Bat Use of an Island off the Coast of Massachusetts

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Abstract - Nantucket, Massachusetts, could provide unique habitat for bats, but few data are available regarding bat populations on the island. We conducted passive acoustic surveys in 2015 and 2016 to inventory bat species and identify seasonal activity patterns. We detected at least 6 species of bats on Nantucket. *Lasiurus cinereus* (Hoary Bat) and *Lasionycteris noctivagans* (Silver-haired Bat) were detected as probable migrants, and *Lasiurus borealis* (Eastern Red Bat), *Eptesicus fuscus* (Big Brown Bat), and *Myotis* species were also present in summer. We detected *Perimyotis subflavus* (Tricolored Bat) in fall and early winter, suggesting that the species may hibernate on the island. In 2016, we mist-netted and radio-tagged *Myotis septentrionalis* (Northern Long-eared Bat), and documented individuals reproducing and hibernating on Nantucket. Given the persistence of this rare species on the island, we suggest that land-conservation organizations should consider maintenance of mature forest stands in their suite of planned management activities.

Introduction

There is growing concern regarding conservation of bat populations in temperate North America, mainly due to the devastating impact of the fungal disease known as White-nose Syndrome (WNS) on cave-hibernating bats (e.g., Frick et al. 2010, Turner et al. 2011) as well as the population-level threat that mortality at wind-energy facilities could pose to long-distance migratory tree bats (Arnett and Baerwald 2013, Frick et al. 2017, Hayes et al. 2013). Three cave-hibernating bat species, *Myotis septentrionalis* Trouessart (Northern Long-eared Bat), *Myotis lucifugus* Le Conte (Little Brown Bat), and *Perimyotis subflavus* Cuvier (Tricolored Bat), are now listed as endangered in the state of Massachusetts (MANHESP 2017) because of population reductions of greater than 90% associated with WNS (Turner et al. 2011); the Northern Long-eared Bat has also been designated as federally threatened under the Endangered Species Act (USFWS 2016a). In addition, 3 long-distance migratory tree bats, *Lasiurus cinereus* de Beauvois (Hoary Bat), *Lasiurus borealis* Muller (Eastern Red Bat), and *Lasionycteris noctivagans* Le Conte (Silver-haired Bat), are listed as Species of Greatest Conservation Need in Massachusetts (MANHESP 2015).

One major challenge in bat conservation is a lack of knowledge about bat populations and their distribution across the landscape (O'Shea and Bogan 2003). Relatively little is known about bat use of coastal areas and offshore islands in the Northeast, but these environments can offer unique habitat to bats. Bat surveys conducted on Martha's Vineyard and Cape Cod, MA, detected large numbers of Northern Long-eared Bats prior to the outbreak of WNS (Buresch 1999, Kelly and

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Ciaranca 2000). Recent surveys on Martha's Vineyard from 2014 to 2016 found that capture rates of Northern Long-eared Bats were lower than those observed during pre-WNS surveys, but healthy maternity colonies were still documented producing pups (Baldwin et al. 2017). This discovery contrasts with sharp declines at many inland sites in the Northeast, where the species is now rarely found (Ford et al. 2011, Francl et al. 2012). The offshore island of Nantucket, MA, could also be providing habitat for persistent populations of Northern Long-eared Bats, but only anecdotal information is available regarding historic populations.

Long-distance migratory tree bats frequent coastal areas, and often utilize islands as stopover habitat during their fall migration (Miller 1897; Peterson et al. 2014, 2016; Smith and McWilliams 2016), roosting temporarily in lighthouses and other sites (Cryan and Brown 2007, Johnson et al. 2011a). Specimens of all 3 long-distance migratory tree-bat species have been collected on Nantucket in August and September (Maria Mitchell Association 2017), and Eastern Red Bats were captured on nearby Tuckernuck Island (Veit 2012). If migratory bats are passing through Nantucket as part of their fall migration route, it will be important to consider risks to bats associated with large-scale offshore wind-energy development planned for federal waters southwest of the island (BOEM 2017).

The goals of this study were to (1) inventory the bat species present on Nantucket using passive acoustic monitoring, (2) characterize the seasonal use of Nantucket by these species as migrants or summer residents, and (3) if present, determine if Northern Long-eared Bats were reproducing or hibernating on the island.

