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Nightly and Yearly Bat Activity Before and After White-nose Syndrome on the Fernow Experimental Forest in West Virginia

Joshua B. Johnson, Jane L. Rodrigue, and W. Mark Ford

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Abstract

In the central Appalachians, conservation concern about bat communities and their population status has become increasingly more significant with the advent and spread of white-nose syndrome (WNS). However, managers often are hampered in their response to WNS by the lack of information on pre-WNS local distribution, abundance, or activity patterns for most bat species. At the Fernow Experimental Forest (FEF), Tucker County, WV, where bat research has been conducted since the mid-1990s, we acoustically monitored bat activity a total of 20 nights each at four sites for 4 years—3 years before and 1 year after WNS was detected—to better assess those local patterns. Within sampling nights, activity of northern myotis (*Myotis septentrionalis*) and big brown bats (*Eptesicus fuscus*) peaked directly after sunset and declined throughout the night, whereas activity of little brown myotis (*Myotis lucifugus*) and Indiana myotis (*Myotis sodalis*) had a unimodal distribution that peaked in the middle of the night. Activity of many bat species differed among sample sites and was highest at a small, artificial pond located on a dry ridgetop. Activity of little brown myotis, northern myotis, and Indiana myotis was lower post-WNS than pre-WNS, consistent with the species' precipitous declines previously reported in WNS-affected areas in the Northeast and upper portions of the Mid-Atlantic.

Cover Photo

Northern myotis. Photo by Jane Rodrigue, U.S. Forest Service.

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INTRODUCTION

Before the outbreak of white-nose syndrome (WNS) in the central Appalachians, researchers had made considerable progress toward a general understanding of bat foraging habitat selection at a variety of spatial scales and landscape conditions for single species as well as entire bat community assemblages (Ford et al. 2005, Francl et al. 2004, Johnson et al. 2012, Owen et al. 2004, Schirmacher et al. 2007). Foraging habitat selection by bats largely is determined by body and wing morphology along with echolocation call characteristics (Kusch and Schotte 2007). Bats with low wing-loading and high-frequency echolocation calls, such as the Indiana myotis (*Myotis sodalis*), typically forage in cluttered areas, such as narrow streams underneath partial to full forest canopies (Ratcliffe and Dawson 2003). Conversely, bats with high wing-loading and low-frequency echolocation calls, such as the hoary bat (*Lasiurus cinereus*), forage in open areas, such as fields and wider streams and rivers (Johnson et al. 2010a). Bats with intermediate wing-loading, such as the eastern red bat (*Lasiurus borealis*), are capable of foraging in a variety of conditions (Ford et al. 2005). Therefore, body morphology and echolocation call characteristics, coupled with roost site selection (Johnson et al. 2009, Johnson et al. 2010b), provide the information necessary for reasonable species-specific predictions about how bats use habitats such as the forested landscapes of the central Appalachians. These predictions are not limited to spatial use of habitat but may include temporal aspects as well.

At the intra-night scale, bat activity typically peaks for several hours just after sunset as bats exit their roosts to forage (Barclay 1982, Kunz 1973). A lesser peak often occurs just before sunrise as bats return to their roosts (Kunz 1973). Bats may intermittently roost at night between foraging bouts, either at their day-roosts or at night-roosts (Henry et al. 2002, Johnson et al. 2002). However, it is not known how these activity budgets and habitat use vary at these smaller intra-night divisions in the central Appalachian region except for hourly activity patterns around northern myotis (*Myotis septenrionalis*) maternity roosts (Johnson et al. 2011).

The recent outbreak of WNS has caused substantial population declines in affected species such as the little brown myotis (*Myotis lucifugus*; Frick et al. 2010) across their distribution range in the Northeast and Mid-Atlantic. Evidence from the Northeast suggests that reduced numbers of little brown myotis following WNS have altered the spatial extent of their foraging patterns (C.A. Dobony, U.S. Army, Fort Drum Military Reservation, personal communication). Consequently, it is becoming increasingly important to determine if spatiotemporal patterns of bat habitat use are similar pre- and post-WNS and if reductions in overall bat abundance display changes in resource selection.

In this report, we evaluated species-specific bat activity at a variety of water sources on the Fernow Experimental Forest (FEF) in West Virginia before and after WNS onset in the local area. The objectives of our study were to (1) examine if species-specific bat activity was partitioned predictively along habitat contrasts, i.e., type of water source, amount of clutter, and landscape position relative to bat species' morphological

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characteristics; (2) determine if bat activity at the FEF followed bimodal patterns with peak foraging bouts immediately after sunset and immediately before sunrise as observed elsewhere; and (3) assess the change in species-specific bat activity before and one full year after WNS onset.

SITE DESCRIPTION

We conducted our research at the FEF in Tucker County, WV (39°00' N, 79°67' W), which is located in the Unglaciated Allegheny Mountains subsection of the Appalachian Plateau Physiographic Province. Elevations range from 530 to 1,100 m with numerous intermittent and perennial dendritic streams incising the steep slopes and plateau-like ridgetops in the area (Madarish et al. 2002). Forests on the FEF are a mosaic of second-growth and third-growth mixed-mesophytic, Allegheny/northern hardwoods and oak (*Quercus* spp.) types with large areas devoted to a variety of manipulative silvicultural and forest hydrologic research (Kochenderfer et al. 2007, Schuler 2004). The FEF contains considerable karst formations and is home to Big Springs Cave, a hibernaculum containing all cavernicolous bat species occurring regionally, including the endangered Indiana myotis and the endangered Virginia big-eared bat (*Corynorhinus townsendii)*. White-nose syndrome was first observed at Big Springs Cave in the winter of 2010-2011 (C. Stihler, West Virginia Division of Natural Resources, personal communication).

METHODS


Anabat II bat detector. Photo by Jane Rodrigue, U.S. Forest Service.

In 2004, 2005, 2006, and 2012, we used Anabat II[1] (Titley Electronics, Ballina, Australia) broadband, frequency-division, bat detectors to passively monitor bat passes, i.e., a series of echolocation pulses, at four water source sites at FEF. These sites (Fig. 1) included Elklick, a fourth-order stream that bisects FEF, elevation 590 m; a constructed concrete weir pond (30 m^2) in Experimental Watershed 1 in the northwestern portion of FEF, elevation 630 m; Big Springs, a first-order headwater stream that flows into Elklick, elevation 660 m; and a small (175 m^2) pond created for hydrology research along the summit of Fork Mountain on the western border of FEF, elevation 840 m (Kochenderfer 2006). We suspended the detectors 1.5 to 2.0 m above the ground with the microphone oriented at a 45° angle over each water source. In 2004-2006, we simultaneously monitored at all four sites on any given night. In 2012, we sampled the sites on consecutive nights. Echolocation passes were recorded to an Anabat CompactFlash storage Zero-Crossing Analysis Interface Module (ZCAIM) and downloaded to a computer for analysis using Analook 4.8p software (Corben 2001). To identify bat passes, we relied on a combination of quantitative (minimum and mean call note frequency) and qualitative (call note curvature and slope) metrics in a dichotomous key developed using a large bat echolocation call library from the eastern United States (M.A. Menzel, West Virginia University, unpublished data, on file at the U.S. Forest Service Northern Research Station, Princeton, WV; Ford et al. 2005, Owen et al. 2004). We retained only echolocation passes with $\geq$ 3 calls appearing in close sequence for identification (Johnson et al 2010a). To test if bat activity levels differed among sites, among segments within sampling nights, and between the pre- and post-WNS years, we fit generalized linear mixed models multi-factor repeated measure design for fixed main effects (site, survey hour

[1]The use of any trade, product, or firm names does not imply endorsement by the U.S. government.

