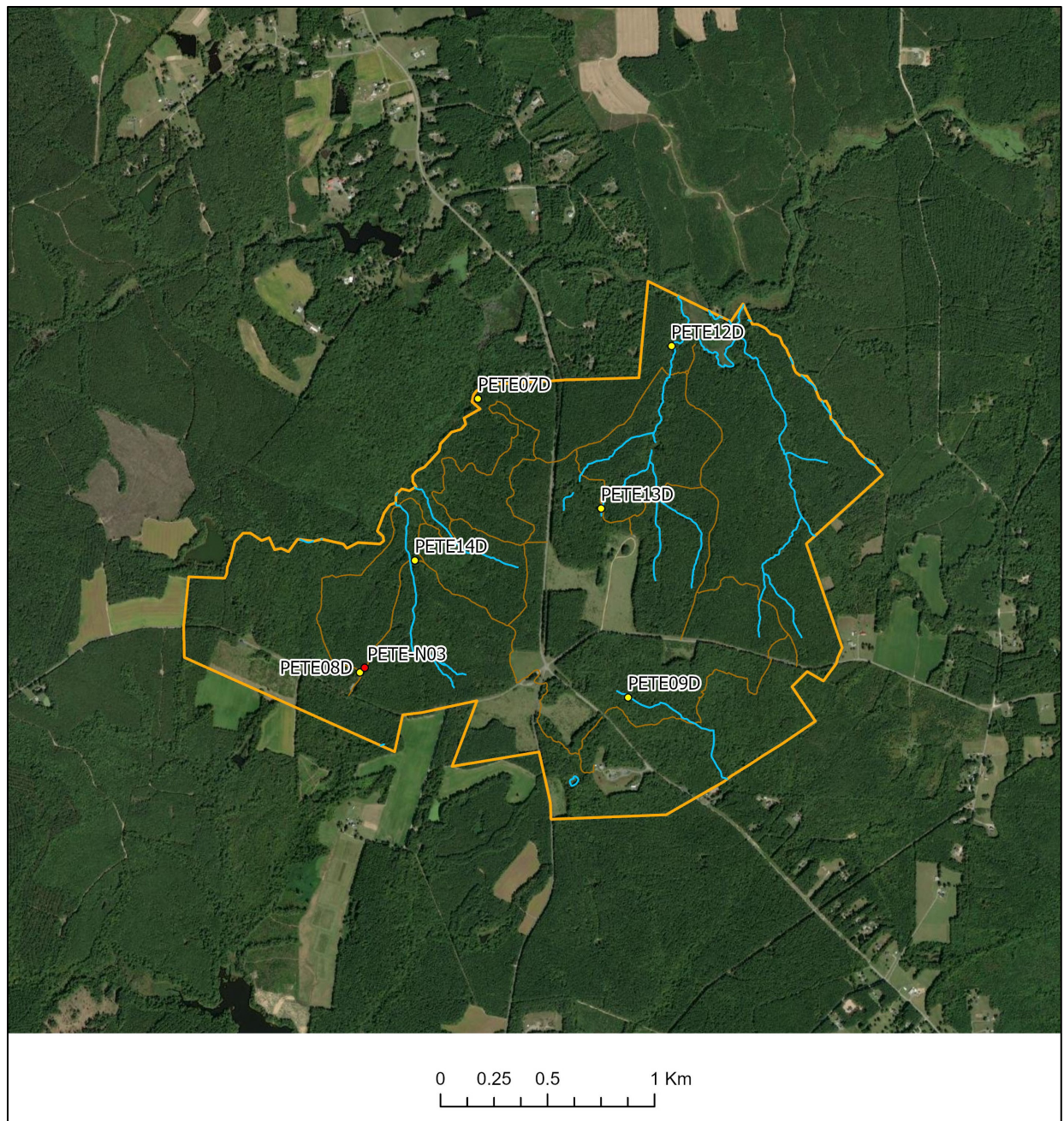


Figure 4. Bat dormant season acoustic detector sites and summer mist-netting sites from 2016-2020 at the Five Forks unit, Petersburg National Battlefield, Virginia.

Methods

I conducted acoustic and mist-netting surveys at PETE with the objectives of assessing bat species communities and documenting locations where WNS-imperiled species occur with specific emphasis on the now 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 little brown, northern long-eared, and Indiana bat capture to facilitate day-roost and reproductive monitoring.

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 5). 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. 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 by the USFWS Indiana and northern long-eared bat survey guidelines (USFWS 2022c). However, for the purpose of presenting seasonal results, I extended this summer period to April 15-September 16 to better reflect bat activity patterns. 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 such as drinking sites or what appeared to be suitable 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 bats, particularly *Myotis* spp., was observed (e.g. PETE25 and PETE08D). Dormant season acoustic survey took place from fall 2017 through spring 2021 and several sites were repeated over consecutive years.



Figure 5. Representative acoustic detector deployment in 2016 at Petersburg National Battlefield, 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). Because non-random sampling was utilized to optimize detection of rare species, model-predicted activity may be biased when extrapolated beyond sample sites. All sampling locations are documented in Figures 1-4 and Appendix A.

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. Selections for validation included calls from multiple sites from every season in which these species were identified. Reported results were not altered to reflect validation determinations. Systematic visual validation of all calls for these species was not performed due to large volume of call files (>40,000).

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).

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 using 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: deciduous forest, mixed forest, open, and wetland by grouping delineation classifications made by the Virginia Department of Conservation and Recreation (Patterson 2008, Appendix B). Mixed 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 a National Oceanic and Atmospheric Administration National Centers for Environmental Information weather station in Petersburg approximately 2.5 kilometers west of PETE (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 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. With the *glmmTMB* package, I used models to predict bat species activity by individual covariate, while holding others fixed (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. The 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. 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

Acoustic detectors sampled for 4,781 detector-nights, 1,731 of which occurred during the summer period. Summer sampling included 40 summer sites in 2016, 2017, 2018, and 2020, as well as 14 dormant sites that recorded during the summer period (Table 1; Appendix A). Summer sites PETE13 and PETE16 failed to collect data due to equipment failure so are not included in results. Non-reproductive season sampling occurred at 20 sites, from 2017-2021, with several 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 ($p \leq 0.05$, Table 2). However, presence of northern long-eared bats was invalidated as identified passes were found to be misidentifications. Total numbers of bat passes identified by species were: big brown bat ($n = 59,488$), eastern red bat ($n = 38,460$), hoary bat ($n = 4,090$), silver-haired bat ($n = 3,642$), little brown bat ($n = 35,003$), northern long-eared bat ($n = 3,646$), Indiana bat ($n = 3,442$), evening bat ($n = 22,782$), tricolored bat ($n = 8,277$), and Mexican free-tailed ($n = 4,733$). 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 Petersburg National Battlefield, Virginia during the summers (April 16-September 15) of 2016, 2017, 2018, and 2020.

Site	Unit ¹	Year	All	EPFU ²	LABO ²	LACI ²	LANO ²	MYLU ²	MYSE ^{2,3}	MYSO ²	NYHU ²	PESU ²	TABR ²
PETE01	EF	2016	66.69	13.54	25.62	4.85	0.00	9.69	0.00	3.46	5.31	3.31	0.92
PETE02	EF	2016	160.15	40.69	19.85	7.15	20.85	13.15	0.38	0.00	30.77	4.85	22.46
PETE03	EF	2016	39.15	17.46	8.69	0.00	0.00	9.31	0.00	3.69	0.00	0.00	0.00
PETE04	EF	2016	19.77	5.38	5.15	0.23	0.00	4.77	0.00	0.69	0.00	3.54	0.00
PETE05	EF	2016	5.77	2.46	0.38	0.00	0.00	0.92	0.69	0.77	0.00	0.54	0.00
PETE06	FF	2016	127.58	29.75	14.08	0.00	6.75	3.17	0.00	0.00	43.25	0.00	30.58
PETE07	FF	2016	4.00	0.00	0.00	2.50	0.00	0.50	0.25	0.58	0.00	0.17	0.00
PETE08	FF	2016	0.17	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE09	FF	2016	0.75	0.00	0.00	0.17	0.00	0.00	0.58	0.00	0.00	0.00	0.00
PETE10	FF	2016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE11	FF	2016	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
PETE12	FF	2016	26.44	15.78	2.78	0.00	0.00	6.44	0.67	0.00	0.00	0.78	0.00
PETE14	EF	2016	0.80	0.40	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00
PETE15	EF	2016	108.64	34.55	12.45	0.00	0.00	20.55	28.91	3.36	0.00	8.82	0.00
PETE17	EF	2017	5.43	3.00	0.29	0.00	0.00	0.57	1.57	0.00	0.00	0.00	0.00
PETE18	EF	2017	217.53	185.67	4.93	0.00	0.00	3.73	21.27	0.00	0.40	1.53	0.00
PETE19	EF	2017	34.00	22.67	3.00	0.00	0.00	6.33	0.00	0.00	0.00	2.00	0.00
PETE20	EF	2017	5.07	1.73	0.33	0.00	0.00	1.00	1.00	0.20	0.00	0.80	0.00
PETE21	EF	2017	456.67	292.27	11.80	0.00	0.00	6.73	0.73	0.00	86.47	7.67	51.00
PETE22	FF	2017	8.43	5.21	0.50	0.21	0.00	0.36	2.14	0.00	0.00	0.00	0.00

¹ EF= Eastern Front, FF = Five Forks

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*).

³ Northern long-eared bat (MYSE) passes were invalidated as misidentifications so this species should not be considered present.

⁴ Sites ending in "D" were dormant season sampling locations that recorded during summer.

Table 1 (continued). Mean nightly activity in number of echolocation passes per night of bat species at Petersburg National Battlefield, Virginia during the summers (April 16-September 15) of 2016, 2017, 2018, and 2020.

Site	Unit ¹	Year	All	EPFU ²	LABO ²	LACI ²	LANO ²	MYLU ²	MYSE ^{2,3}	MYSO ²	NYHU ²	PESU ²	TABR ²
PETE23	FF	2017	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE24	FF	2017	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE25	FF	2017	775.93	138.00	160.36	0.00	0.00	412.71	12.50	0.00	0.00	52.36	0.00
PETE26	FF	2018	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE27	FF	2018	1.84	0.00	0.47	0.42	0.00	0.84	0.00	0.00	0.00	0.00	0.11
PETE28	FF	2018	661.76	163.38	153.24	1.86	0.00	3.62	0.52	0.00	314.52	21.81	2.81
PETE29	FF	2018	66.29	2.81	6.00	0.43	0.00	11.48	15.95	23.76	0.00	5.43	0.43
PETE30	EF	2018	136.90	46.95	72.81	0.00	0.00	9.00	3.24	0.24	4.67	0.00	0.00
PETE31	EF	2018	14.10	9.45	0.45	0.20	0.00	2.40	0.45	0.20	0.00	0.95	0.00
PETE32	EF	2018	2.10	0.00	0.30	1.45	0.00	0.25	0.10	0.00	0.00	0.00	0.00
PETE33	EF	2018	95.24	29.24	35.48	0.00	0.00	22.00	0.38	4.52	0.00	3.43	0.19
PETE34	EF	2020	3.22	1.85	0.25	0.28	0.15	0.17	0.06	0.03	0.05	0.28	0.11
PETE35	EF	2020	78.75	5.63	7.12	0.15	0.44	9.75	4.83	28.85	0.13	21.33	0.52
PETE36	EF	2020	193.63	103.14	30.67	0.63	1.75	25.27	3.02	4.22	8.92	13.90	2.11
PETE37	EF	2020	61.88	8.94	15.63	0.00	0.00	32.88	2.13	0.00	1.31	1.00	0.00
PETE38	EF	2020	0.92	0.81	0.00	0.04	0.00	0.00	0.08	0.00	0.00	0.00	0.00
PETE39	EF	2020	5.56	1.55	0.27	1.75	0.00	0.87	0.15	0.00	0.00	0.18	0.80
PETE40	EF	2020	24.23	12.81	2.04	0.19	0.00	1.96	5.88	0.00	0.28	0.44	0.63
PETE41	FF	2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE42	FF	2020	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00

¹ EF= Eastern Front, FF = Five Forks

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*).

³ Northern long-eared bat (MYSE) passes were invalidated as misidentifications so this species should not be considered present.

⁴ Sites ending in "D" were dormant season sampling locations that recorded during summer.

Table 1 (continued). Mean nightly activity in number of echolocation passes per night of bat species at Petersburg National Battlefield, Virginia during the summers (April 16-September 15) of 2016, 2017, 2018, and 2020.

Site	Unit ¹	Year	All	EPFU ²	LABO ²	LACI ²	LANO ²	MYLU ²	MYSE ^{2, 3}	MYSO ²	NYHU ²	PESU ²	TABR ²
PETE01D ⁴	EF	2018	4.63	2.25	0.50	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE02D ⁴	EF	2018	167.76	62.78	26.11	0.43	0.86	3.68	0.16	0.00	58.97	12.24	2.51
PETE03D ⁴	EF	2019	111.08	37.15	28.78	0.25	0.00	36.12	0.99	0.48	2.10	5.08	0.14
PETE04D ⁴	EF	2019	16.37	6.97	0.87	1.42	0.00	5.42	0.79	0.89	0.00	0.00	0.00
PETE05D ⁴	EF	2019	395.33	157.51	114.95	0.77	0.00	5.05	0.46	0.15	115.36	0.00	1.08
PETE06D ⁴	EF	2019	31.87	10.66	4.39	0.04	0.00	5.63	2.34	3.98	0.13	4.59	0.12
PETE08D ⁴	FF	2019	189.09	24.48	84.58	0.31	0.12	68.21	1.53	1.65	0.00	7.83	0.38
PETE09D ⁴	FF	2019	0.90	0.04	0.00	0.48	0.21	0.00	0.00	0.00	0.00	0.00	0.16
PETE10D ⁴	EF	2019	34.81	9.31	3.19	0.62	0.11	1.93	0.00	0.00	19.06	0.21	0.38
PETE11D ⁴	EF	2019	8.24	6.71	0.00	0.12	0.00	0.65	0.47	0.12	0.00	0.18	0.00
PETE16D ⁴	EF	2020	25.83	1.67	0.00	20.33	0.00	0.00	0.00	0.00	3.83	0.00	0.00
PETE17D ⁴	EF	2020	93.20	20.00	20.40	0.40	5.60	15.60	0.00	0.00	31.20	0.00	0.00
PETE18D ⁴	EF	2020	49.33	24.00	5.17	0.00	0.50	14.00	3.50	0.00	0.00	2.17	0.00
PETE20D ⁴	EF	2020	9.50	6.50	0.00	0.00	2.50	0.50	0.00	0.00	0.00	0.00	0.00

¹ EF= Eastern Front, FF = Five Forks

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*).