Methods

Acoustic-detector deployment

The island of Nantucket, MA (120 km^2) is situated 43 km south of Cape Cod, and 15 km east of Martha's Vineyard, another offshore island. Between 2015 and 2016, we deployed passive acoustic-detector stations at 15 locations on Nantucket (Fig. 1). Each station consisted of an Anabat II acoustic detector (Titley Scientific, www.titley-scientific.com) set in a PVC junction-box, with the microphone pointed downward into a PVC elbow. All units were powered by a 12-v battery charged by a small solar panel. We mounted detectors 1–3 m above the ground, either hung from a tree, a shrub, or 2 poles set in the ground. Detectors operated between 6:00 PM and 8:00 AM every night. From April to mid-November 2015, we deployed 8 stations at 4 localities, with the 2 stations at each locality at least 100 m apart, which represented non-overlapping detection radii (Table 1). In mid-August, we moved 1 station from the Squam Farm site to Gibbs Pond, in order to sample a broader range of sites. In 2016, we deployed 8 stations at more widely dispersed localities between April and December (Table 1). We checked the stations periodically throughout the season to download data and ensure proper operation.

Bat call identification

We followed US Fish and Wildlife Service Indiana Bat Survey Guidelines (2017) to identify bat calls. We processed probable bat-call files through 2 auto-classification software systems, manually examined candidate calls as identified by the software, and consulted with experts in the field, as appropriate. With the exception of data collected at the Ram Pasture station, we viewed all files manually using AnalookW 4.1 software prior to auto-classification. We used manual identification as a first pass to differentiate noise files from probable bat-call files that contained at least 2 pulses. We employed both EchoClass V3.1 (US Army Engineer Research and Development Center 2015) and KaleidoscopePro (Wildlife Acoustics Inc., Maynard, MA) to analyze the files that contained probable bat calls. The Ram Pasture station generated over 58,000 files; therefore we did not manually pre-screen files at this site before running them through the auto-classification software. We excluded from analysis data from nights with an average of 100 files per hour or higher (>1400 files per night); we found they contained few to no bat calls, and were associated with either high average-wind speeds (>8 m/s) when bats were unlikely to be active, or showed evidence of device malfunction and mechanical noise. At Ram Pasture, the busiest site, true spikes in bat activity led to averages of ~70 call files per hour, but never exceeded 100 call files per hour.

We ran the bat-call files through EchoClass using the Species Set 2 list, which includes the 9 bat species currently known to occur in Massachusetts: *Eptesicus fuscus* de Beauvois (Big Brown Bat), *Myotis leibii* Audubon and Bachman (Eastern Small-footed Bat), Eastern Red Bat, Hoary Bat, Little Brown Bat, Northern Long-eared Bat, Silver-haired Bat, Tricolored Bat, and from historic records, *Myotis sodalis* Miller and Allen (Indiana Bat). EchoClass returns a maximum likelihood