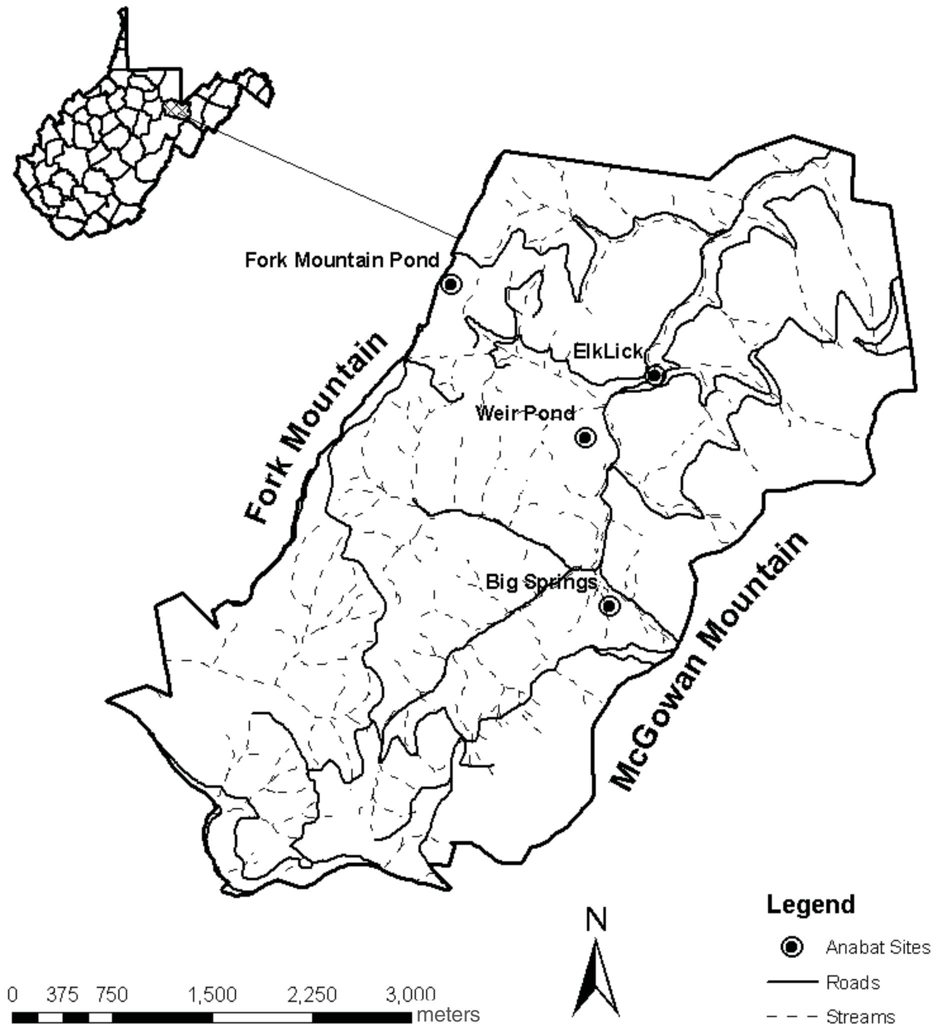


Figure 1.—Location of acoustic sampling sites for bats on the Fernow Experimental Forest, West Virginia, 2004-2006, and 2012.

period, and year), using the PROC GLIMMIX procedure for a negative binomial distribution and using a log-link function and a power covariance structure (SAS 9.3, SAS Inc., Cary, NC) for each identified bat species. We defined hour period as early (1-4 hours after sunset), mid (5-8 hours after sunset) and late (9-12 hours after sunset). We used a variety of pre-planned orthogonal contrasts to examine site, hour period, and year comparisons of interest.

RESULTS

In 2004, 2005, 2006, and 2012, we sampled 10, 4, 4, and 2 nights, respectively, at all four sites. We recorded 25,612, 14,607, 13,411, and 2,602 total echolocation passes, respectively, during the 4 years of sampling. Overall, we recorded echolocation passes from nine bat species (n = number of echolocation passes recorded), including little brown myotis (n = 27,166), northern myotis (n = 3,380), Indiana myotis (n = 9,212), eastern small-footed myotis (*M. leibii*; n = 197), big brown bats (*Eptesicus fuscus*; n = 347), eastern red bats (n = 8,059), hoary bats (n = 34), silver-haired bats (*Lasionycteris noctivagans*; n = 2), and tri-colored bats (*Perimyotis subflavus*; n = 160). We failed to positively identify 7,675 passes due to poor quality or < 3 recorded pulses. The numbers of echolocation passes from hoary bats and silver-haired bats were inadequate for meaningful analyses.

For little brown myotis, northern myotis, Indiana myotis, and eastern red bats, numbers of recorded passes differed among years (Table 1). Moreover, when comparing number of passes recorded in 2004-2006 (pre-WNS) to those in 2012 (post-WNS), we found that activity of little brown myotis, northern myotis, Indiana myotis, and eastern red bats was lower in 2012 (Table 2). Within sampling nights, mean activity by hour period differed among hours for all species except eastern small-footed myotis (Tables 1 and 2, Figs. 2-5). Activity of northern myotis and big brown bats peaked directly after sunset and declined throughout the night (Table 2, Figs. 2, 5). Activity of little brown myotis and Indiana myotis had a unimodal distribution that peaked toward the middle of the night (Table 2, Figs. 2, 4). There was a significant location and year interaction effect for all species except eastern small-footed myotis and tri-colored bats (Table 1, Figs. 6, 8). Activity of most bat species differed among sample sites. Big brown bat, little brown myotis, and eastern red bat activity was highest at Elklick and Fork Mountain (Table 2, Figs. 5, 7). Northern myotis activity was higher at the smaller water sources, including Big Springs, than at larger water sources, such as Elklick (Table 2, Fig. 3). Indiana myotis activity was highest at Fork Mountain (Table 2, Fig. 4).