³ Northern long-eared bat (MYSE) passes were invalidated as misidentifications so this species should not be considered present.

⁴ Sites ending in "D" were dormant season sampling locations that recorded during summer.

Table 2. Mean nightly activity of bat species at Petersburg National Battlefield, 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 ^{2,3}	MYSO ²	NYHU ²	PESU ²	TABR ²
PETE01D	EF	5.89	0.85	0.71	1.39	0.13	1.43	0.00	0.00	0.00	0.96	0.43
PETE02D	EF	21.97	3.03	1.75	0.18	3.42	0.19	0.00	0.00	9.99	1.64	1.78
PETE03D	EF	5.46	3.09	0.32	0.41	0.01	0.57	0.30	0.18	0.00	0.19	0.39
PETE04D	EF	2.58	0.22	0.00	2.15	0.00	0.10	0.03	0.00	0.00	0.03	0.06
PETE05D	EF	7.48	5.65	0.31	0.07	0.00	0.07	0.02	0.00	1.27	0.07	0.00
PETE06D	EF	3.27	1.24	0.00	0.15	0.61	0.24	0.76	0.24	0.00	0.03	0.00
PETE07D	FF	1.33	0.00	0.00	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE08D	FF	14.49	1.15	3.06	0.68	0.28	9.10	0.00	0.04	0.00	0.00	0.18
PETE09D	FF	0.09	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.05
PETE10D	EF	2.64	0.44	0.00	0.12	0.99	0.15	0.00	0.00	0.75	0.03	0.17
PETE11D	EF	6.32	0.84	0.99	0.16	0.29	2.92	0.26	0.14	0.00	0.44	0.29
PETE12D	FF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE13D	FF	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12
PETE14D	FF	0.67	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.19
PETE15D	EF	0.60	0.16	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.00	0.00
PETE16D	EF	3.46	0.35	0.00	0.08	1.92	0.19	0.00	0.00	0.00	0.00	0.92
PETE17D	EF	3.64	0.00	0.14	2.05	0.14	0.55	0.23	0.00	0.00	0.00	0.55
PETE18D	EF	23.05	2.14	0.09	13.00	1.18	2.27	2.18	0.95	0.00	0.00	1.23
PETE19D	EF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE20D	EF	1.00	0.35	0.00	0.29	0.35	0.00	0.00	0.00	0.00	0.00	0.00

¹ EF= Eastern Front, FF = Five Forks.

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*).

³ Northern long-eared bat (MYSE) passes were invalidated as misidentifications so this species should not be considered present.

Table 3. Mean nightly activity of bat species at Petersburg National Battlefield Park, Virginia during winter from December 1-February 28 of the dormant season in echolocation passes per night.

Site	Unit ¹	All	EPFU ²	LABO ²	LACI ²	LANO ²	MYLU ²	MYSE ^{2, 3}	MYSO ²	NYHU ²	PESU ²	TABR ²
PETE01D	EF	36.36	0.00	0.67	0.00	13.75	0.57	0.00	0.00	2.78	1.47	17.13
PETE02D	EF	6.60	0.23	1.02	0.05	1.58	0.74	0.00	0.00	0.07	2.11	0.81
PETE03D	EF	1.97	1.14	0.04	0.09	0.04	0.27	0.07	0.08	0.00	0.00	0.24
PETE04D	EF	5.35	0.21	0.00	3.94	0.02	0.00	0.00	0.00	0.00	0.00	1.17
PETE05D	EF	9.01	4.41	1.10	0.43	0.43	0.99	0.00	0.00	0.00	0.70	0.96
PETE06D	EF	2.43	1.20	0.12	0.17	0.44	0.12	0.09	0.03	0.00	0.00	0.25
PETE07D	FF	0.36	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.28
PETE08D	FF	0.54	0.00	0.11	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.35
PETE09D	FF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE10D	EF	1.65	0.50	0.00	0.00	0.50	0.45	0.00	0.00	0.00	0.00	0.20
PETE11D	EF	10.63	1.16	1.84	0.79	0.21	2.58	0.00	0.00	0.00	0.00	4.05
PETE12D	FF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE13D	FF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE14D	FF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE15D	EF	1.29	0.71	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.33
PETE16D	EF	0.56	0.17	0.00	0.15	0.00	0.05	0.00	0.00	0.00	0.00	0.20
PETE17D	EF	1.84	0.00	0.06	0.35	0.65	0.45	0.10	0.00	0.00	0.00	0.23
PETE18D	EF	2.21	1.24	0.00	0.21	0.28	0.14	0.00	0.00	0.00	0.00	0.34
PETE19D	EF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE20D	EF	0.69	0.00	0.00	0.00	0.56	0.13	0.00	0.00	0.00	0.00	0.00

¹ EF= Eastern Front, FF = Five Forks.

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*).

³ Northern long-eared bat (MYSE) passes were invalidated as misidentifications so this species should not be considered present.

Table 4. Mean nightly activity of bat species at Petersburg 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 ^{2,3,4}	MYSO ²	NYHU ²	PESU ²	TABR ²
PETE01D	EF	16.77	0.00	0.00	0.00	9.45	1.50	0.00	0.00	4.18	0.18	1.45
PETE02D	EF	41.12	4.74	2.51	0.09	3.37	8.07	0.00	0.00	18.37	3.63	0.33
PETE03D	EF	21.71	18.66	0.82	0.20	0.00	1.38	0.10	0.06	0.00	0.33	0.15
PETE04D	EF	7.41	1.48	0.00	4.28	0.14	0.52	0.00	0.00	0.00	0.00	0.99
PETE05D	EF	55.27	26.66	6.13	0.34	0.17	15.69	0.54	0.00	4.23	1.12	0.39
PETE06D	EF	12.16	3.15	0.24	0.17	3.02	4.25	0.84	0.22	0.26	0.00	0.00
PETE08D	FF	24.66	2.70	6.97	0.00	0.13	11.79	1.24	0.12	0.28	0.64	0.78
PETE09D	FF	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
PETE10D	EF	36.37	10.24	4.00	0.98	11.22	2.17	0.41	0.00	3.13	0.57	3.65
PETE11D	EF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE13D	FF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE15D	EF	5.77	1.87	0.79	0.26	0.00	1.38	0.82	0.64	0.00	0.00	0.00
PETE16D	EF	61.68	5.95	0.63	28.54	0.00	0.00	0.27	0.00	22.73	2.07	1.49
PETE17D	EF	36.03	12.70	5.90	2.08	1.60	4.15	0.35	0.00	6.23	1.80	1.23
PETE18D	EF	53.84	21.09	9.20	0.55	0.11	13.34	4.50	0.16	0.89	2.66	1.34
PETE19D	EF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PETE20D	EF	4.43	2.62	0.16	0.05	1.38	0.22	0.00	0.00	0.00	0.00	0.00

¹ EF= Eastern Front, FF = Five Forks.

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*).

³ Northern long-eared bat (MYSE) passes were invalidated as misidentifications so this species should not be considered present.

Big brown bat

Big brown bat activity was the highest of species identified at PETE and common among most sample locations (Table 1). Activity was very high at several locations in the Eastern Front (PETE18, PETE21, and PETE05D) and Five Forks (PETE25 and PETE28) where mean passes per night exceeded 100 during the summer. Seasonally, big brown bat activity increased sharply in early April and peaked in the summer with greatest activity occurring in early July, then declined in early August (Figure 5). Activity was low in fall through winter but did occur sporadically at most sites. The GLMM showed activity was much higher in open habitats and included significant predictors: habitat type, distance to water, nightly precipitation, and minimum temperature (Figure 6).

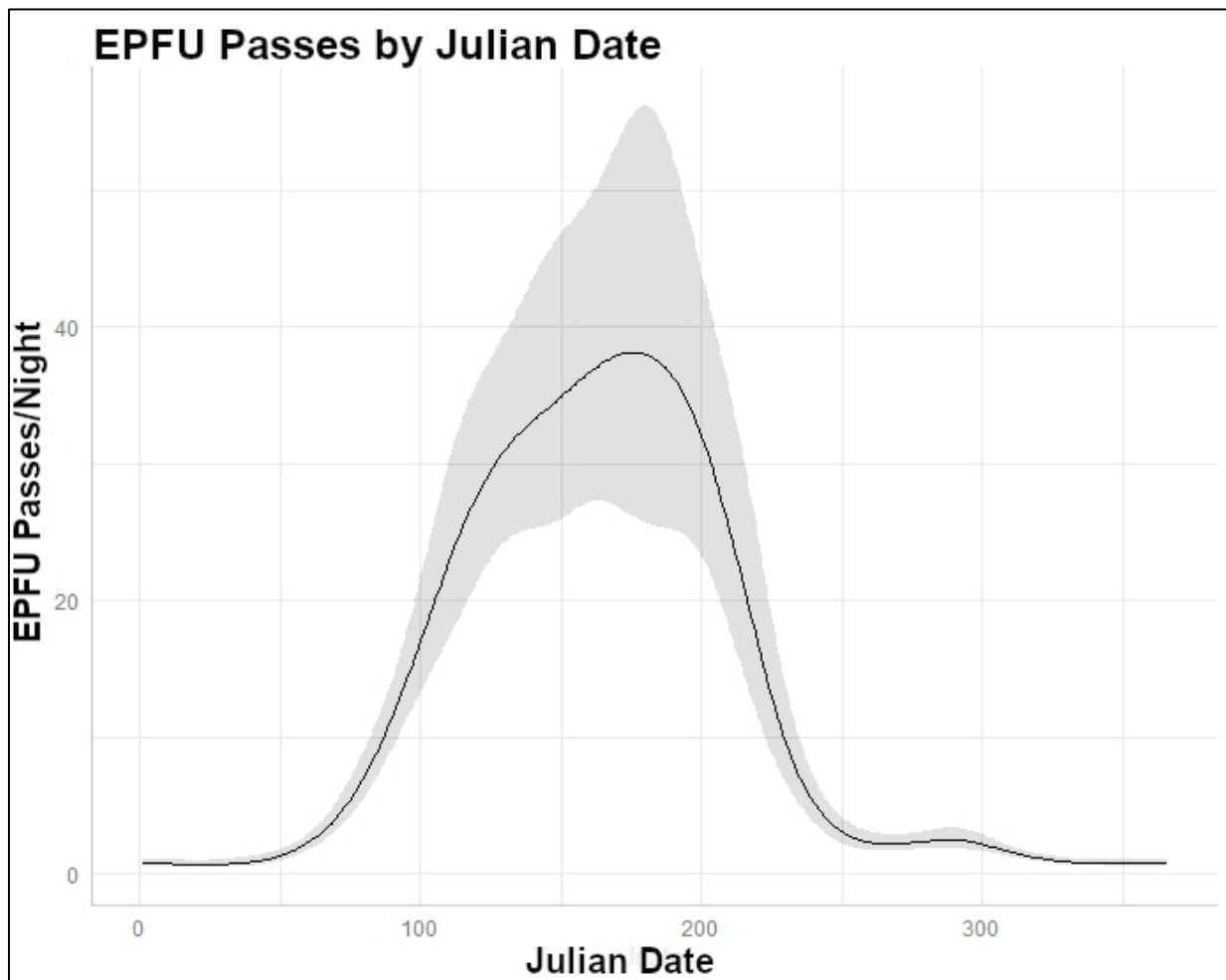


Figure 5. Big brown bat (*Eptesicus fuscus*) activity (mean passes/night) as predicted by a generalized additive model of activity by Julian date at Petersburg National Battlefield, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

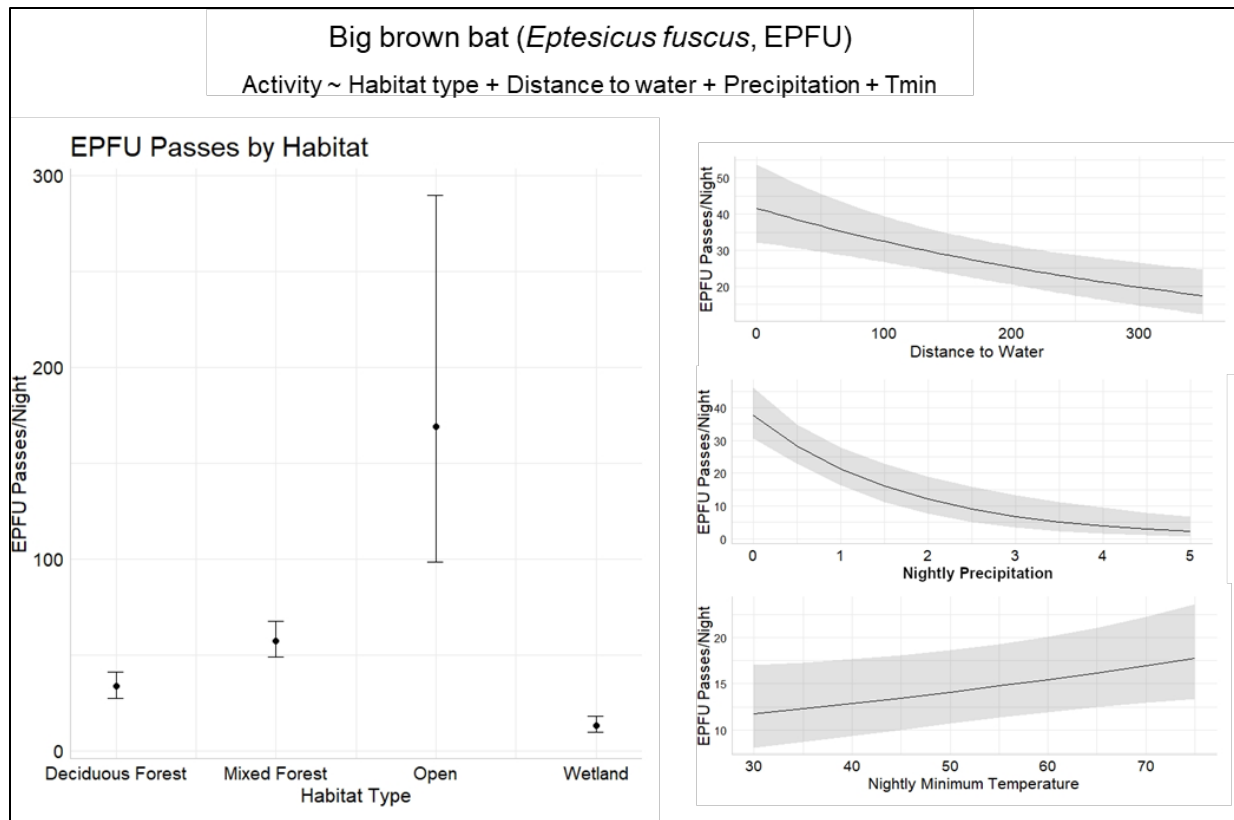


Figure 6. Predicted activity (mean passes per night and standard error) for big brown bats (*Eptesicus fuscus*, EPFU) by generalized linear mixed model during summer at Petersburg National Battlefield, Virginia by covariates habitat, distance to water (m), nightly precipitation (cm), and minimum temperature (°F).