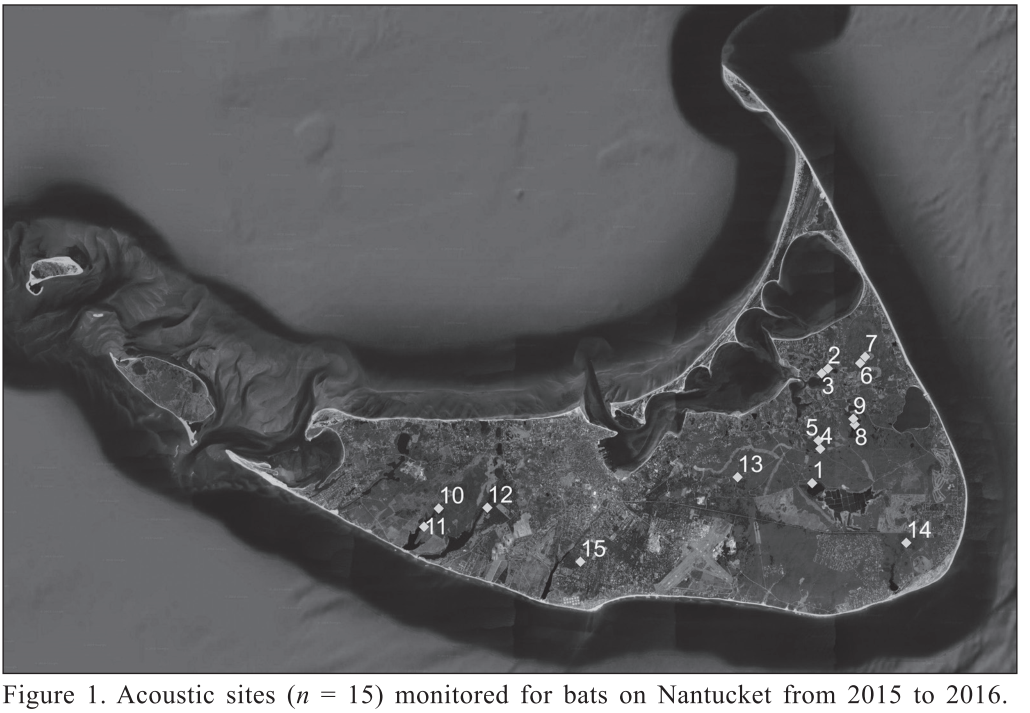

Figure 1. Acoustic sites (n = 15) monitored for bats on Nantucket from 2015 to 2016. Numbers refer to stations as listed in Table 1. Basemap courtesy of TerraMetrics (2017).

Table 1. Acoustic study sites surveyed on Nantucket, 2015–2016. Numbers before station names refer to map locations in Figure 1. *Due to the large volume of calls at the Ram Pasture site, we did not separate noise files from probable bat-call files before performing auto-classification analysis.

Station	Site description	Dates deployed	Nights analyzed (% deployed)	Nights with activity (% analyzed)	Total bat calls
(1) Gibbs Farm	Scrub Oak edge of large kettle pond, near active cranberry bog and hardwood forest	25 Aug 2015– 13 Nov 2015	55 (69%)	13 (24%)	93
(2) Medouie 1	Shrub treeline on edge of salt marsh	29 Apr 2015– 13 Nov 2015	114 (58%)	40 (35%)	161
(3) Medouie 2	Shrub edge of brackish marsh, surrounded by mature forested and shrub swam	30 Apr 2015– 13 Nov 2015	166 (84%)	44 (27%)	419
(4) Norwood 1	Small kettle pond surrounded by Scrub Oak shrubland	30 Apr 2015– 13 Nov 2015	184 (93%)	102 (55%)	551
(5) Norwood 2	Forest edge in mosaic of fields, Scrub Oak, and hardwood forest	30 Apr 2015– 13 Nov 2015	165 (84%)	119 (72%)	691
(6) Squam 1	Hardwood forest edge by grazed field	29 Apr 2015– 13 Nov 2015	138 (70%)	49 (36%)	755
(7) Squam 2	Clearing in hardwood forest	29 Apr 2015– 21 Aug 2015	104 (100%)	24 (23%)	61
(8) Stump 1	Scrub Oak edge of large pond, surrounded by hardwood forest	30 Apr 2015– 13 Nov 2015	182 (92%)	136 (75%)	2821
(9) Stump 2	Field adjacent to Scrub Oak wetland, surrounded by mosaic of hardwood forest and fields	30 Apr 2015– 13 Nov 2015	136 (69%)	67 (49%)	286
(6) Squam 1	Hardwood forest edge by grazed field	2 May 2016– 7 Dec 2016	201 (91%)	107 (53%)	3876
(8) Stump 1	Scrub Oak edge of large pond, surrounded by hardwood forest	2 May 2016– 24 Jul 2016	84 (100%)	39 (46%)	535
(10) Ram Pasture	Edge of shrub forest near Pitch Pine stand, wetland complex	2 May 2016– 12 Dec 2016	186 (83%)	152 (82%)	~58,000*
(11) West Hummock	Low shrub-edged large pond	2 May 2016– 14 Aug 2016	91 (87%)	52 (57%)	627
(12) Lost Farm	Pitch Pine forest edge by field, large pond nearby	2 May 2016– 12 Dec 2016	115 (51%)	42 (37%)	2024
(13) Sconset	East side of small wetland, in hardwood stand	19 Aug 2016– 13 Oct 2016	42 (75%)	25 (60%)	339
(14) Pout Pond	Grassy pond-shore edge	25 Jul 2016– 7 Dec 2016	120 (88%)	52 (43%)	266
(15) Beattie	Forested residential area	4 Nov– 10 Dec 2016	37 (100%)	7 (19%)	13