DISCUSSION

Similar to research in the Northeast showing declines in activity by populations of WNS-affected bat species, our research showed that activity of little brown myotis, northern myotis, and Indiana myotis was significantly reduced after WNS was observed at FEF than before (Brooks 2011, Dzal et al. 2011, Ford et al. 2011). A pre-hibernation fall swarm bat survey in 2011 at Big Springs Cave on the FEF recorded only one little brown myotis and no other species (J. Rodrigue, unpublished data, on file at the U.S. Forest Service Northern Research Station, Princeton, WV) and subsequent winter cave counts similarly have shown massive reductions in little brown myotis, Indiana myotis, and tri-colored bat numbers (C. Stihler, West Virginia Division of Natural Resources, unpublished data, on file at the U.S. Forest Service Northern Research Station).

Intra-nightly activity levels varied among species: little brown myotis and Indiana myotis activity peaked 5-8 hours after sunset, and northern myotis and big brown bat activity peaked 1-4 hours after sunset. We observed no peaks in bat activity before sunrise, as observed elsewhere (Kunz 1973). Activity at water sources may be higher when activity at diurnal roost trees is lower. For example, in southern Michigan, activity near Indiana myotis day-roosts was higher in early and late segments of the night, corroborating with our results showing that activity at water sources was higher in the middle of the night when bats were away from day-roosts (Murray and Kurta 2004). Similarly, the lowest northern myotis activity at these water sources was in the 4 hours before sunrise, which has been shown to be a high activity period at northern myotis diurnal roost trees at FEF (Johnson et al. 2011).

Our four sites differed in waterbody size and clutter condition. At the less structurally cluttered and larger water sources (Fork Mountain and Elklick), big brown bat, eastern red bat, and little brown myotis activity was higher than at the more cluttered and smaller water source sites (Watershed 1 and Big Springs). Big brown bats have high wing-loading and low-frequency echolocation calls, not suitable for efficiently using cluttered space as would be encountered over Big Springs or Watershed 1 where the forest canopy essentially remains continuous over the water source (Ford et al. 2005). Conversely, northern myotis have low wing-loading and high-frequency echolocation calls, making cluttered water sources such as at Big Springs a preferred place to forage, as we observed and Ford et al. 2005 demonstrated across a more complete gradient of cluttered and uncluttered sites on the FEF.

Indiana myotis activity was highest at Fork Mountain pond, an artificial waterhole on a ridgetop not near other water. Water sources in upland areas have been documented as sites of high bat species richness, particularly if open enough where bats with high wing-loading can efficiently forage (Johnson et al. 2010a). Moreover, human-made water sources in upland areas can offer novel and productive water and foraging resources for bats that are readily used (Huie 2002, Maslonek 2009). As WNS impacts continue, these water and foraging sites may become increasingly important to surviving bat populations because habitat configuration and resource offerings will need to be "optimal" in their presentation to bats to maintain survivor fitness, prevent extirpation, and facilitate future population growth.

Table 1.—Differences in nightly (Time) and yearly (Year) bat pass data recorded at four water sources (Site) before (2004-2006) and after (2012) white-nose syndrome was detected at Fernow Experimental Forest, West Virginia

Species	Variable	$F_{(ndf,\ ddf)}$	*F*	*P*
Little brown myotis	Site	3,198	36.77	<0.001
(Myotis lucifugus)	Year	3,198	29.96	<0.001
	Site*Year	9,198	4.41	<0.001
	Time	2,198	15.93	<0.001
	Site*Time	6,198	0.39	0.888
	Year*Time	6,198	0.76	0.606
Northern myotis	Site	3,198	24.14	<0.001
(Myotis septentrionalis)	Year	3,198	10.35	<0.001
	Site*Year	9,198	7.89	<0.001
	Time	2,198	26.47	<0.001
	Site*Time	6,198	1.44	0.202
	Year*Time	6,198	1.78	0.105
Indiana myotis	Site	3,198	37.80	<0.001
(Myotis sodalis)	Year	3,198	12.73	<0.001
	Site*Year	9,198	6.38	<0.001
	Time	2,198	16.96	<0.001
	Site*Time	6,198	0.70	0.653
	Year*Time	6,198	1.54	0.167
Small-footed myotis	Site	3,198	0.27	0.848
(Myotis leibii)	Year	3,198	1.74	0.160
	Site*Year	9,198	1.65	0.103
	Time	2,198	1.31	0.273
	Site*Time	6,198	0.91	0.487
	Year*Time	6,198	0.46	0.835

continued

Table 1.—continued

Species	Variable	$F_{(ndf, ddf)}$	F	P
Big brown bat	Site	3,198	9.09	<0.001
(Eptesicus fuscus)	Year	3,198	2.37	0.072
	Site*Year	9,198	4.01	<0.001
	Time	2,198	15.31	<0.001
	Site*Time	6,198	3.92	0.001
	Year*Time	6,198	1.12	0.355
Red bat	Site	3,198	27.70	<0.001
(Lasiurus borealis)	Year	3,198	5.50	0.001
	Site*Year	9,198	3.64	<0.001
	Time	2,198	5.12	0.007
	Site*Time	6,198	2.51	0.023
	Year*Time	6,198	1.77	0.106
Tri-colored bat	Site	3,198	7.08	<0.001
(Perimyotis subflavus)	Year	3,198	1.95	0.122
	Site*Year	9,198	1.23	0.281
	Time	2,198	3.78	0.025
	Site*Time	6,198	0.34	0.916
	Year*Time	6,198	1.93	0.077

Table 2.—Differences in nightly (Early = hours 1-4 after sunset; Mid = hours 5-8 after sunset; Late = hours 9-12 after sunset) bat pass data recorded at four water sources before (2004-2006) and after (2012) white-nose syndrome was detected at Fernow Experimental Forest, West Virginia

Species	Contrast	$F_{(ndf, ddf)}$	F	P
Little brown myotis	Early > Late	1, 198	23.61	<0.001
(Myotis lucifugus)	Early = Mid	1, 198	0.04	0.838
	Mid > Late	1, 198	25.33	<0.001
	Big Springs < Elklick	1, 198	55.43	<0.001
	Big Springs < Fork Mountain & Watershed 1	1, 198	16.63	<0.001
	Fork Mountain > Watershed 1	1, 198	54.92	<0.001
	Fork Mountain & Watershed 1 < Elklick	1, 198	20.04	<0.001
	Pre-WNS > Post-WNS	1, 198	68.05	<0.001
Northern myotis	Early > Late	1, 198	51.07	<0.001
(Myotis septentrionalis)	Early = Mid	1, 198	3.48	0.064
	Mid > Late	1, 198	29.97	<0.001
	Big Springs > Elklick	1, 198	34.98	<0.001
	Big Springs > Fork Mountain & Watershed 1	1, 198	9.33	0.003
	Fork Mountain > Watershed 1	1, 198	35.73	<0.001
	Fork Mountain & Watershed 1 > Elklick	1, 198	13.91	<0.001
	Pre-WNS > Post-WNS	1, 198	11.92	<0.001