Little brown bat

Little brown bats were the second most commonly identified cave bat at PETE. Identified passes were widespread and occurred mostly at low to moderate levels. One site at Five Forks, PETE25, recorded extremely high levels of activity with a mean of 412 calls per night. Overall trends of activity increased in early April, peaking in early July, then declining in late July (Figure 7). Passes were identified in winter months at the Eastern Front. The GLMM showed activity to be most associated with coniferous and mixed forest habitats (Figure 8). However, results should be interpreted with caution as visual validation of selected calls revealed many false identifications of little brown bat calls by the software, though many calls were confirmed as accurate.

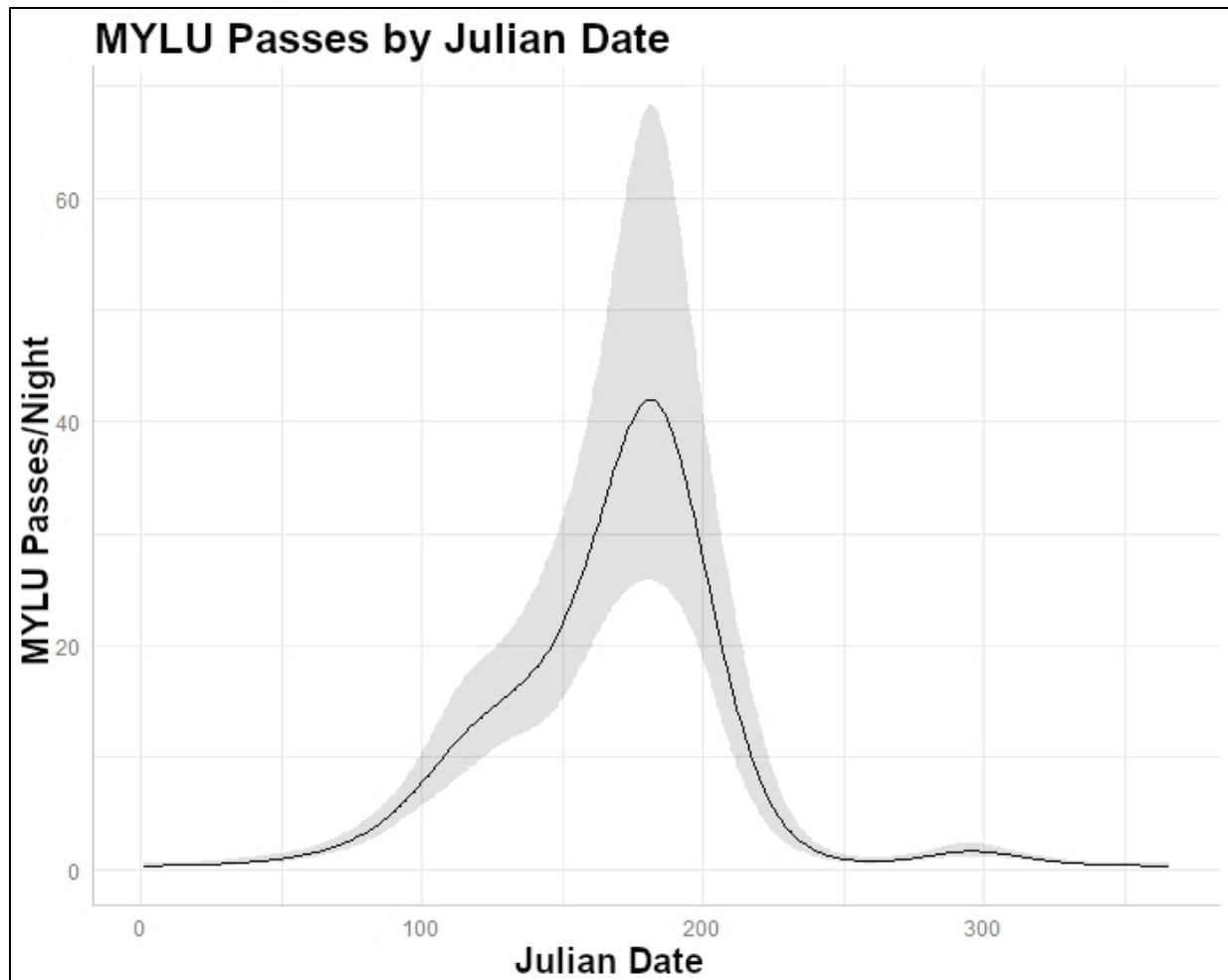


Figure 7. Little brown bat (*Myotis lucifugus*) activity (mean passes/night) as predicted by a generalized additive model of activity by Julian date at Petersburg National Battlefield, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

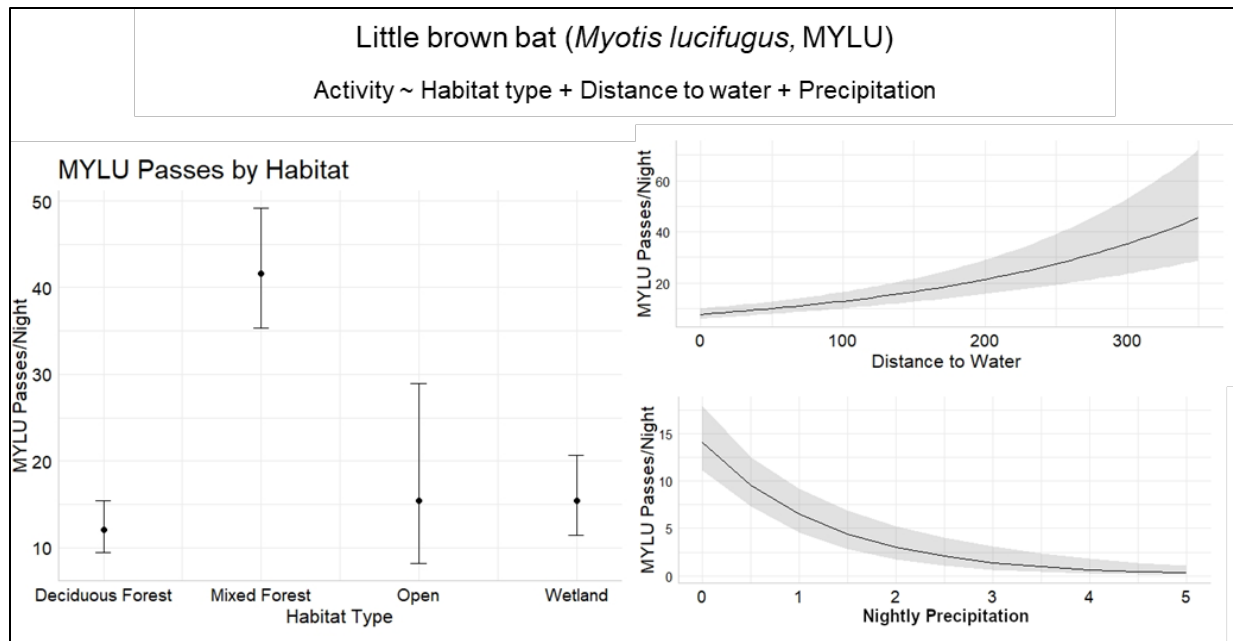


Figure 8. Predicted activity (mean passes per night and standard error) for little brown bats (*Myotis lucifugus*; MYLU) by generalized linear mixed model during summer at Petersburg National Battlefield, Virginia by covariates: habitat, distance to water (m) and nightly precipitation (cm).

Northern long-eared bat

Northern long-eared bat calls were identified at most summer sites; however, visual inspection of identified passes revealed all examined calls to be misidentifications of eastern red bats, little brown bats, or unidentifiable calls. I examined calls from sites where greatest activity was identified including: PETE15, PETE18, PETE25, PETE29, and PETE40 and no calls were confirmed as northern long-eared bats.

Indiana bat

Indiana bats were identified at under half of summer sample sites at low levels and at Eastern Front site PETE35 and Five Forks site PETE29 at moderate levels of activity. Visual validation of identified Indiana bat calls found many to be misidentifications (i.e., eastern red bats), however, there were also many identifications that were valid identifications or could not be ruled out. Very few passes were identified during the dormant season and no calls from the winter appeared to be plausible identifications. The GAM showed activity increasing in late April, peaking in mid-June, then declining by late July (Figure 9). Habitat type was not statistically significant in predicting activity in the GLMM, though highest activity occurred at an open habitat site (Figure 10).

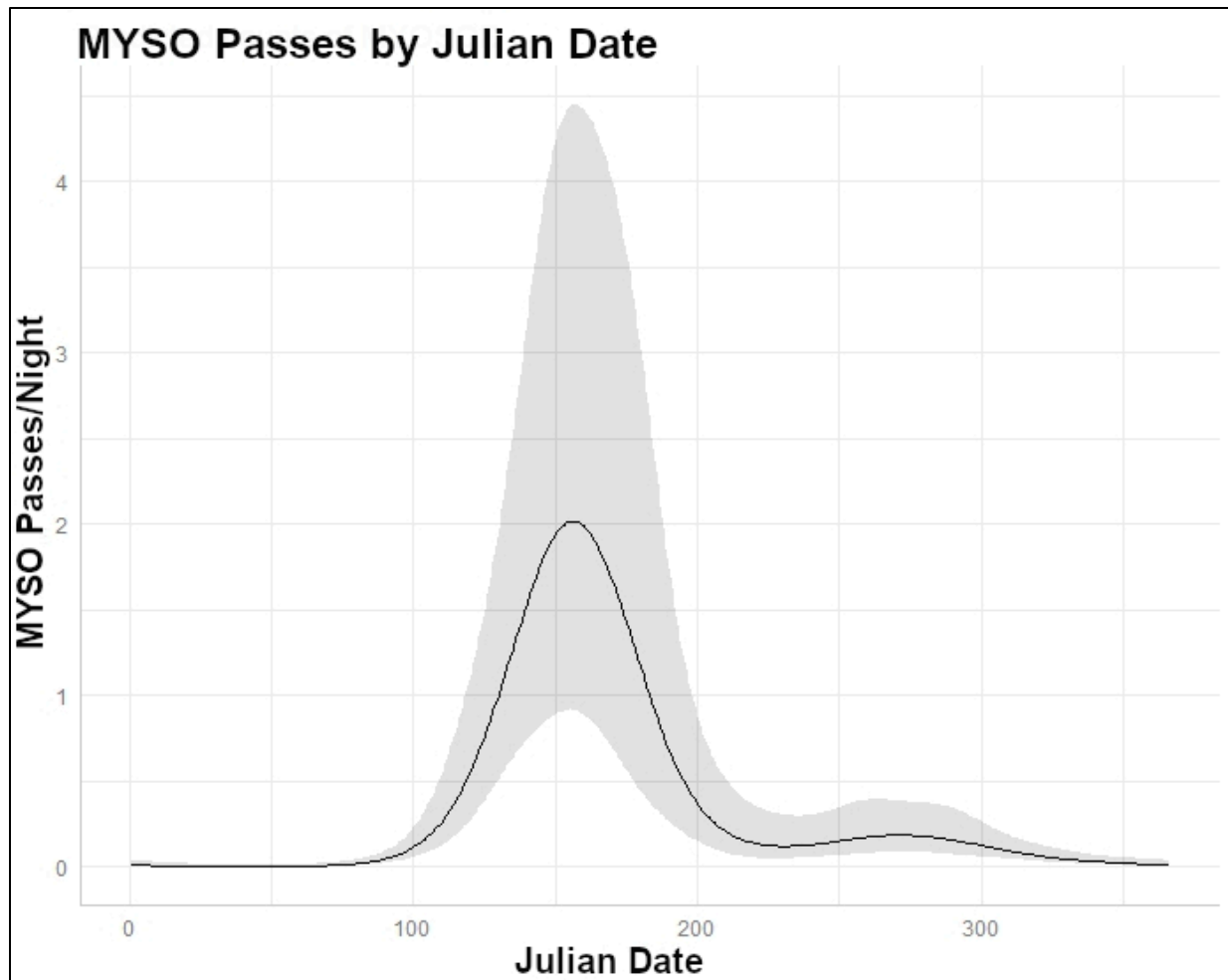


Figure 9. Indiana bat (*Myotis sodalis*) activity (mean passes/night) at Petersburg National Battlefield, Virginia as predicted by a generalized additive model of activity by Julian date. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

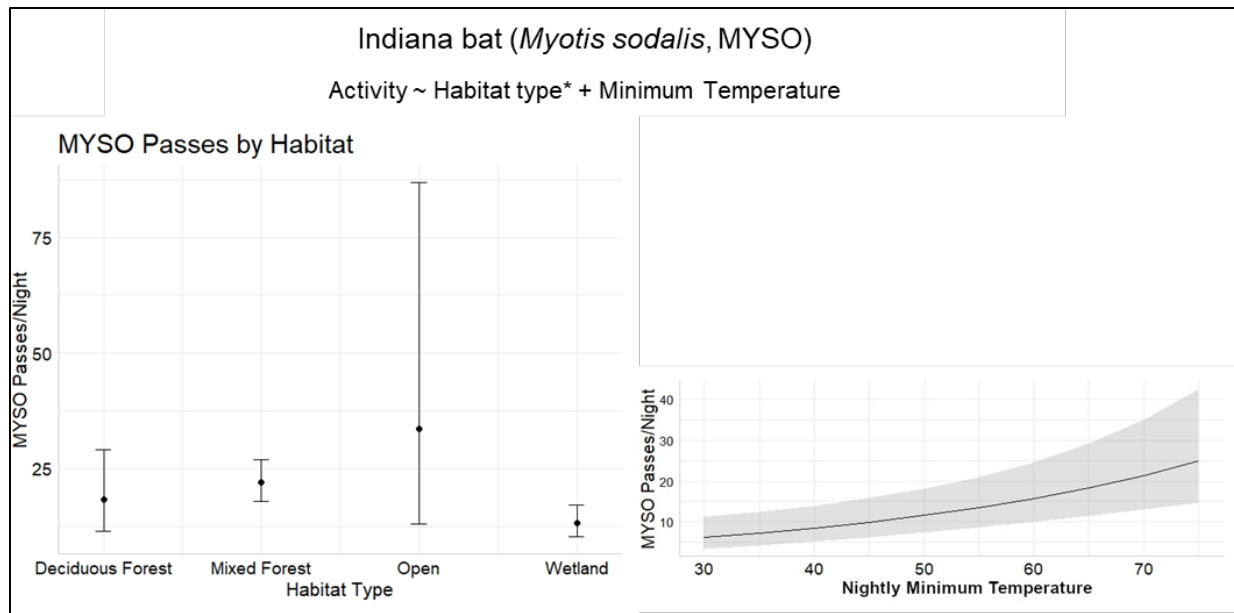


Figure 10. Predicted activity (mean passes per night and standard error) for Indiana bats (*Myotis sodalis*, MYSO) by generalized linear mixed model during summer at Petersburg National Battlefield, Virginia by covariates habitat and nightly minimum temperature (°F). *Habitat type was not a significant predictor of activity.