estimate indicating the probability that the presence of a species at a site on a given night was falsely identified, therefore a low *P*-value indicates a species is likely present at the site. We also analyzed bat-call files using KaleidoscopePro, with the software set to the "0 Balanced" (neutral) setting, and the Massachusetts region selected for the same 9 bat species. KaleidoscopePro also provides a maximum likelihood estimator describing the probability that a species was misidentified at a site, based on how many detections of each bat the classifier found, and a confusion matrix representing how likely a species was to be mis-identified. Both auto-classification programs were approved by the US Fish and Wildlife Service for identification of Indiana and Northern Long-eared Bats in zero-cross acoustic data.

As a final step, we viewed and qualitatively vetted calls identified by EchoClass and KaleidoscopePro using comparisons with established keys (Chenger and Tyburec 2011, Keinath 2011) and reference call-libraries. At a minimum, we required the following conditions for positive identification: Hoary Bats—calls a minimum frequency of <22 kHz; Eastern Red Bats—a minimum frequency of 32–42 kHz, which varied 1–2 kHz across pulses; Tricolored Bats—a minimum frequency of 38–42 kHz, with consistency across pulses and a strong constant-frequency component; Eastern Small-footed Bats—a minimum frequency of >45 kHz; other *Myotis* species—a minimum frequency of 38–42 kHz, best distinguished by the slope of the call, with some overlap; probable Northern Long-eared Bats—slope >200 octaves per second (Johnson et al. 2011b); potential Little Brown or Indiana Bat—calls with a slope <200 octaves per second; and Big Brown or Silver-haired Bat—minimum frequency of ~25 kHz, with flat calls of ~25–30 kHz diagnostic of Silver-haired Bats.

We manually vetted at least 1 call per station-night per species, as identified by KaleidoscopePro. We also vetted all calls identified by the auto-classification programs as Big Brown Bat, Tricolored Bat, Eastern Small-footed Bat, or Indiana Bat because these calls were relatively few in number. We shared selected examples of identified calls of each bat species with experts who were more proficient and experienced than we were in identifying bat calls.

Seasonal variation in detections

We categorized sampling nights into 5 seasons: spring migration (15 April–31 May), maternity period (1 June–15 July), volancy period (16 July–15 August), fall migration (16 August–15 November), and late season (16 November–15 December). These 5 seasons roughly reflected regional patterns of behavior of cave-hibernating and migratory bats in terms of timing of migration, pup volancy, and hibernation (e.g., Burns et al. 2014, Davis and Hitchcock 1965, Dowling et al. 2017, Kunz et al. 1998, Peterson et al. 2016, Townsend et al. 2008). We evaluated seasonal variation in detection rates in 2 ways. To obtain a detection probability, for each season, we summed the number of nights we detected bats for each station-year and divided by the total number of sampling nights during that station-year. We used ANOVA (package 'aov'; R Core Team 2017) to test the effect of season on probability of detection for all bat calls combined, and separately for *Myotis* spp., Eastern Red Bats, Hoary Bats, Silver-haired Bats, Big Brown Bats, and Tricolored Bats, as identified by KaleidoscopePro. We used Tukey's HSD to evaluate differences among categories within season.

We qualitatively assessed seasonal-activity patterns based on call identifications confirmed through manual vetting. Differentiation between the calls of Big Brown Bats and Silver-haired Bats is challenging (Betts 1998); therefore, we only classified a call as from a Silver-haired Bat when a flat call was present in the appropriate frequency range. We shared clear examples of calls auto-classified as Big Brown Bat with multiple experts, in order to determine if the species was present in each season. Differentiating among *Myotis* spp. is also prone to error (Britzke et al. 2013); therefore, we pooled detections of all 4 *Myotis* spp. The majority of *Myotis* calls detected were steep in slope (>200 octaves per second), suggesting they were from Northern Long-eared Bats.