continued

Table 2.—continued

Species	Contrast	$F_{(ndf, ddf)}$	F	P
Indiana myotis	Early > Late	1, 198	25.46	<0.001
(Myotis sodalis)	Early = Mid	1, 198	0.04	0.833
	Mid > Late	1, 198	27.38	<0.001
	Big Springs = Elklick	1, 198	0.08	0.783
	Big Springs = Fork Mountain & Watershed 1	1, 198	0.26	0.610
	Fork Mountain > Watershed 1	1, 198	110.49	<0.001
	Fork Mountain & Watershed 1 = Elklick	1, 198	0.04	0.837
	Pre-WNS > Post-WNS	1, 198	35.80	<0.001
Small-footed myotis	Early = Late	1, 198	1.85	0.175
(Myotis leibii)	Early = Mid	1, 198	0.01	0.936
	Mid = Late	1, 198	2.16	0.144
	Big Springs = Elklick	1, 198	0.05	0.819
	Big Springs = Fork Mountain & Watershed 1	1, 198	0.18	0.668
	Fork Mountain = Watershed 1	1, 198	0.18	0.670
	Fork Mountain & Watershed 1 = Elklick	1, 198	0.51	0.475
	Pre-WNS = Post-WNS	1, 198	2.98	0.086
Big brown bat	Early > Late	1, 198	29.84	<0.001
(Eptesicus fuscus)	Early > Mid	1, 198	9.27	0.003
	Mid > Late	1, 198	6.87	0.010
	Big Springs < Elklick	1, 198	10.58	0.001
	Big Springs < Fork Mountain & Watershed 1	1, 198	10.96	0.001
	Fork Mountain > Watershed 1	1, 198	11.66	<0.001
	Fork Mountain & Watershed 1 = Elklick	1, 198	0.05	0.829
	Pre-WNS < Post-WNS	1, 198	5.21	0.024
Red bat	Early > Late	1, 198	10.24	0.002
(Lasiurus borealis)	Early = Mid	1, 198	2.53	0.113
	Mid = Late	1, 198	2.74	0.100
	Big Springs < Elklick	1, 198	12.23	<0.001
	Big Springs < Fork Mountain & Watershed 1	1, 198	19.81	<0.001
	Fork Mountain > Watershed 1	1, 198	56.13	<0.001
	Fork Mountain & Watershed 1 = Elklick	1, 198	0.44	0.510
	Pre-WNS > Post-WNS	1, 198	15.37	<0.001
Tri-colored bat	Early = Late	1, 198	1.52	0.220
(Perimyotis subflavus)	Early = Mid	1, 198	2.41	0.123
	Mid > Late	1, 198	7.37	0.007
	Big Springs = Elklick	1, 198	2.19	0.140
	Big Springs = Fork Mountain & Watershed 1	1, 198	1.82	0.179
	Fork Mountain > Watershed 1	1, 198	15.95	<0.001
	Fork Mountain & Watershed 1 = Elklick	1, 198	0.08	0.783
	Pre-WNS = Post-WNS	1, 198	1.01	0.316

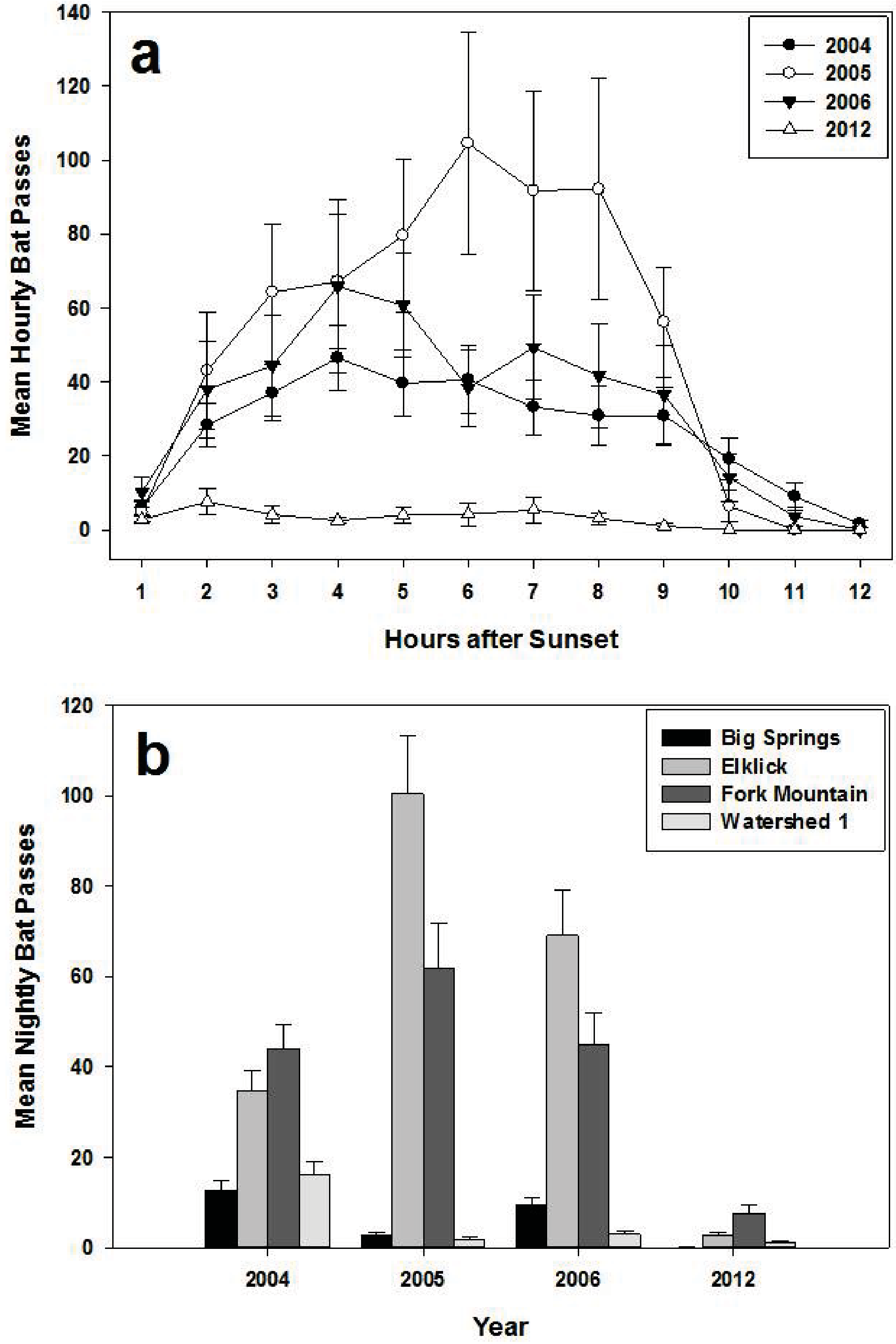


Figure 2.—Mean (± 1 SE) nightly passes (**a**) and mean (± 1 SE) hourly passes (**b**) of little brown myotis (*Myotis lucifugus*) recorded at four water sources at Fernow Experimental Forest, West Virginia, 2004-2006, and 2012.