Tricolored bat

Tricolored bats were identified at most summer sites. Highest activity occurred at PETE25 and PETE28 at Five Forks and PETE35 at the Eastern Front. They were identified sporadically through the winter at the Eastern Front at site PETE02D. Activity increased in mid-April, peaked in late June, and declined in early September (Figure 11). Activity was not significantly different among habitat types in the GLMM (Figure 12).

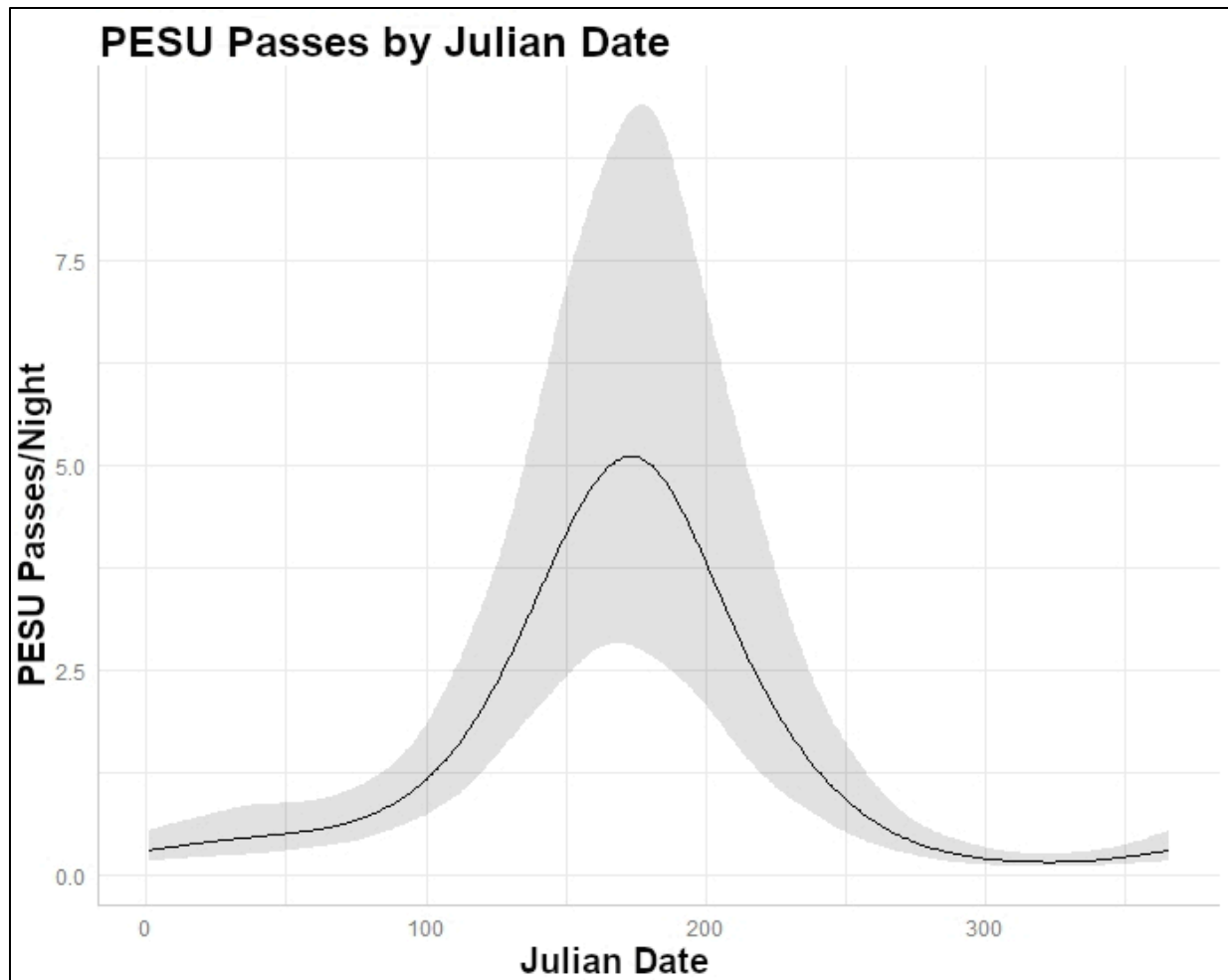


Figure 11. Tricolored bat (*Perimyotis subflavus*) activity (mean passes/night) as predicted by a generalized additive model of activity by Julian date at Petersburg National Battlefield, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

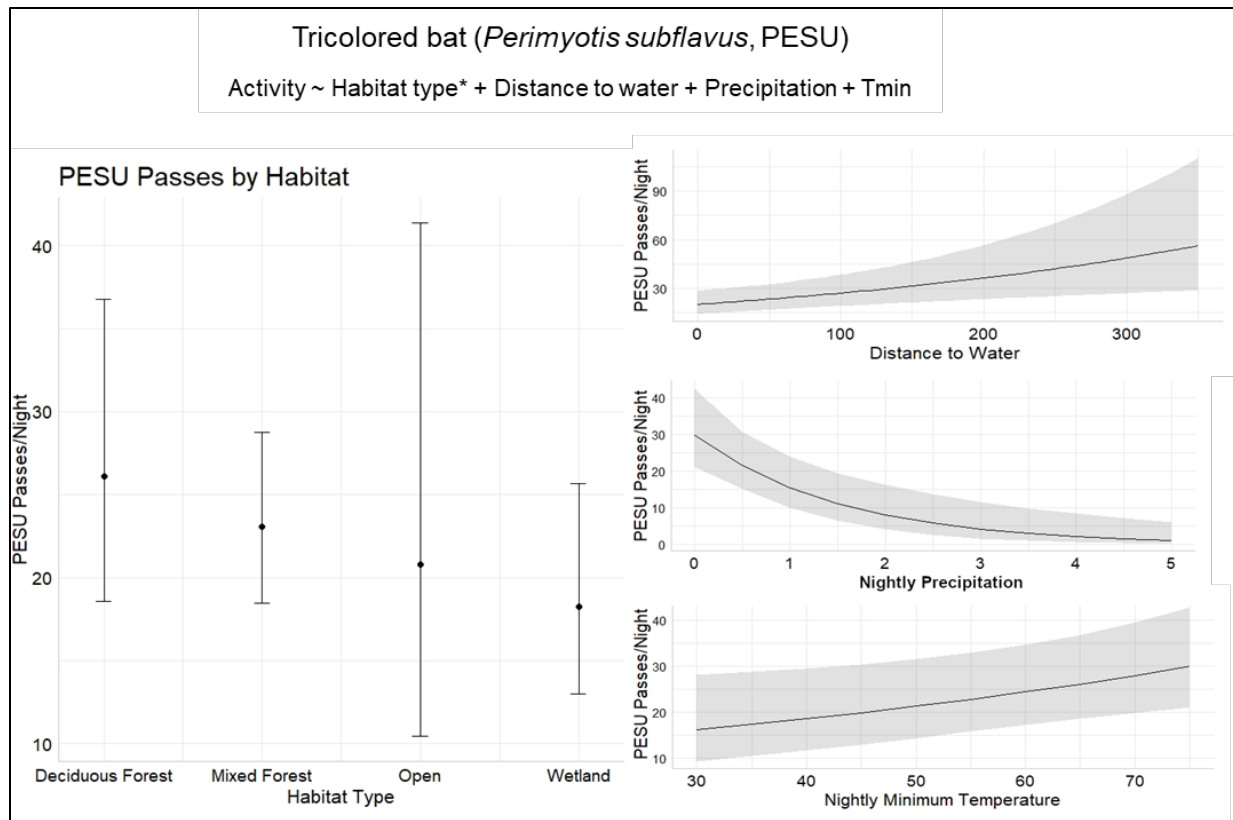


Figure 12. Predicted activity (mean passes per night and standard error) for tricolored bats (*Perimyotis subflavus*, PESU) by generalized linear mixed model during summer at Petersburg National Battlefield, Virginia by covariates habitat, distance to water (m), nightly precipitation (cm), and minimum nightly temperature (°F). *Habitat type was not a significant predictor of activity.

Eastern red bat

Activity of eastern red bats was second highest overall and they were identified at the majority of sample locations. High activity levels were recorded at Eastern Front sites PETE05D and PETE30 and Five Forks sites PETE25/PETE08D and PETE28 during summer. During the dormant season, activity was very low overall, but passes were identified through the winter at the Eastern Front. The GAM of activity showed it sharply increasing in mid-April, peaking in mid-June, and then declining in late July (Figure 13). The GLMM showed higher activity was associated with mixed forest sites (Figure 14).

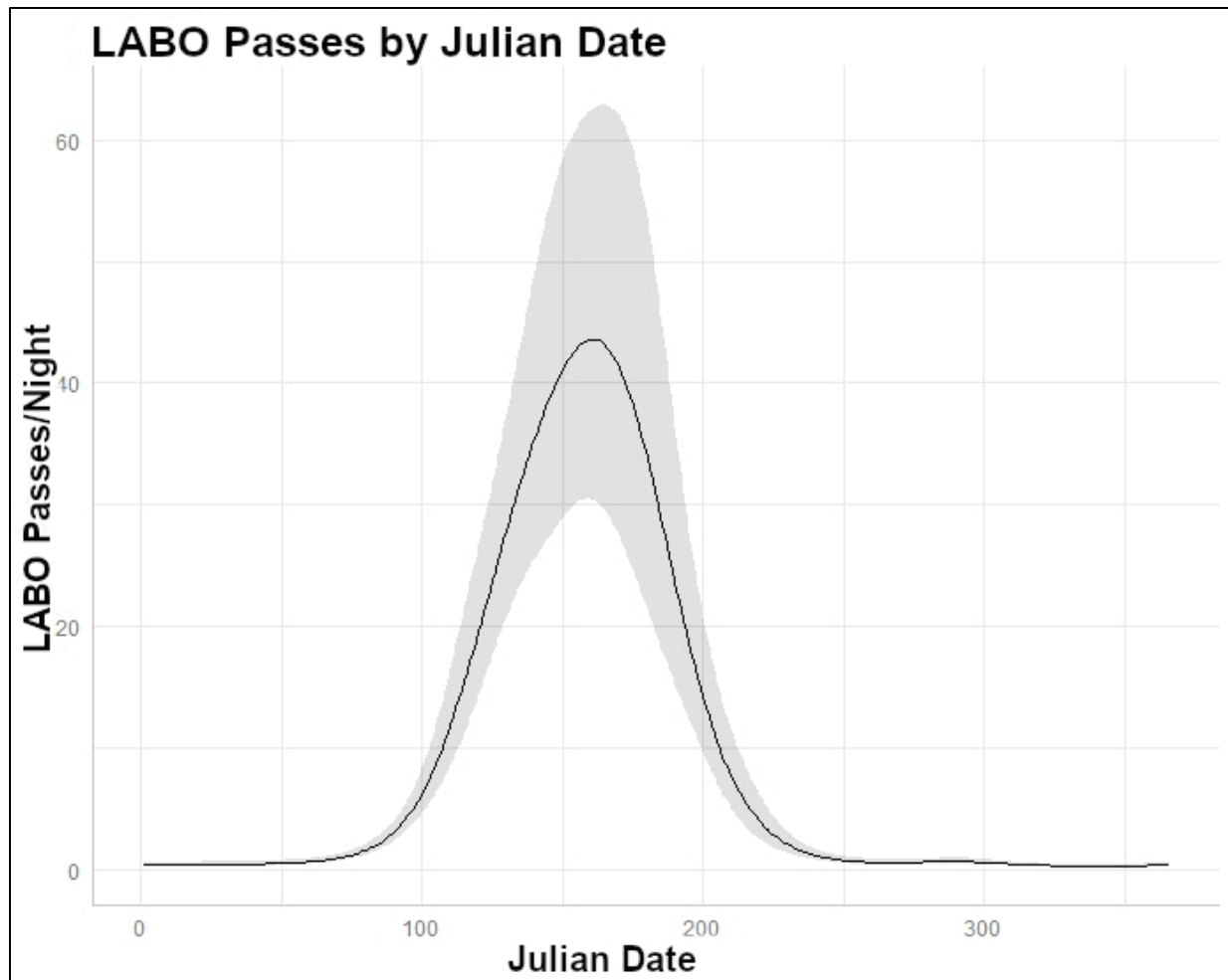


Figure 13. Eastern red bat (*Lasiurus borealis*) activity (mean passes/night) as predicted by a generalized additive model of activity by Julian date at Petersburg National Battlefield, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

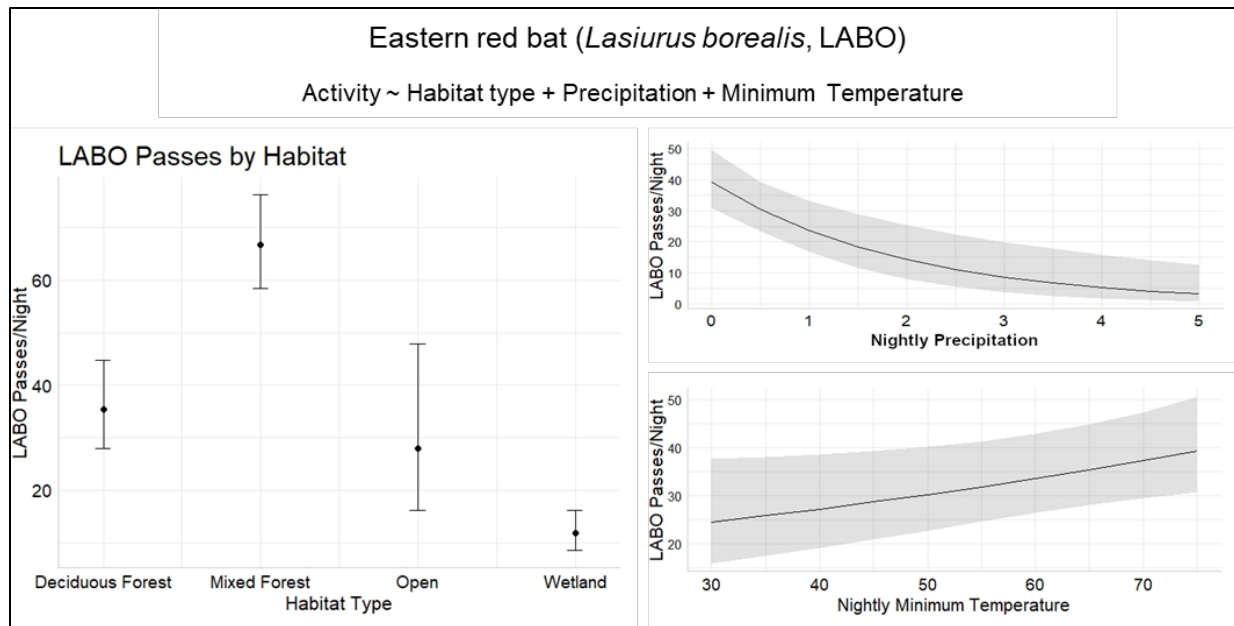


Figure 14. Predicted activity (mean passes per night and standard error) for eastern red bats (*Lasiurus borealis*) by generalized linear mixed model during summer at Petersburg National Battlefield, Virginia by covariates habitat type and nightly precipitation (cm).