Bat capture and tagging

We mist-netted across potential travel corridors and over wetland areas on 3 nights in the spring (29 April, 30 April, and 2 May 2016 at Squam Farm), 2 nights in the summer (19 July at Squam Farm, 20 July at Ram Pasture), and 2 nights in the fall (30 October at Ram Pasture, 31 October at Lost Farm), using 38-mm mist nets. Each night we deployed 1 triple-high mist net set-up (3 stacked nets, each 4 m across x 2.6 m high, total height ~6.5 m) and 2–4 single-high mist nets (1 net, 4 or 6 m across x 2.6 m high). In addition, on 1 November, we hand-captured bats roosting at a known roost site. We only operated mist nets in conditions with low wind and no precipitation, although temperatures fell below preferred conditions of ≥10 °C during spring and fall trapping. We identified to species, sexed, and weighed captured bats, and measured their forearms. We aged bats based on wing-joint ossification but could not differentiate young-of-the-year from adult bats during fall trapping. We attached 0.29-g Lotek NTQB-1 coded radio-tags (Lotek Wireless, Inc., Newmarket, ON, Canada) to bats using animal ID tag cement (Nasco, Modesto, CA), after shaving a small area of fur between the scapulae. Radio-tags operated on a single frequency, and emitted a signal every 4.7 seconds, 24 h per day, for an estimated battery life of about 3 weeks. To reduce the likelihood of negative effects from tagging, all transmitters were <5% of bat-body weight (Aldridge and Brigham 1988). We conducted bat capture and handling efforts under MassWildlife Scientific Collection Permit # 181.16SCM and University of Massachusetts-Amherst IACUC Protocol Sievert 2015-0009, and followed American Society of Mammalogists standards (Sikes and Gannon 2011). We used mist nets only on Nantucket, and all gear was treated in accordance with National WNS Decontamination Protocols (USFWS 2012, 2016b) to minimize the likelihood of spreading WNS.

Bat tracking and roost monitoring

We manually tracked tagged bats to roost sites using a Lotek SRX-800 receiver, and recorded roost characteristics. When possible, we conducted emergence counts. We tracked bats until tags dropped off or the battery life of the tags expired. We tracked 1 bat to a hibernation site, where we conducted visual surveys of the site on

31 October 2016, 8 November 2016, and 24 February 2017, and used an iButton 1-wire Hygrochron (Maxim Integrated, San Jose, CA) to record temperature and humidity at the site through the winter. We employed an automated telemetry station erected on a balcony at a house ~85 m from the roost and monitored movements of bats roosting in the hibernation site from 2 November to 10 December 2016. The station consisted of an omni-directional antenna connected to a sensorgnome receiver (www.sensorgnome.org) that continuously monitored for radio-tags 24 h per day. During this time period, there were 3 other automated telemetry stations on Nantucket and 12 automated telemetry stations on Cape Cod deployed as part of the Motus Wildlife Tracking System (Taylor et al. 2017), which could have detected coastal or off-island movements by tagged bats. In the summer, we calculated the number of days tracked based on manual tracking to roost locations and roost emergence. In the fall, we calculated the number of days tracked based on visual inspection at the hibernation location, and variation in signal strength, as detected via automated telemetry. We used manual tracking to confirm radio-tag presence at the hibernation site, but since bats did not emerge on most nights, this method did not allow us to differentiate between tags on torpid bats and dropped tags.

Results

Acoustic-detector deployment

We deployed acoustic detectors at station locations for 80 to 198 nights between late April and mid-November 2015, and 37 to 224 nights between early May and mid-December 2016. Detector malfunction and ambient noise led to some missed nights, but most detector stations functioned for the majority of their deployment. We successfully recorded during 51–100% of nights deployed (Table 1), and recorded data for a total of 2120 detector-nights.