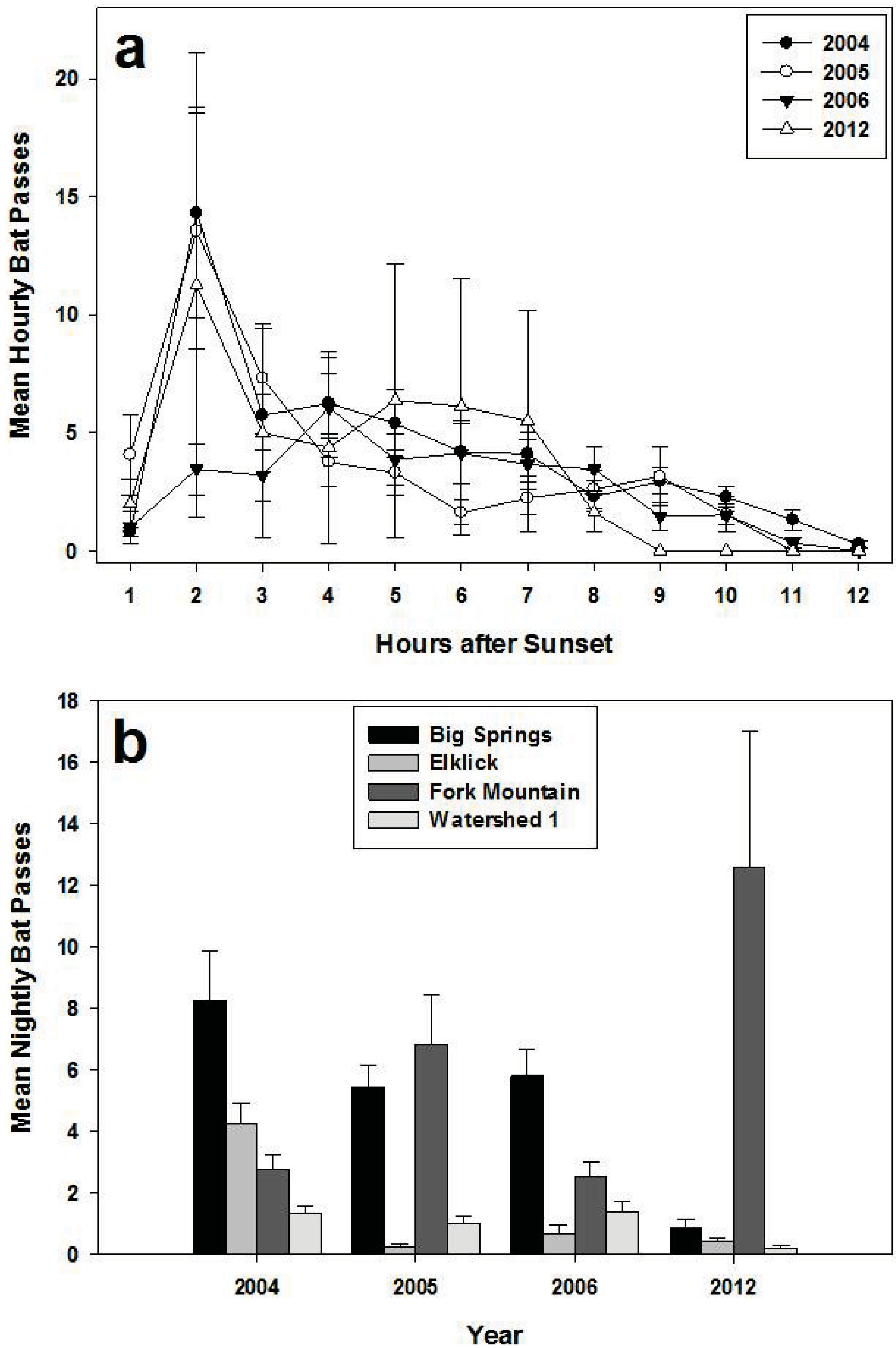


Figure 3.—Mean (± 1 SE) nightly passes (**a**) and mean (± 1 SE) hourly passes (**b**) of northern myotis (*Myotis septentrionalis*) recorded at four water sources at Fernow Experimental Forest, West Virginia, 2004-2006, and 2012.