Hoary bat

Hoary bat passes were identified at most sites at low levels, except for several nights of very high activity at site PETE16D in mid-March and early April. Activity was low during summer but was observed through the dormant season and winter passes were identified at the Eastern Front. The GAM showed activity was highest in mid-March then declined through the summer, but increased slightly in late October/early November (Figure 15). The GLMM of activity only included habitat as a significant predictor and higher activity was associated with open and wetland habitats (Figure 16).

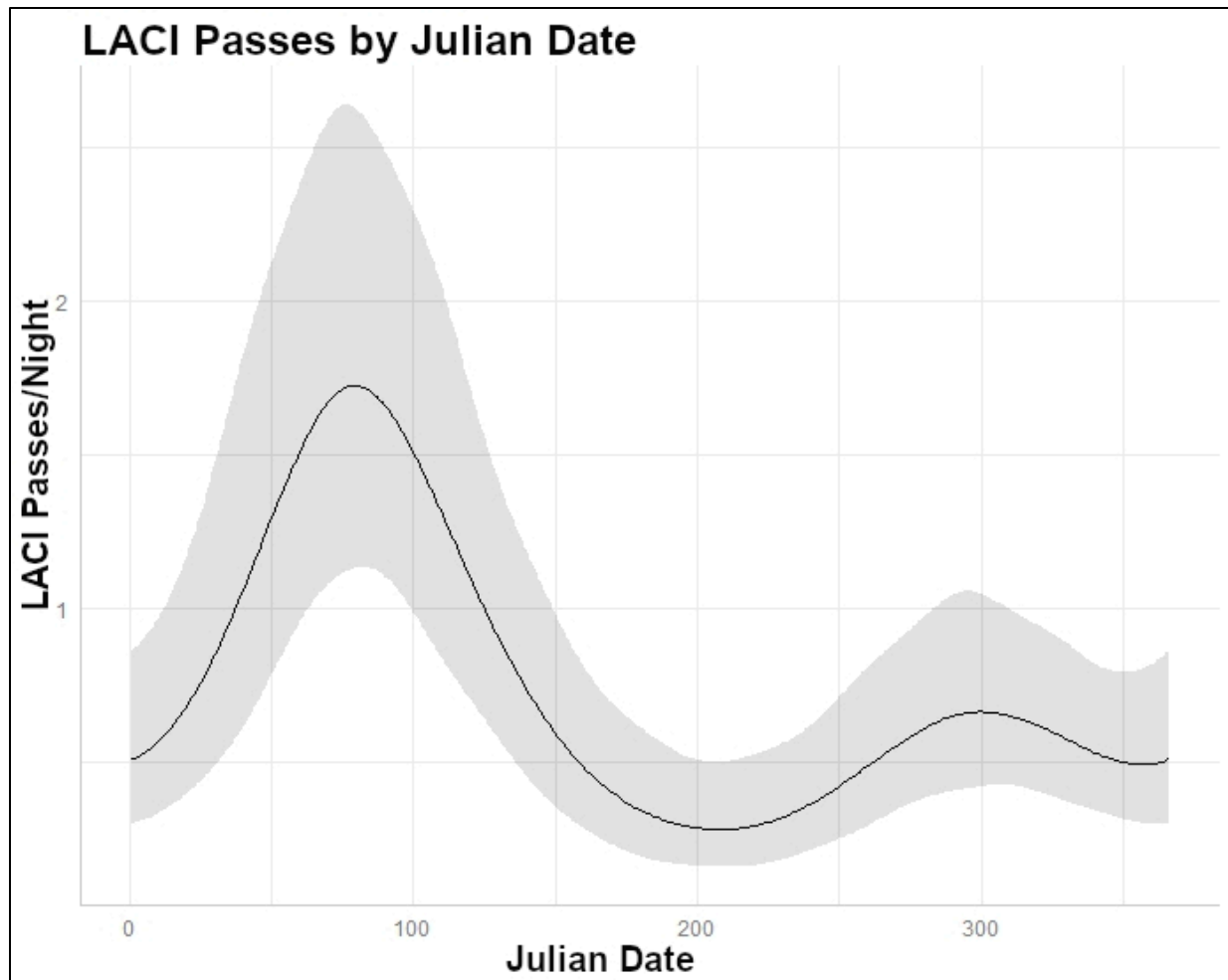


Figure 15. Hoary bat (*Lasiurus cinereus*) activity (mean passes/night) as predicted by a generalized additive model of activity by Julian date at Petersburg National Battlefield, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

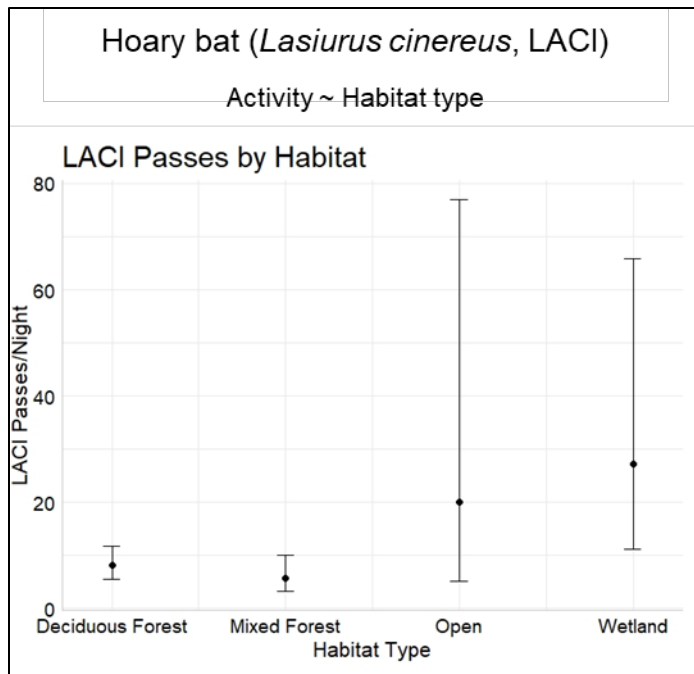


Figure 16. Predicted activity (mean passes per night and standard error) for hoary bats (*Lasiurus cinereus*, LACI) by generalized linear mixed model during summer at Petersburg National Battlefield, Virginia by covariate habitat type.

Silver-haired bat

Silver-haired bats were identified at 12 summer sample sites at low levels except for a few nights of high activity in early May at Eastern Front site PETE02. During the dormant season, activity was also low overall except for sporadic nights of high activity in December, January, and March at PETE01D and PETE10D. The predicted activity of the GAM followed these high activity observations (Figure 17). The GLMM showed higher activity was associated with open and wetland habitats, which was reflective of the few sites that recorded nights of high activity (Figure 18).

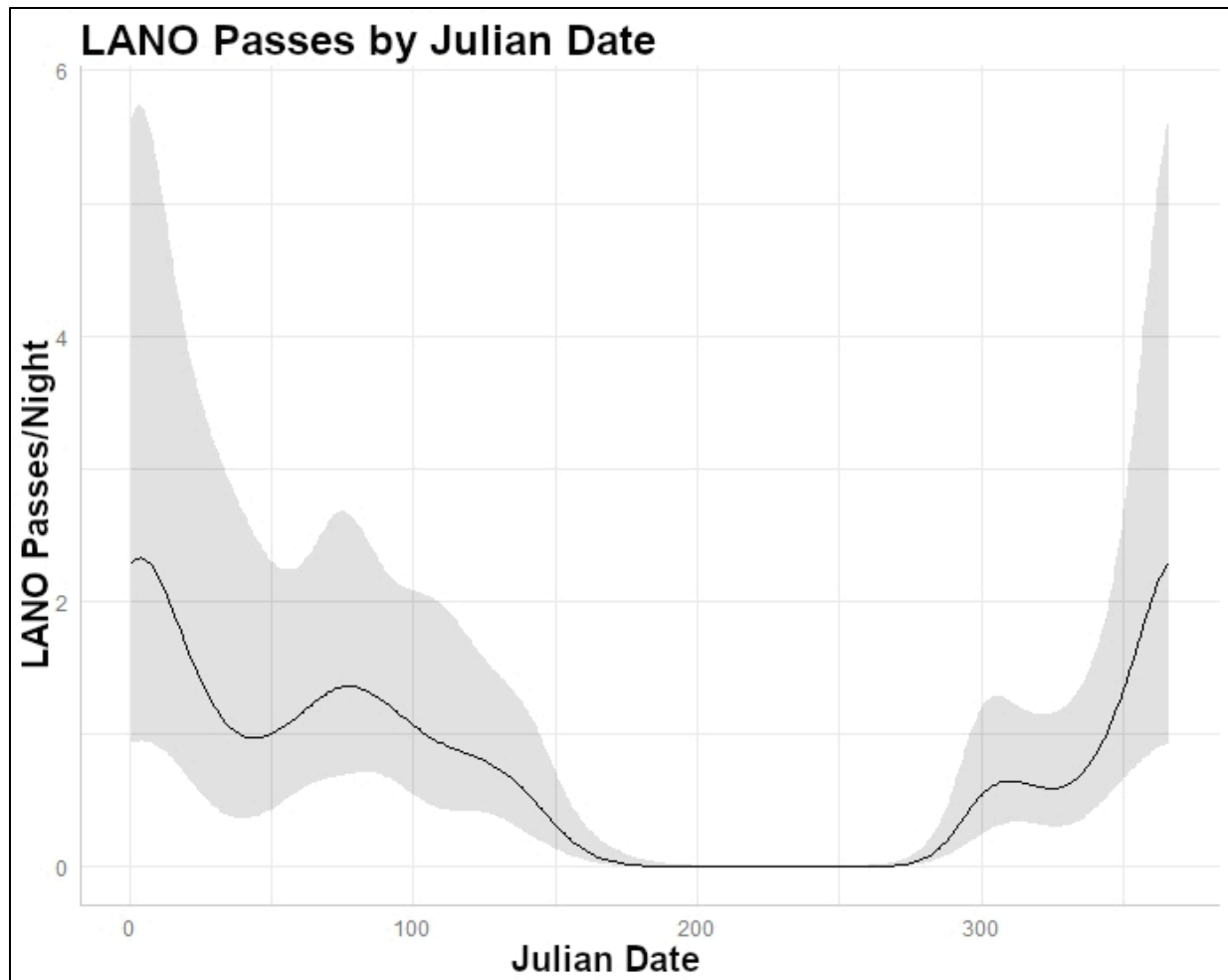


Figure 17. Silver-haired bat (*Lasionycteris noctivagans*) activity (mean passes/night) as predicted by a generalized additive model of activity by Julian date at Petersburg National Battlefield, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

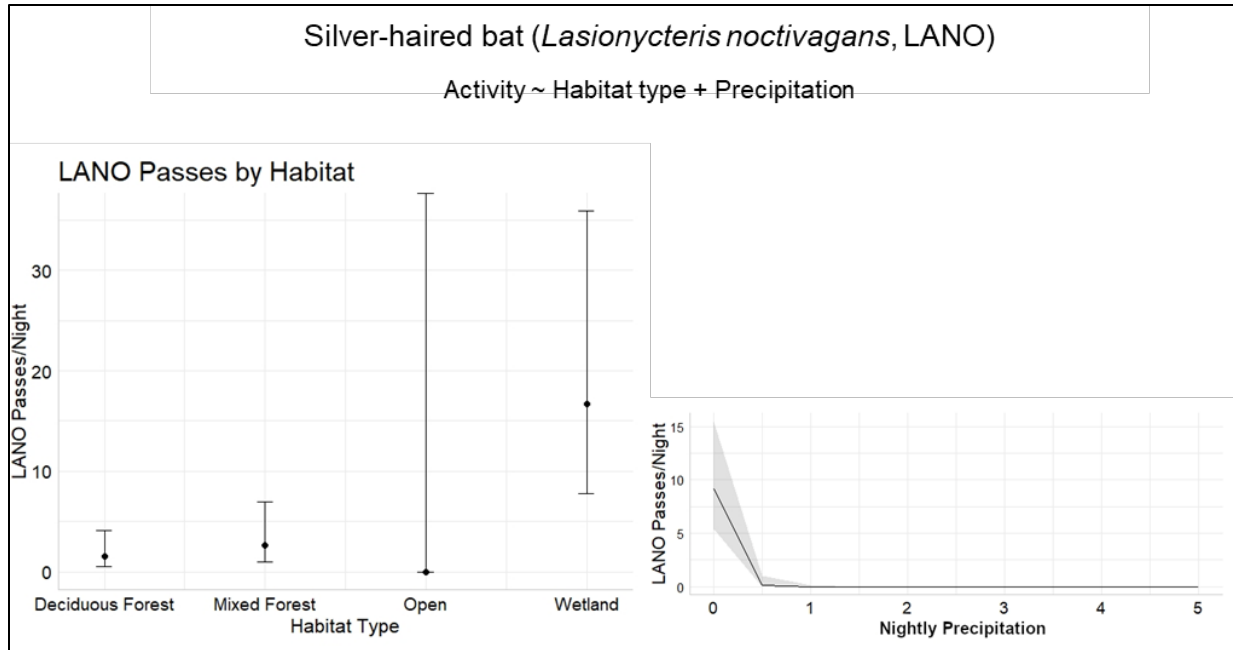


Figure 18. Predicted activity (mean passes per night and standard error) for silver-haired bats (*Lasionycteris noctivagans*, LANO) by generalized linear mixed model during summer at Petersburg National Battlefield, Virginia by covariates: habitat type and nightly precipitation (cm).

Evening bat

Evening bats were identified at 18 summer sites at varying levels of activity. Highest activity was identified at Five Forks site PETE28 and Eastern Front Sites PETE05D and PETE21. The GAM of activity showed it occurred mostly during summer, increasing in early April, peaking in late May, then declining through September (Figure 19). Evening bats were observed at low levels through fall and during winter at the Eastern Front (PETE01D). The GLMM showed activity was highest in deciduous forest habitats and lowest at wetland sites (Figure 20).