Bat-species presence

Excluding the Ram Pasture site, we identified a total of 13,518 files as probable bat calls. EchoClass software classified 5670 calls to species at Ram Pasture, and 727 calls at the other stations combined. EchoClass software estimated that 8 of 9 bat species found in Massachusetts were likely present on at least 1 station on Nantucket ($P < 0.05$) (Table 2). The exception was the Eastern Small-footed Bat, for which individual call-sequences were only identified at the Ram Pasture site in 2016. Using EchoClass, Eastern Red Bats were the most commonly detected species, identified as present ($P < 0.05$) in 13 of 17 station-years surveyed, with individual call-sequences recorded at 2 other stations. Northern Long-eared Bats were identified as present ($P < 0.05$) at the Ram Pasture and Lost Farm stations in 2016.

KaleidoscopePro software identified 11,856 calls to species at the Ram Pasture station, and 2401 calls at the other stations combined. KaleidoscopePro software determined all 9 bat species found in Massachusetts were present on at least 1 station on Nantucket ($P < 0.05$) (Table 3). Using KaleidoscopePro, Eastern Red Bats were the most commonly identified bat species, with their presence identified ($P < 0.05$) in 16 of 17 station-years. The Eastern Small-footed Bat, which was not

Table 2. Bat species estimated to be present at 13 stations on Nantucket in 2015 and 2016 based on EchoClass software. *P*-value indicates the likelihood the species was misidentified. Squam 2 (2015) and Beatties (2016) are not shown due to lack of calls identified to species at these sites. *n* = # of nights with calls, C = # of calls. LABO = *Lasiurus borealis*, LACI = *L. cinereus*, LANO = *Lasionycteris noctivagans*, EPFU = *Eptesicus fuscus*, MYLE = *Myotis leibii*, MYLU = *M. lucifugus*, MYSE = *M. septentrionalis*, MYSO = *M. sodalis,* and PESU = *Perimyotis subflavus*.[Table continued on following page.]

Station/	Species presence								
year	LABO	LACI	LANO	EPFU	MYLE	MYLU	MYSE	MYSO	PESU
Gibbs Farm 2015	$P > 0.1$ (3N, 3C)	-	-	$P > 0.1$ (1N, 1C)	-	-	-	$P > 0.1$ (1N, 1C)	-
Medouie 1 2015	$P = 0$ (3N, 5C)	$P > 0.1$ (1N, 1C)	-	$P > 0.1$ (1N, 1C)	-	-	-	-	-
Medouie 2 2015	$P=0$ (12N, 28C)	$P = 0.023$ (6N, 10C)	$P = 0$ (3N, 30C)	$P = 0$ (2N, 16C)	-	-	-	-	$P > 0.1$ (1N, 1C)
Norwood 1 2015	$P = 0$ (12N, 19C)	-	-	$P > 0.1$ (1N, 1C)	-	-	-	-	$P > 0.1$ (1N, 1C)
Norwood 2 2015	$P > 0.1$ (4N 4C)	-	-	-	-	-	-	-	-
Squam 1 2015	$P = 0$ (6N, 10C)	-	-	-	-	-	-	-	-
Stump 1 2015	$P = 0$ (29N, 111C)	$P = 0.0054$ (8N, 15C)	$P > 0.1$ (2N, 2C)	-	-	$P = 0$ (1N, 2C)	-		
Stump 2 2015	$P = 0$ (10N, 12C)	-	-	-	-	-	-	-	-
Squam 1 2016	$P = 0$ (16N, 54C)	-	-	-	-	-	-	-	-
Stump 1 2016	$P = 0$ (3N, 14C)	-	-	-	-	-	-	-	-
Ram Pasture 2016	$P = 0$ (120N, 3932C)	$P = 0$ (24N, 94C)	$P > 0.1$ (2N, 2C)	$P = 0$ (3N, 4C)	$P > 0.1$ (33N, 86C)	$P = 0$ (14N, 24C)	$P = 0$ (100N, 1383C)	$P = 0$ (51N, 138C)	$P = 0$ (5N, 7C)

Table 2, continued.