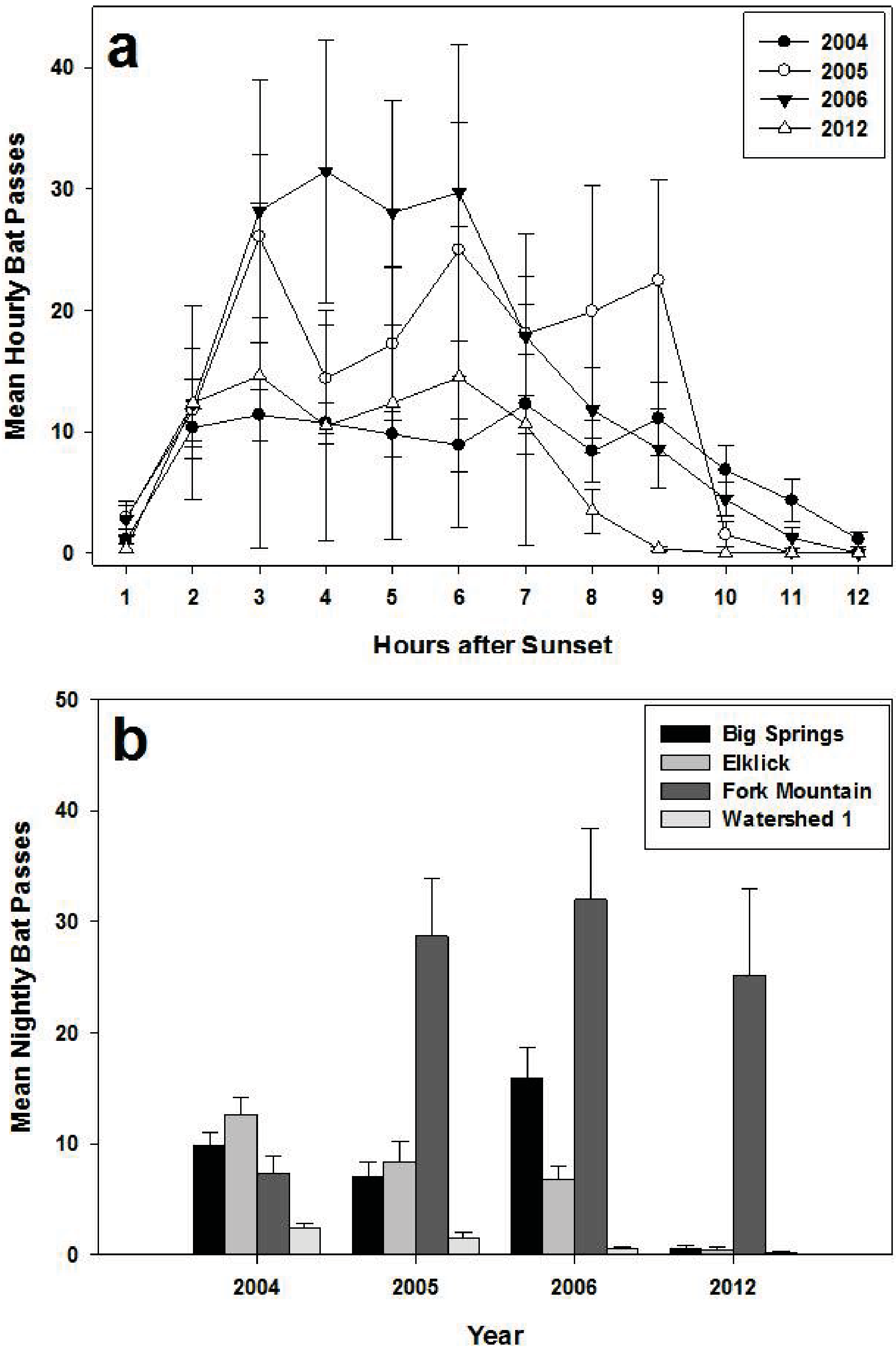


Figure 4.—Mean (± 1 SE) nightly passes (**a**) and mean (± 1 SE) hourly passes (**b**) of Indiana myotis (*Myotis sodalis*) recorded at four water sources at Fernow Experimental Forest, West Virginia, 2004-2006, and 2012.

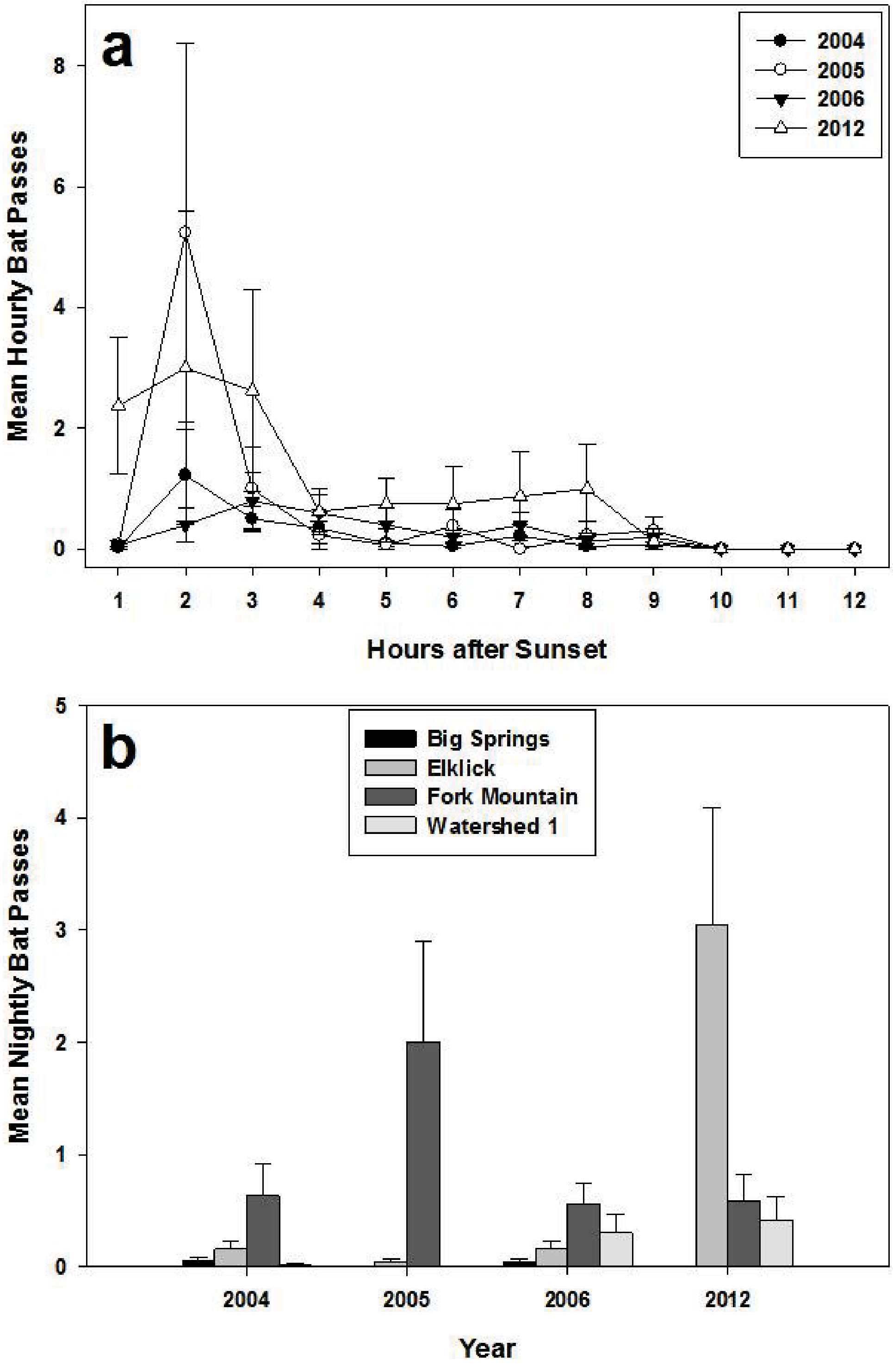


Figure 5.—Mean (± 1 SE) nightly passes (**a**) and mean (± 1 SE) hourly passes (**b**) of big brown bats (*Eptesicus fuscus*) recorded at four water sources at Fernow Experimental Forest, West Virginia, 2004-2006, and 2012.