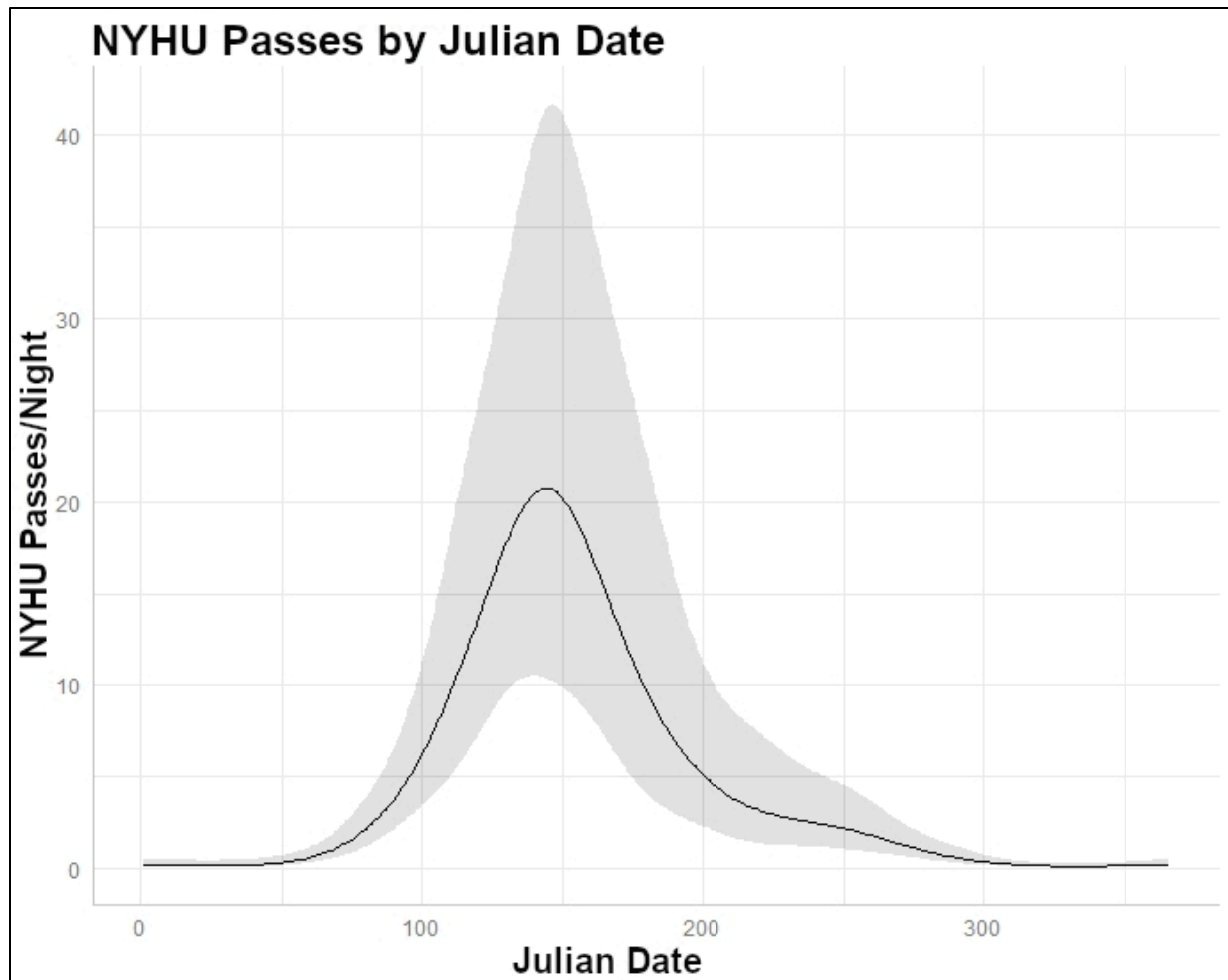


Figure 19. Evening bat (*Nycticeius humeralis*) activity (mean passes/night) predicted by a generalized additive model of activity by Julian date at Petersburg National Battlefield, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

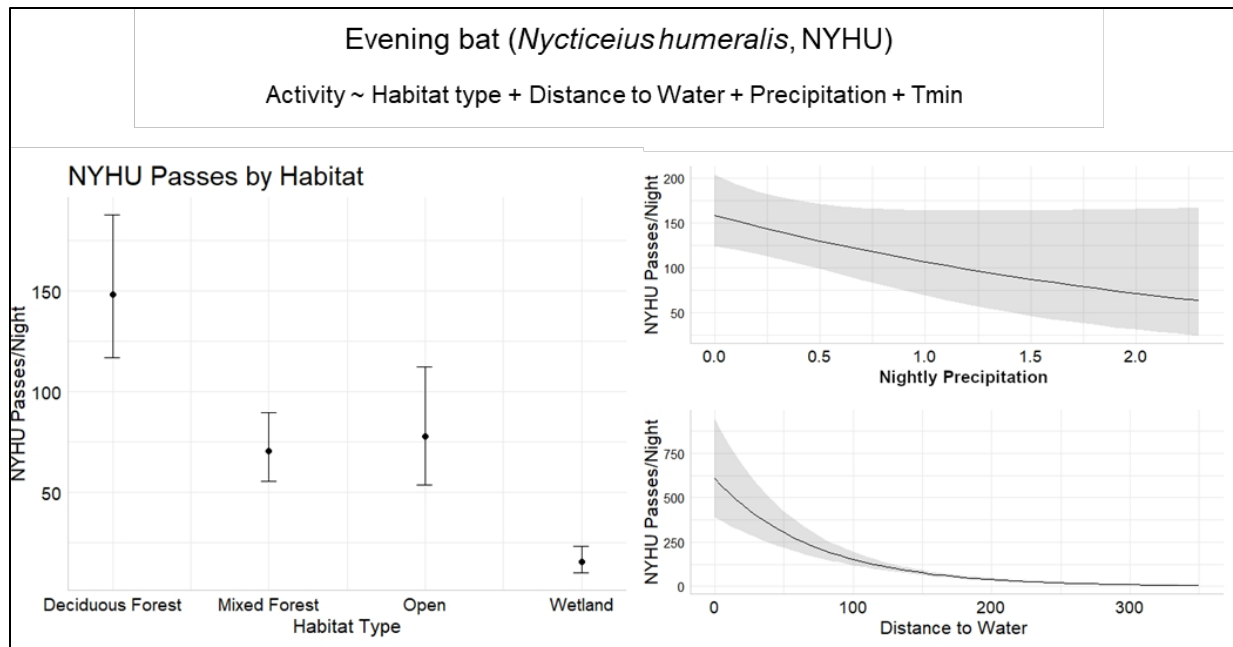


Figure 20. Predicted activity (mean passes per night and standard error) for evening bats (*Nycticeius humeralis*, NYHU) by generalized linear mixed model during summer at Petersburg National Battlefield, Virginia by covariates: habitat type, distance to water (m), and nightly precipitation (cm).

Mexican free-tailed bat

Mexican free-tailed bats were identified at less than half of summer sites at mostly low levels but did appear to occur regularly at PETE21, PETE06, and PETE02. During winter, there were several nights in December and January in which over 200 passes were recorded. The GAM predicted activity to be highest in the winter in response to these high activity nights and also showed increased activity in mid-July (Figure 21). The GLMM found activity to be highest in open habitats (Figure 22).

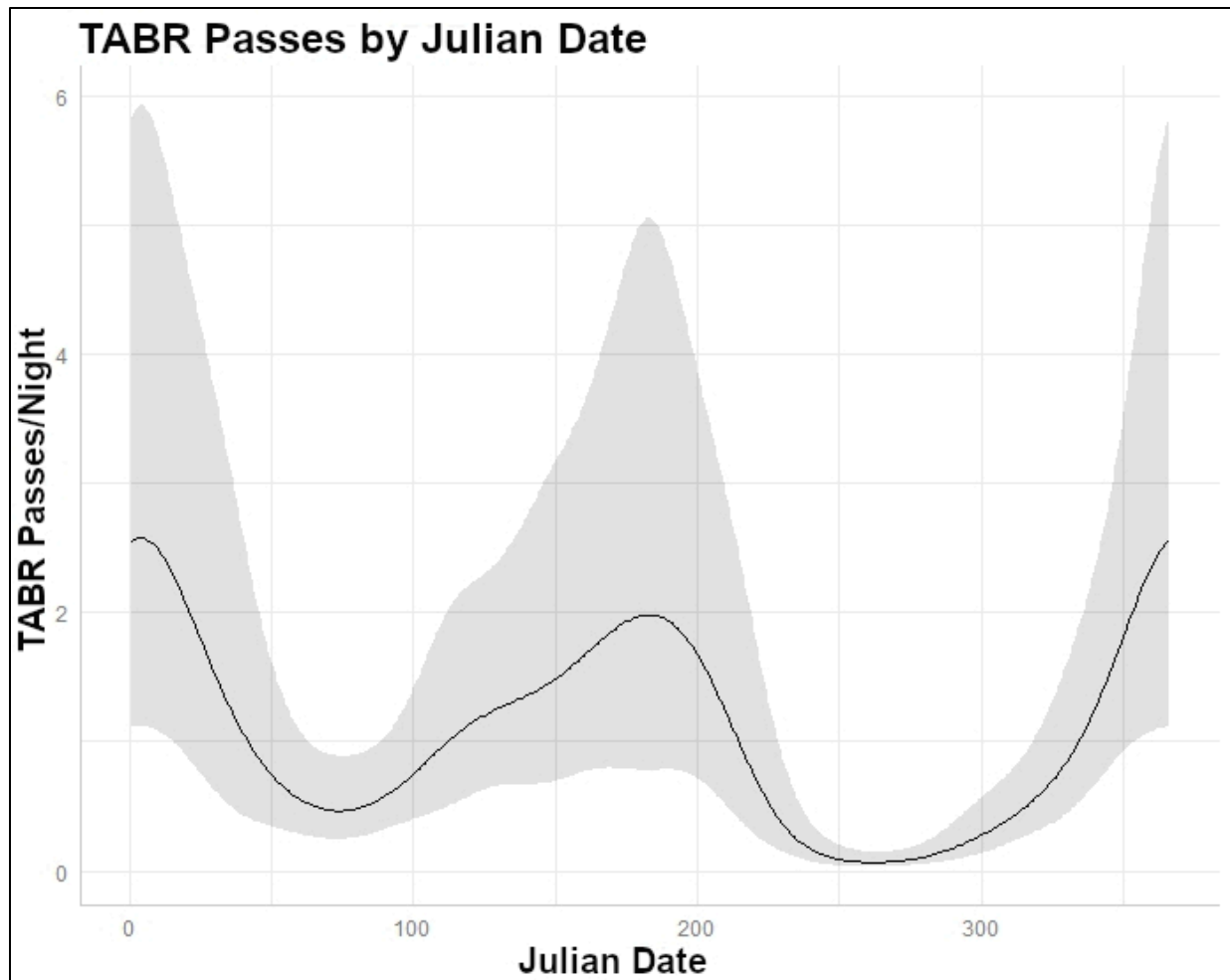


Figure 21. Mexican free-tailed bat (*Tadarida brasiliensis*) activity (mean passes/night) predicted by a generalized additive model of activity by Julian date at Petersburg National Battlefield, Virginia. Julian Day 100 = April 10; 200 = July 19; 300 = October 27.

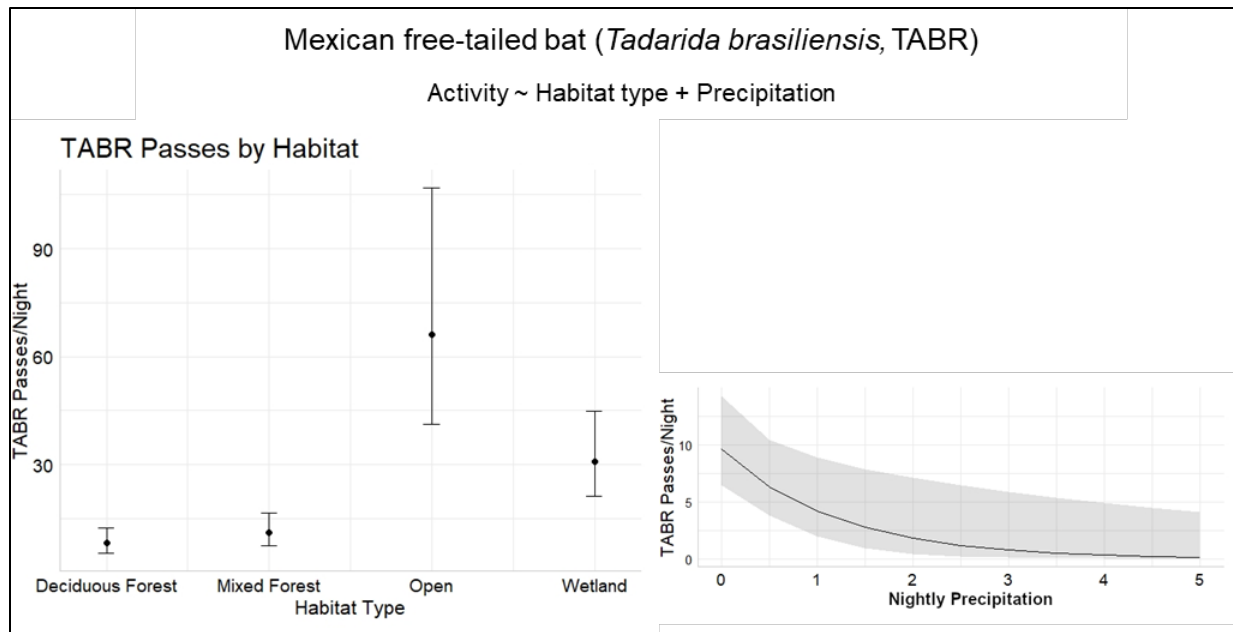


Figure 22. Predicted activity (mean passes per night and standard error) for Mexican free-tailed bat (*Tadarida brasiliensis*, TABR) by generalized linear mixed model during summer at Petersburg National Battlefield, Virginia by covariates: habitat type and nightly precipitation (cm).

Capture Survey

I captured four bat species during capture surveys: big brown, eastern red, evening, and little brown bats from 2016-2019 (Table 5; Appendix D). Capture surveys could not be completed in 2020 due to a national moratorium on bat capture surveys in light of potential transmission of COVID-19 to native bats. I conducted capture surveys on 15 nights at five sites, targeting 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 attempting to confirm presence of *Myotis* species identified in acoustic surveys and documented a single male little brown bat on June 6, 2018 at Five Forks (PETE25/PETE08D/PETE-N03; cover photo).

I captured big brown and eastern red bats on most occasions. Captures included several reproductive female and big brown and eastern red bats indicating maternity colonies of each species were present or nearby the Eastern Front and Five Forks. Three evening bats were captured over the course of sampling including one juvenile male at the Eastern Front.