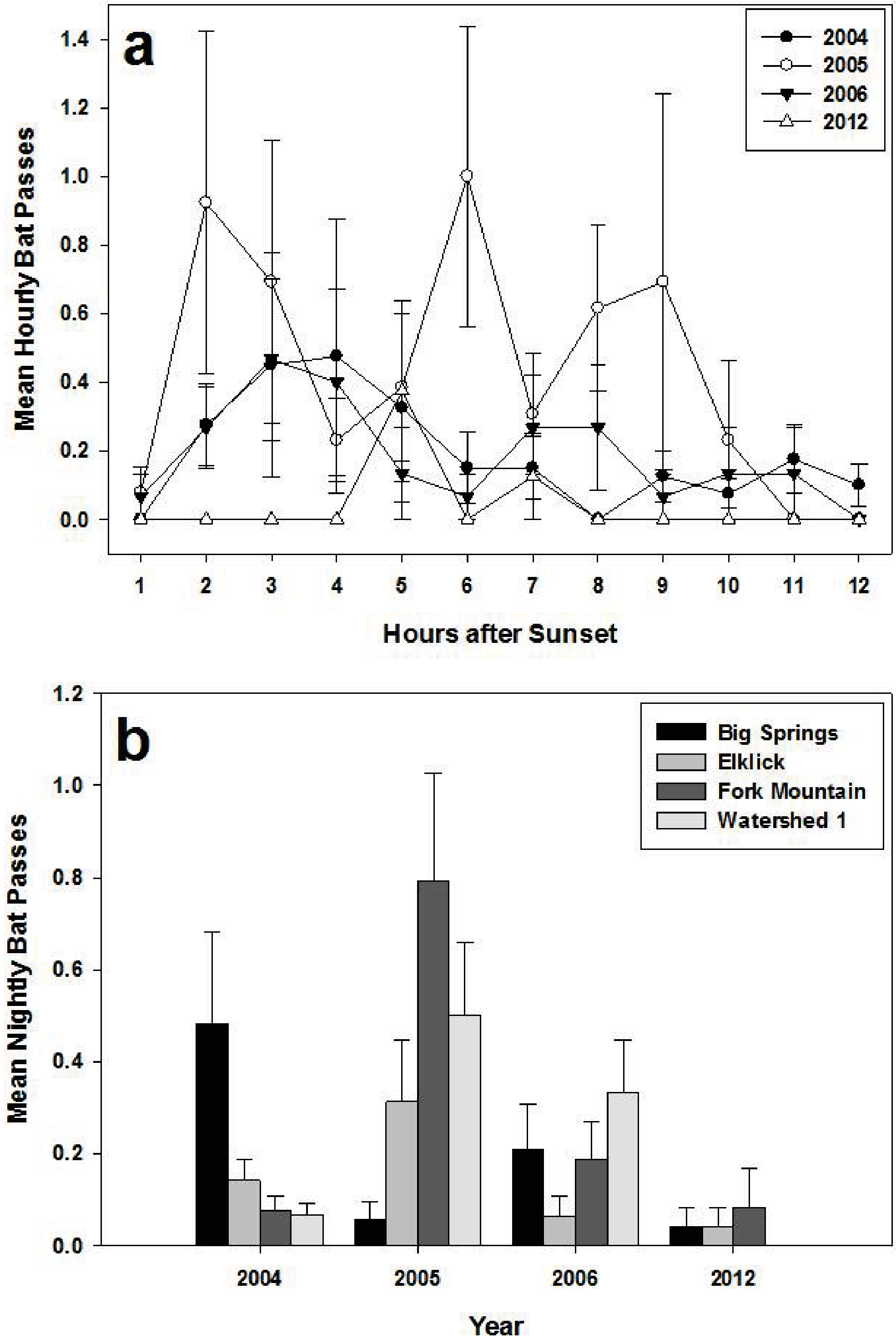


Figure 6.—Mean (± 1 SE) nightly passes (**a**) and mean (± 1 SE) hourly passes (**b**) of eastern small-footed myotis (*Myotis leibii)* recorded at four water sources at Fernow Experimental Forest, West Virginia, 2004-2006, and 2012.

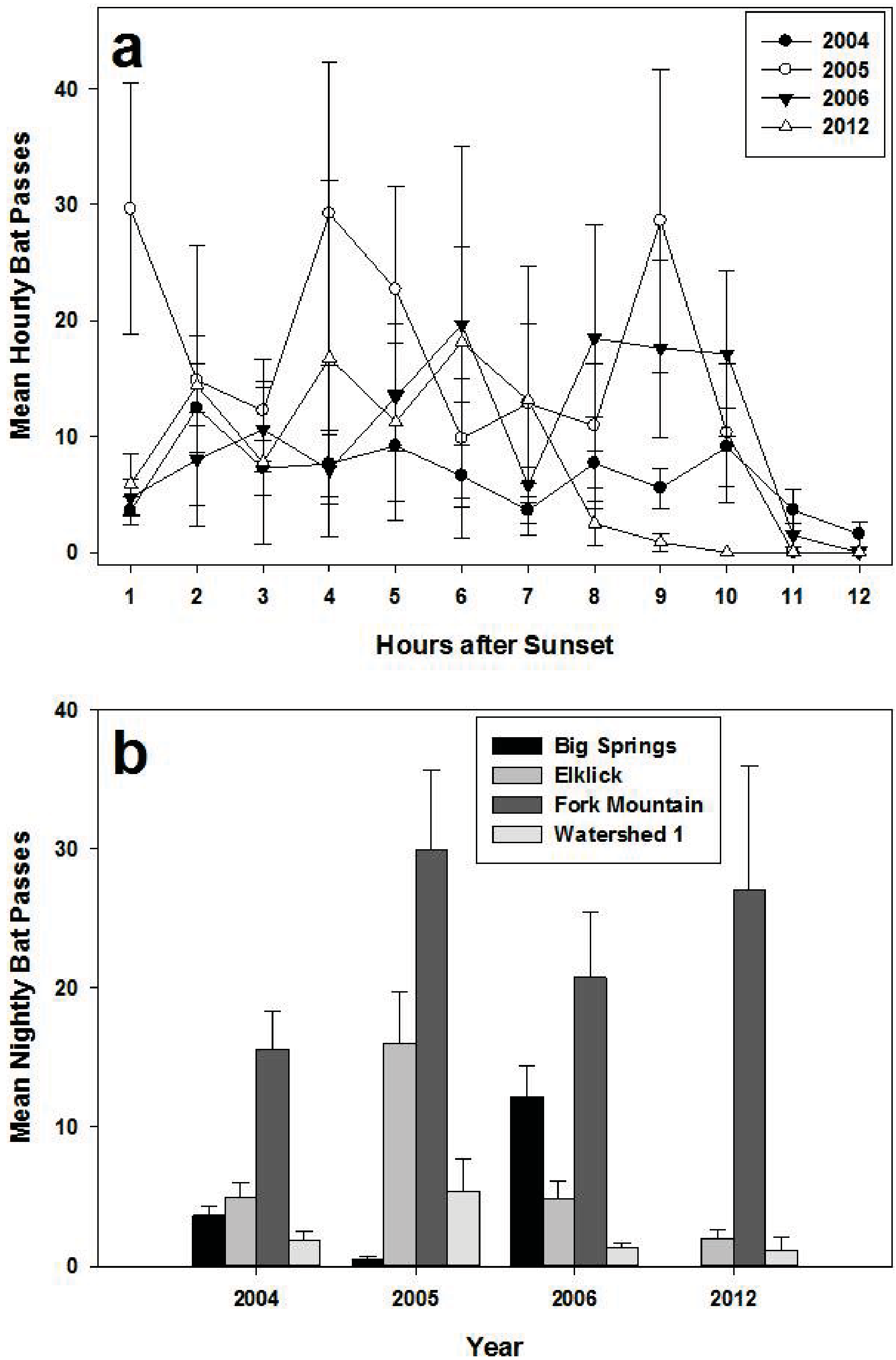
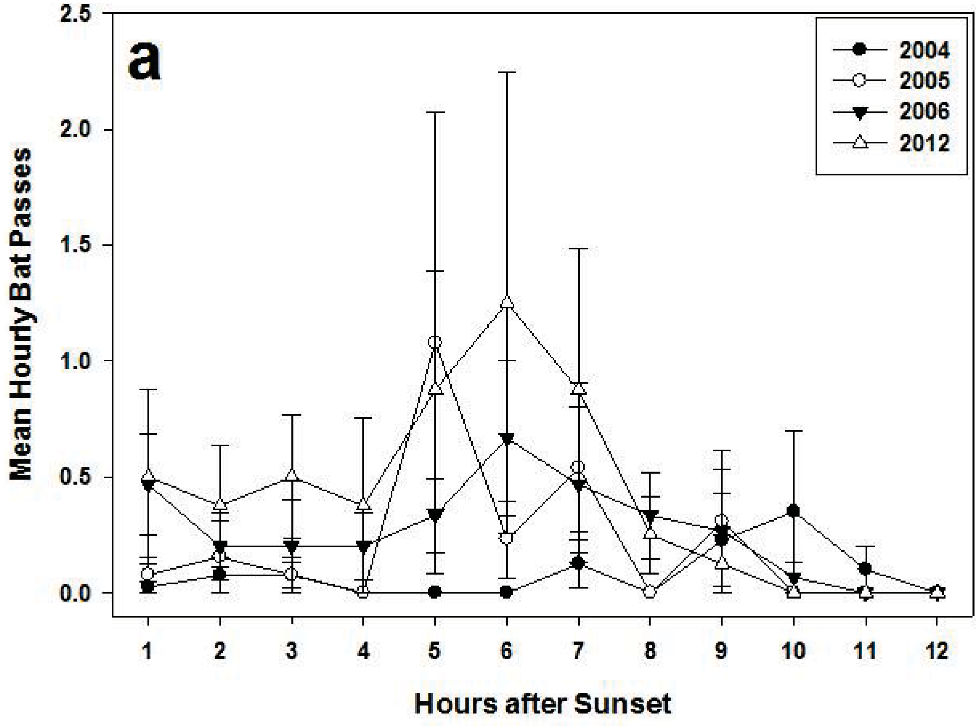