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

Net Site	Parcel ¹	Date	EPFU ²		LABO ²		MYLU ²		NYHU ²	
			# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³
PETE-N01	EF	7/7/2016	3	AM, NR	0	–	0	–	0	–
	EF	7/7/2016	1	AF, L		–		–		–
	EF	7/18/2016	4	AM, NR	0	–	0	–	1	JM, NR
	EF	7/18/2016	3	AF, L	0	–	0	–	0	–
	EF	7/18/2016	1	JF, NR	0	–	0	–	0	–
	EF	8/4/2016	3	AM, NR	1	AM, D	0	–	1	AM, D
	EF	8/4/2016	3	AM, D	0	–	0	–	0	–
	EF	8/4/2016	1	AF, PL	0	–	0	–	0	–
	EF	8/4/2016	1	AF, NR	0	–	0	–	0	–
PETE-N01	EF	5/9/2017	1	AM, NR	6	AF, U	0	–	0	–
	EF	5/9/2017	1	AF, NR	0	–	0	–	0	–
	EF	5/10/2017	2	AF, U	0	–	0	–	0	–
	EF	5/10/2017	1	AM, NR	0	–	0	–	0	–
	EF	7/20/2017	5	AM, NR	1	AF, NR	0		0	
	EF	7/20/2017	1	AF, PL	2	AM, NR	0	–	0	–
	EF	7/20/2017	1	AF, NR	0	–	0	–	0	–

¹ Units: EF= Eastern Front, FF= Five Forks.

² Species: EPFU = big brown bat (*Eptesicus fuscus*), LABO = eastern red bat (*Lasiurus borealis*), MYLU = little brown bat (*Myotis lucifugus*), 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.

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

Net Site	Parcel ¹	Date	EPFU ²		LABO ²		MYLU ²		NYHU ²	
			# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³
PETE-N01 (continued)	EF	8/2/2017	1	AM, NR	3	AM, NR	0		1	AM, D
	EF	8/2/2017	1	AF, NR	1	AF, NR	0	–	0	–
PETE-N02	EF	8/3/2017	2	AM, NR	2	AM, NR	0	–	0	–
	EF	8/3/2017	2	AF, NR	2	AF, NR	0	–	0	–
	EF	8/3/2017	1	AF, PL	1	JM, NR	0	–	0	–
PETE-N03	FF	6/6/2018	5	AF, U	5	AF, U	1	AM, NR	0	–
	FF	6/6/2018	3	AF, L	1	AF, L	0	–	0	–
	FF	6/6/2018	2	AM, NR	1	AF, P	0	–	0	–
	FF	6/7/2018	1	AF, U	0	–	0	–	0	–
	FF	6/7/2018	1	AM, NR	0	–	0	–	0	–
PETE-N01	EF	3/20/2019	0	–	0	–	0	–	0	–
	EF	4/16/2019	0	–	3	AM, NR	0	–	0	–
	EF	4/16/2019	0	–	1	AF, U	0	–	0	–
PETE-N03	FF	4/18/2019	0	–	3	AM, NR	0	–	0	–
	FF	4/18/2019	0	–	1	AF, U	0	–	0	–

¹ Units: EF= Eastern Front, FF= Five Forks.

² Species: EPFU = big brown bat (*Eptesicus fuscus*), LABO = eastern red bat (*Lasiurus borealis*), MYLU = little brown bat (*Myotis lucifugus*), 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.

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

Net Site	Parcel ¹	Date	EPFU ²		LABO ²		MYLU ²		NYHU ²	
			# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³	# Captured	Age & Sex ³
PETE-N04	EF	10/1/2019	2	AF, NR	0	–	0	–	0	–
	EF	10/1/2019	1	AM, D	0	–	0	–	0	–
PETE-N05	EF	10/17/2019	0	–	0	–	0	–	0	–

¹ Units: EF= Eastern Front, FF= Five Forks.

² Species: EPFU = big brown bat (*Eptesicus fuscus*), LABO = eastern red bat (*Lasiurus borealis*), MYLU = little brown bat (*Myotis lucifugus*), 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.

Discussion

Acoustic results identified a community of nine species of bats that occur at PETE. Generally, cave bat species: big brown, little brown, Indiana, 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. Migratory species eastern red bats and evening bats exhibited highest activity during the summer as well. Migratory species hoary bats, silver-haired bats, and Mexican free-tailed bats exhibited highest nightly activity in the dormant season, indicating PETE may be more important as a migratory stopover or wintering site, rather than for summer maternity habitat for these species. Interestingly, all species except for Indiana bats appeared to occur, albeit at 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, evening, and tricolored bats at PETE are supported by findings of Grider *et al* (2016), who observed all of these species wintering south of PETE in the Coastal Plain of northeastern North Carolina. Tree bat species eastern red, hoary, and silver-haired bat have 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 and Chesterfield County 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 PETE 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.

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 are more associated with open habitats and smaller, more maneuverable and clutter-adapted bats being more 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 PETE. 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 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 oak in Missouri and oaks in Maryland (Agosta 2002, Timponi et al. 2006).

Prevalence and abundance of acoustic detections and captures throughout PETE indicate their populations have not been severely impacted by WNS, although comparative data of pre-WNS detection rates at PETE 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 open 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). It is also considered a habitat generalist overall and is likely to occur all habitats (Agosta 2002, Duchamp et al. 2004).

Sharp increases in activity in late March and early April suggest the end of their hibernation period and increased activity by local residents and regional migrants. Sustained dormant season activity through winter months at the Eastern Front suggests at least some individuals remain nearby and utilize areas of the park. Big brown bats are known to hibernate in anthropogenic structures so winter occurrences at the Eastern Front 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 July is likely related to reproduction based on capture results (Deeley et al. 2022).

Big brown bats were the most commonly captured species during capture surveys and were documented on most netting occasions. Captures of reproductive females and juveniles indicate

maternity colonies with active recruitment at or nearby locations at both the Eastern Front and Five Forks. Results suggest big brown bats are maintaining abundant populations following WNS, and that they utilize PETE 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 PETE, however, manual 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.

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 diagnostic little brown bat echolocation calls and captured a single male little brown bat at Five Forks in 2018, where very high levels of acoustic activity were identified. Only one little brown bat was captured whereas seven eastern red bats were captured that night, further supporting the misidentification of eastern red bats by acoustic software. Little brown bats do occur at PETE, but likely at low levels of abundance. Both the Eastern Front and Five Forks should be considered areas of use from a conservation perspective, and winter occurrence of little brown bats at the Eastern Front is likely. 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 and Chesterfield County (VA Department of Energy 2022) or farther west in the Ridge and Valley. 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 habitats during summer. Forest habitat associations correspond with previous observations of little brown bats (Fenton and Barclay 1980, Ford et al. 2005). 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 (Francl 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 (Barbour 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 of 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 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 now faces potential extirpation (Frick et al. 2015, Reynolds et al. 2016, Turner et al. 2011). Northern long-eared bats have been reclassified as an endangered species in 2022 (USFWS 2022a). 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 PETE was an important objective in this study.

Northern long-eared bat activity was identified at low to moderate levels, but review of identified calls found all to be misidentifications and no calls were validated as being northern long-eared bats. Most misidentifications were attributable to feeding buzz calls of eastern red bats. A smaller portion appeared to be misidentifications of little brown bats. Results of acoustic identifications of northern long-eared bats were included in tables, but northern long-eared bats appeared absent from PETE based on thorough review of identified calls.

Although they were not documented throughout this extensive multi-year survey, northern long-eared bats should continue to be considered for potential occurrence at PETE in the future. 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 PETE, and Marine Corps Base-Quantico to the north of PETE and Shenandoah National Park to the west of PETE (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 35 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 PETE. 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 PETE 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 PETE 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 post-WNS in Caroline County, VA approximately 60 miles north of PETE, where an active maternity colony was identified, supporting its possible summer occurrence at PETE (St. Germain et al. 2017).

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 PETE and are typically 77-89 mm long, weigh between 4-8 g, and have a wingspan of 210 to 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 are state endangered in Virginia (USFWS 2022b, Straw et al. 2022, VDGIF 2016).

Identification of tricolored bat calls by Kaleidoscope is generally highly accurate, so results and analysis are more reliable for this species. They were identified at most sample sites at both the Eastern Front and Five Forks during the summer and were observed at moderate levels of activity at several sites indicating PETE is important summer habitat for persisting populations in the area.

Habitat type was not significant in predicting activity in the GLMM. High variance of nightly activity among habitat types resulted in overlapping standard errors of model-predicted activity means by habitat type so no significant habitat associations could be interpreted. Historically, tricolored bats have been observed foraging over waterways and ponds and associated with wetland and riparian habitats (Ford et al. 2005, Fujita and Kunz 1984).

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 could be associated with reproduction, specifically either increased foraging during lactation or increased abundance following juvenile volancy (Fujita and Kunz 1984). During the dormant season, activity was very low and sporadic. Passes recorded from December through February at the Eastern Front suggest some individuals are wintering nearby. Tricolored bats are known to hibernate in a variety anthropogenic structures and have been observed wintering in Caroline County, VA approximately 60 miles north of PETE 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 and 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 both the Eastern Front and Five Forks during the summer. I captured reproductive females at Five Forks and a juvenile at the Eastern Front showing active recruitment at both locations. Parturition appears to occur in mid-June based on timing of capture of pregnant and lactating females in early June.

The GLMM for eastern red bats showed activity was highest in coniferous and mixed forests, which resulted from several sites recording high activity levels at Five Forks, which is mostly loblolly pine. This is contrary to other findings of eastern red bats being more associated with open and moderately-cluttered habitats, which correspond with 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 mid-June, which aligns with the lactation phase based on capture results (Deeley et al. 2022). GAM predicted activity decreased greatly in mid-July, suggesting some summer residents emigrated during this time. Fall, winter, and spring activity indicated some individuals wintered locally to the Eastern Front, 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 PETE 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 mid-March and early April that recorded very high activity levels at Eastern Front site PETE16D. 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 PETE through the summer and occur at both 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 associated with open habitats, which is consistent with their ecology (Ford et al. 2005). Higher activity was also associated with wetland and riparian habitats because of high activity observed at site PETE16D, which was adjacent a stream. Temporally, the GAM showed predicted activity peaking during mid-March, which reflects instances of very high activity 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).

Interestingly, highest activity occurred on isolated nights in December, January, and March at the Eastern Front (PETE01D and PETE10D) suggesting that PETE is an important overwintering destination for silver-haired bats, or at least a migratory stop (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). Further, summer calls identified as silver-haired bats may in fact be misidentifications of big brown bats (Austin et al. 2020). The GLMM predicted highest activity in open and wetland and riparian habitats, however, this was attributable to incidences of isolated high activity at sites PETE01D and PETE10D, and did not appear to be representative of silver-haired activity patterns throughout the dataset.

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 have increased presence from early April through August and are somewhat common at the Eastern Front and Five Forks. There were three captures of evening bats at the Eastern Front including a juvenile male in mid-July, suggesting parturition likely occurred in mid-June or earlier. Declines in acoustic activity in the fall suggest most summer inhabitants migrate away from PETE to winter. However, sustained activity at Eastern Front sites PETE01D and PETE02D through February indicates some individuals winter near these sites. Similar to big brown bats, evening bats may be wintering in buildings nearby (Boyles et al. 2006). The GLMM showed activity was fairly high among habitat types except wetland and riparian forest habitats where it was lowest.

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 in trees (Wilkins 1989). Mexican free-tailed bats have recently expanded their range into Virginia (McCracken et al. 2018).

Acoustic results indicate that Mexican free-tailed bats occur at mostly low levels, but that migratory groups pass through in December and January. Although winter passes were mostly observed at high levels on these sporadic, individual nights, there was also sustained activity at lower levels at the Eastern Front (e.g. PETE11D) that suggest some Mexican free-tailed bats winter locally. Their potential for wintering locally is supported by a record of a Mexican free-tailed bat in February 2015 from Henrico County, Virginia, approximately 50 miles northwest of PETE (McCracken et al. 2018). Higher activity in late June suggests some summer residence and potentially local recruitment (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 PETE. Although acoustic results included high levels of activity identified as little brown bats, high rates of misidentifications and a single capture in the course of targeted mist-netting suggest this previously common species now occurs at low abundances at PETE. Acoustic misidentifications were also problematic for federally endangered northern long-eared bats and Indiana bats that were identified at much lower levels. Review of identified calls invalidated identifications of northern long-eared bats but could not rule out the validity of Indiana bat passes. Presence of Indiana bats remains questionable, however, as very few calls passed validation and similarities with little brown bat calls make confident identification difficult. Tricolored bats seem to be somewhat common during the summer. Northern long-eared bats do not appear to occur in any season.

Considerations for future bat research should include continued effort to confirm or disprove the presence of Indiana bats, further investigate the occurrence of little brown bats, and continue to consider potential occurrence of northern long-eared bats. Additional species such as the southeastern myotis (*Myotis austroriparius*), the Seminole bat (*Lasiurus seminolus*), and Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) have potential to expand to PETE and should also 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 PETE (VAFWIS 2022).

The forests and natural habitats preserved in the Eastern Front and Five Forks are important bat habitats, especially in the case of the Eastern Front, where surroundings are becoming increasingly urbanized. Management practices should include consideration for bat species use of these diverse habitats. Mixed forests appear to be important for foraging habitat for little brown bats. Mixed and deciduous forests are requisite for the roosting of all bat species that occur. Open habitats and forest edges are important for big brown, eastern red, hoary, and Mexican free-tailed bats as foraging habitat. Riparian habitats and ponds are important as water sources and supporting insect prey. Standing snags should be retained where safe because many species, including federally protected 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 Indiana bats during the maternity season. Management practices during the dormant season should be considerate of potential dormant season and winter occurrences of bats

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Appendix A: Acoustic and Capture Survey Site Coordinates

Table A-1. Acoustic and capture survey sample site coordinates of bats in NAD 1983 UTM Zone 18N, Petersburg National Battlefield, Virginia.