Figure 7.—Mean (± 1 SE) nightly passes (**a**) and mean (± 1 SE) hourly passes (**b**) of eastern red bats (*Lasiurus borealis*) recorded at four water sources at Fernow Experimental Forest, West Virginia, 2004-2006, and 2012.



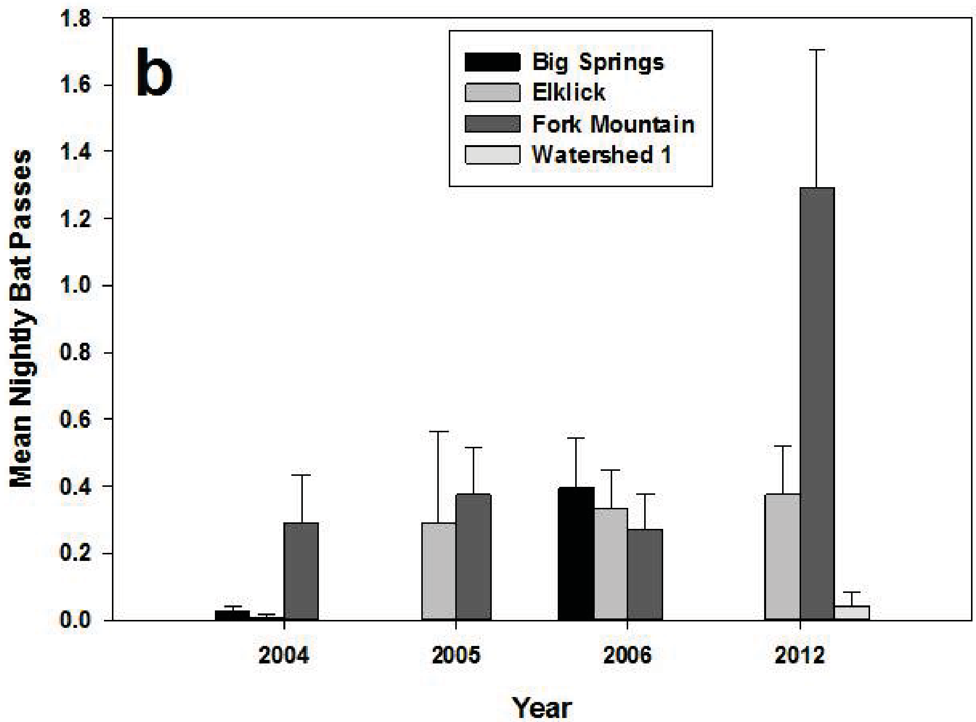


Figure 8.—Mean (± 1 SE) nightly passes (**a**) and mean (± 1 SE) hourly passes (**b**) of tri-colored bats (*Perimyotis subflavus*) recorded at four water sources at Fernow Experimental Forest, West Virginia, 2004-2006, and 2012.

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Elklick Creek on the Fernow. Photo by W. Mark Ford, U.S. Geological Survey.

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In the central Appalachians, conservation concern about bat communities and their population status has become increasingly more significant with the advent and spread of white-nose syndrome (WNS). However, managers often are hampered in their response to WNS by the lack of information on pre-WNS local distribution, abundance, or activity patterns for most bat species. At the Fernow Experimental Forest (FEF), Tucker County, WV, where bat research has been conducted since the mid-1990s, we acoustically monitored bat activity a total of 20 nights each at four sites for 4 years—3 years before and 1 year after WNS was detected—to better assess those local patterns. Within sampling nights, activity of northern myotis (*Myotis septentrionalis*) and big brown bats (*Eptesicus fuscus*) peaked directly after sunset and declined throughout the night, whereas activity of little brown myotis (*Myotis lucifugus*) and Indiana myotis (*Myotis sodalis*) had a unimodal distribution that peaked in the middle of the night. Activity of many bat species differed among sample sites and was highest at a small, artificial pond located on a dry ridgetop. Activity of little brown myotis, northern myotis, and Indiana myotis was lower post-WNS than pre-WNS, consistent with the species' precipitous declines previously reported in WNS-affected areas in the Northeast and upper portions of the Mid-Atlantic.

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