Site ID	Latitude	Longitude	Y Projected	X Projected
PETE01	37.245863	-77.357765	4124751.5370	290876.9749
PETE02	37.226635	-77.354965	4122611.7550	291072.2655
PETE03	37.234659	-77.364237	4123522.6320	290271.7872
PETE04	37.228416	-77.372417	4122848.0500	289528.6734
PETE05	37.219978	-77.377779	4121923.6810	289029.3848
PETE06	37.134699	-77.621291	4113031.0290	267157.8520
PETE07	37.138629	-77.62672	4113480.4770	266687.5949
PETE08	37.152772	-77.615688	4115022.8010	267710.9682
PETE09	37.151642	-77.611826	4114887.9500	268050.5479
PETE10	37.141604	-77.637211	4113836.4730	265764.7567
PETE11	37.144452	-77.630639	4114136.2930	266357.3573
PETE12	37.143156	-77.61524	4113954.6390	267721.3282
PETE13	37.246813	-77.356485	4124854.1230	290993.1480
PETE14	37.233301	-77.352715	4123346.4680	291290.2980
PETE15	37.232358	-77.363811	4123266.3610	290303.2056
PETE16	37.217456	-77.37151	4121629.8780	289578.6837
PETE17	37.243345	-77.35857	4124473.9110	290798.5992
PETE18	37.236878	-77.354301	4123746.8820	291159.4565
PETE19	37.230287	-77.359337	4123026.6520	290694.4323
PETE20	37.2295	-77.364748	4122951.3060	290212.1466
PETE21	37.223034	-77.370002	4122245.4780	289728.0029
PETE22	37.148046	-77.624769	4114520.6610	266889.8470
PETE23	37.149871	-77.619223	4114709.5530	267388.0853
PETE24	37.138338	-77.616254	4113422.4830	267616.5000
PETE25	37.139037	-77.632661	4113540.3870	266161.0543
PETE26	37.14775	-77.621636	4114480.1140	267167.2390
PETE27	37.144421	-77.628312	4114127.1210	266563.9763
PETE28	37.137948	-77.618919	4113385.7410	267378.5464
PETE29	37.143318	-77.631048	4114011.4640	266317.5329

Table A-1 (continued). Acoustic and capture survey sample site coordinates of bats in NAD 1983 UTM Zone 18N, Petersburg National Battlefield, Virginia.

Site ID	Latitude	Longitude	Y Projected	X Projected
ETE30	37.245145	-77.354611	4124664.8980	291154.7803
PETE31	37.241095	-77.354517	4124215.2900	291151.9360
PETE32	37.229335	-77.374196	4122953.9830	289373.3812
PETE33	37.222652	-77.3668	4122195.9820	290011.0758
PETE34	37.243107	-77.354374	4124438.2320	291170.1773
PETE35	37.228645	-77.353705	4122832.0090	291189.6134
PETE36	37.237025	-77.359459	4123774.5910	290702.2477
PETE37	37.234206	-77.368263	4123481.2960	289913.3333
PETE38	37.225078	-77.368818	4122469.6570	289838.7421
PETE39	37.226386	-77.372671	4122623.3600	289500.4895
PETE40	37.218745	-77.368424	4121766.0530	289856.1215
PETE41	37.146527	-77.620397	4114341.3590	267273.5474
PETE42	37.135892	-77.614305	4113146.2820	267782.1667
PETE43	37.141388	-77.625899	4113784.6170	266769.0100
PETE01D	37.246631	-77.357404	4124835.9590	290911.1222
PETE02D	37.238857	-77.356532	4123971.4040	290966.9917
PETE03D	37.234694	-77.363287	4123524.4100	290356.1703
PETE04D	37.229452	-77.374099	4122966.7500	289382.3135
PETE05D	37.245014	-77.354204	4124649.4630	291190.5235
PETE06D	37.232511	-77.363991	4123283.7380	290287.6592
PETE07D	37.150792	-77.627725	4114832.6520	266635.7148
PETE08D	37.139017	-77.632889	4113538.7300	266140.7373
PETE09D	37.138271	-77.618767	4113421.2100	267393.0399
PETE10D	37.242527	-77.356767	4124379.1580	290956.2860
PETE11D	37.230893	-77.354056	4123082.2280	291164.6735
PETE12D	37.153115	-77.616998	4115064.0740	267595.6608
PETE13D	37.146192	-77.62046	4114304.3390	267266.9237
PETE14D	37.143792	-77.630168	4114061.8940	266397.1661
PETE15D	37.239528	-77.357775	4124048.6070	290858.5714
PETE16D	37.233202	-77.352491	4123334.9890	291309.8991
PETE17D	37.231533	-77.364516	4123176.3790	290238.3674

Table A-1 (continued). Acoustic and capture survey sample site coordinates of bats in NAD 1983 UTM Zone 18N, Petersburg National Battlefield, Virginia.

Site ID	Latitude	Longitude	Y Projected	X Projected
PETE18D	37.234239	-77.368232	4123484.8890	289916.1753
PETE19D	37.224849	-77.368896	4122444.4200	289831.1850
PETE20D	37.226289	-77.372525	4122612.2720	289513.1747
PETE-N01	37.234636	-77.364601	4123520.8860	290239.4285
PETE-N02	37.229337	-77.37415	4122954.1030	289377.4682
PETE-N03	37.139225	-77.632652	4113561.2270	266162.4331
PETE-N04	37.245879	-77.355592	4124748.5110	291069.7837
PETE-N05	37.230734	-77.354143	4123064.7770	291156.5155

Appendix B: Crosswalk Table for Habitat Classification

Table B-1. Crosswalk of U.S. National Vegetation Classification Habitat Classes to general habitat classes used in generalized linear mixed models of nightly bat activity at Petersburg National Battlefield.

U.S. National Vegetation Classification Habitat Class¹	General Habitat Class
Acidic Oak - Hickory Forest	Deciduous forest
Barren Land	Open
Beaver Wetland Complex	Wetland
Coastal Plain / Piedmont Acidic Seepage Swamp	Wetland
Coastal Plain / Piedmont Floodplain Swamp Forest (Mixed Oak - Red Maple Type)	Wetland
Coastal Plain / Piedmont Small-Stream Floodplain Forest	Wetland
Coastal Plain Mixed Oak / Heath Forest	Coniferous Forest
Cultural Meadow	Open
Disturbed Calcareous Forest	Deciduous forest
Forested Earthworks	Deciduous forest
Loblolly Pine - Hardwood Forest	Coniferous Forest
Loblolly Pine Plantation / Early-Successional Loblolly Pine Forest	Coniferous Forest
Mesic Mixed Hardwood Forest	Deciduous forest
Open Earthworks	Open
Other Urban or Built-up Land	Open
Semipermanent Impoundment	Wetland
Successional Mixed Scrub	Open
Successional Sweetgum Forest	Deciduous forest
Successional Tuliptree Forest	Deciduous forest
Transportation, Communications, and Utilities	Open

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

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 Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
Intercept – Deciduous Forest	3.0178	0.3802	7.937	< 0.0001
Habitat – Coniferous/Mixed Forest	0.5370	0.1201	-3.700	0.0002
Habitat – Open	1.6162	0.0057	5.539	< 0.0001
Habitat – Wetland	-0.9338	0.1842	-5.070	< 0.0001
Distance to Water	-0.0025	0.0007	-3.700	0.0002
Precipitation	-0.5668	0.1171	-4.841	< 0.0001
Minimum Temperature	0.0127	0.0057	2.229	0.0258

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

Parameter	Estimate	Standard Error	Z Value	P-Value
Intercept – Julian Date	1.5373	0.0493	31.200	< 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 Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
Intercept – Deciduous Forest	2.1882	0.1259	17.383	< 0.0001
Habitat – Coniferous/Mixed Forest	1.2223	0.1532	7.976	< 0.0001
Habitat – Open	0.2270	0.3442	0.659	0.5100
Habitat – Wetland	0.2232	0.1788	1.248	0.2120
Distance to Water	0.0051	0.0007	7.569	< 0.0001
Precipitation	-0.7549	0.1268	-5.954	< 0.0001

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

Parameter	Estimate	Standard Error	Z Value	P-Value
Intercept – Julian Date	0.9594	0.0608	15.770	< 0.0001

Indiana bat (*Myotis sodalis*, MYSO)

Table C-5 and Table C-6 show the activity model parameters for Indiana bat.

Table C-5. Generalized linear mixed model (GLMM) parameter estimates of Indiana bat (*Myotis sodalis*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Deciduous Forest)	0.9275	0.4753	1.952	0.0510
Habitat – Coniferous/Mixed Forest	0.1822	0.2507	0.727	0.4670
Habitat – Open	0.6040	0.5250	1.150	0.0250
Habitat – Wetland	-0.3230	0.2615	-1.235	0.2170
Minimum Temperature	0.0305	0.0076	3.986	< 0.0001

Table C-6. Generalized additive model (GAM) parameter estimate of Indiana bat (*Myotis sodalis*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	-2.3996	0.1643	-14.60	< 0.0001

Tricolored bat (*Perimyotis subflavus*, PESU)

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

Table C-7. Generalized linear mixed model (GLMM) parameter estimates of tricolored bat (*Perimyotis subflavus*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Deciduous Forest)	2.2258	0.4233	5.329	< 0.0001
Habitat – Coniferous/Mixed Forest	-0.1249	0.2217	-0.564	0.5730
Habitat – Open	-0.2275	0.3945	-0.577	0.5641
Habitat – Wetland	-0.3580	0.2352	-1.522	0.1280

Table C-7 (continued). Generalized linear mixed model (GLMM) parameter estimates of tricolored bat (*Perimyotis subflavus*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
Distance to Water	0.0029	0.0010	2.979	0.0029
Minimum Temperature	0.0136	0.0060	2.256	0.0241
Precipitation	-0.6575	0.1785	-3.684	0.0002

Table C-8. Generalized additive model (GAM) parameter estimate of tricolored bat (*Perimyotis subflavus*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	-0.3286	0.1138	-2.889	0.0038

Eastern red bat (*Lasiurus borealis*, LABO)

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

Table C-9. Generalized linear mixed model (GLMM) parameter estimates of eastern red bat (*Lasiurus borealis*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Deciduous Forest)	2.9820	0.3512	8.492	< 0.0001
Habitat – Coniferous/Mixed Forest	0.6338	0.1368	4.634	< 0.0001
Habitat – Open	-0.2384	0.3012	-0.791	0.4287
Habitat – Wetland	-1.0989	0.1962	-5.601	< 0.0001
Precipitation	-0.5081	0.1447	-3.510	0.0004
Minimum Temperature	0.0105	0.0051	2.077	0.0378

Table C-10. Generalized additive model (GAM) parameter estimate of eastern red bat (*Lasiurus borealis*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	0.6001	0.0612	9.799	< 0.0001

Hoary bat (*Lasiurus cinereus*, LACI)

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

Table C-11. Generalized linear mixed model (GLMM) parameter estimates of hoary bat (*Lasiurus cinereus*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Deciduous Forest)	2.0958	0.1872	11.195	< 0.0001
Habitat – Coniferous/Mixed Forest	-0.3426	0.3202	-1.070	0.2846
Habitat – Open	0.9057	0.7077	1.280	0.2006
Habitat – Wetland	1.2102	0.4769	2.538	0.0112

Table C-12. Generalized additive model (GAM) parameter estimate of hoary bat (*Lasiurus cinereus*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	-0.3233	0.1058	-3.057	0.0022

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

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

Table C-13. Generalized linear mixed model (GLMM) parameter estimates of silver-haired bat (*Lasionycteris noctivagans*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Deciduous Forest)	2.2106	0.2689	8.222	< 0.0001
Habitat – Coniferous/Mixed Forest	0.5406	0.4075	1.327	0.1846
Habitat – Open	-18.978	8777.11	-0.002	0.9983
Habitat – Wetland	2.3909	0.3669	6.517	< 0.0001
Precipitation	-8.9561	2.3764	-3.769	0.0002

Table C-14. Generalized additive model (GAM) parameter estimate of silver-haired bat (*Lasionycteris noctivagans*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	-1.5653	0.2085	-7.506	< 0.0001

Evening bat (*Nycticeius humeralis*, NYHU)

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

Table C-15. Generalized linear mixed model (GLMM) parameter estimates of evening bat (*Nycticeius humeralis*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Deciduous Forest)	6.4800	0.2303	28.142	< 0.0001
Habitat – Coniferous/Mixed Forest	-0.7424	0.1938	-3.830	0.0001
Habitat – Open	-0.6445	0.2222	-2.900	0.0037
Habitat – Wetland	-2.2656	0.2774	-8.167	< 0.0001
Distance to Water	-0.0137	0.0012	-11.275	< 0.0001
Precipitation	-0.3994	0.2261	-1.766	0.0774

Table C-16. Generalized additive model (GAM) parameter estimate of evening bat (*Nycticeius humeralis*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	0.3568	0.1339	2.665	0.0077

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

Table C-17 and Table C-18 show the activity model parameters for Mexican free-tailed bat.

Table C-17. Generalized linear mixed model (GLMM) parameter estimates of Mexican free-tailed bat (*Tadarida brasiliensis*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Deciduous Forest)	2.2610	0.2021	11.189	< 0.0001
Habitat – Coniferous/Mixed Forest	0.3001	0.2913	1.030	0.3029
Habitat – Open	2.0992	0.3293	6.374	< 0.0001
Habitat – Wetland	1.3360	0.2768	4.827	< 0.0001
Precipitation	-0.8345	0.3385	-2.465	0.0137

Table C-18. Generalized additive model (GAM) parameter estimate of Mexican free-tailed bat (*Tadarida brasiliensis*) activity at Petersburg National Battlefield, Virginia.

Parameter	Estimate	Standard Error	Z Value	P-Value
(Intercept – Julian Date)	-0.4329	0.1373	-3.153	0.0016

Appendix D: Capture Survey Sites and Net Arrangements

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

Date	Site	Unit	Description	# of Nets	Placement
7/7/2016	PETE-N01	Eastern Front	Deciduous forest trail with stream	4	3 across trail, 1 adjacent stream
7/18/2016	PETE-N01	Eastern Front	Deciduous forest trail with stream	4	3 across trail, 1 adjacent stream
8/4/2016	PETE-N01	Eastern Front	Deciduous forest trail with stream	4	3 across trail, 1 adjacent stream
5/9/2017	PETE-N01	Eastern Front	Deciduous forest trail with stream	3	2 across trail, 1 across stream
5/10/2017	PETE-N01	Eastern Front	Deciduous forest trail with stream	4	2 across trail, 2 across stream
7/20/2017	PETE-N01	Eastern Front	Deciduous forest trail with stream	4	2 across trail, 2 across stream
8/2/2017	PETE-N01	Eastern Front	Deciduous forest trail with stream	2	2 across trail
8/3/2017	PETE-N02	Eastern Front	Deciduous forest stream	3	2 across stream, 1 across trail
6/6/2018	PETE-N03	Five Forks	Mixed forest trail	2	2 across trail
6/7/2018	PETE-N03	Five Forks	Mixed forest trail	3	3 across trail
3/20/2019	PETE-N01	Eastern Front	Deciduous forest trail with stream	3	2 across trail, 1 across stream
4/16/2019	PETE-N01	Eastern Front	Deciduous forest with stream	4	3 across trail, 1 across stream
4/18/2019	PETE-N03	Five Forks	Mixed forest trail	2	2 across trail
10/1/2019	PETE-N04	Eastern Front	Deciduous forest trail	2	2 across trail
10/17/2019	PETE-N05	Eastern Front	Mixed forest trail	2	2 across trail

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