Station/ year	Species presence								
	LABO	LACI	LANO	EPFU	MYLE	MYLU	MYSE	MYSO	PESU
West Hummock 2016	$P = 0$ (12N, 27C)	$P = 1$ (3N, 3C)	$P > 0.1$ (1N, 1C)	-	-	-	$P > 0.1$ (2N, 2C)	$P > 0.1$ (1N, 1C)	-
Lost Farm 2016	$P = 0$ (27N, 186C)	$P > 0.1$ (1N, 1C)	$P = 0.086$ (3N, 4C)	$P > 0.1$ (2N, 2C)	-	$P > 0.1$ (1N, 1C)	$P = 0$ (17N, 60C)	$P = 0$ (7N, 15C)	-
Sconset 2016	$P = 0$ (1N, 4C)	$P > 0.1$ (1N, 1C)	-	-	-	-	-	-	-
Pout Pond 2016	$P = 0$ (24N, 64C)	-	-	-	-	$P > 0.1$ (1N, 1C)	$P > 0.1$ (5N, 5C)	$P > 0.1$ (3N, 3C)	$P = 0$ (1N, 1C)

Table 3. Bat species estimated to be present at 14 stations on Nantucket in 2015 and 2016 based on KaleidoscopePro software. *P*-value indicates the likelihood the species was misidentified at a site. Squam 2 (2015) not shown; 1 LACI call identified at this site. N = # of nights with calls, C = # of calls. LABO = *Lasiurus borealis*, LACI = *L. cinereus*, LANO = *Lasionycteris noctivagans*, EPFU = *Eptesicus fuscus*, MYLE = *Myotis leibii*, MYLU = *M. lucifugus*, MYSE = *M. septentrionalis*, MYSO = *M. sodalis,* and PESU = *Perimyotis subflavus*. [Table continued on following page.]

Station/ year	Species presence								
	LABO	LACI	LANO	EPFU	MYLE	MYLU	MYSE	MYSO	PESU
Gibbs Farm 2015	$P < 0.0001$ (3N, 6C)	-	$P < 0.0001$ (4N, 8C)	$P = 0.92$ (2N, 2C)	-	-	-	$P = 0.068$ (1N, 1C)	$P = 0.39$ (1N, 1C)
Medouie 1 2015	$P < 0.0001$ (8N, 9C)	$P = 0.27$ (2N, 2C)	$P < 0.0001$ (6N, 56C)	$P = 1$ (4N, 4C)	-	-	-	-	-
Medouie 2 2015	$P < 0.0001$ (17N, 46C)	$P < 0.0001$ (9N, 17C)	$P < 0.0001$ (9N, 130C)	$P = 1$ (5N, 20C)	-	-	$P = 0.15$ (1N, 1C)	-	$P = 0.15$ (3N, 4C)
Norwood 1 2015	$P = 1$ (18N, 41C)	$P < 0.0001$ (14N, 192C)	$P = 1$ (11N, 14C)	$P = 1$ (3N, 4C)	-	-	$P < 0.0001$ (2N, 5C)	$P = 0.59$ (1N, 1C)	-

Table 3, continued.

Station/ year	Species presence								
	LABO	LACI	LANO	EPFU	MYLE	MYLU	MYSE	MYSO	PESU
Norwood 2 2015	$P < 0.0001$ (10N, 12C)	$P = 0.038$ (2N, 2C)	$P < 0.0001$ (5N, 16C)	$P = 1$ (1N, 1C)	-	-	-	-	-
Squam 1 2015	$P < 0.0001$ (10N, 18C)	$P = 0.74$ (1N, 1C)	$P < 0.0001$ (3N, 39C)	$P = 0.74$ (1N, 9C)	-	$P = 1$ (1N, 1C)	-	-	-
Stump 1 2015	$P < 0.0001$ (52N, 266C)	$P < 0.0001$ (12N, 29C)	$P < 0.0001$ (30N, 452C)	$P = 1$ (13N, 20C)	$P = 0.0057$ (2N, 3C)	$P = 1$ (5N, 11C)	-	$P < 0.0001$ (2N, 6C)	$P = 1$ (1N, 2C)
Stump 2 2015	$P < 0.0001$ (6N, 7C)	-	$P = 1$ (3N, 3C)	-	-	-	$P < 0.0001$ (5N, 6C)	-	-
Squam 1 2016	$P = 0$ (57N, 102C)	$P = 0$ (13N, 13C)	P=0.0001 (19N, 19C)	$P = 0.24$ (11N, 11C)	-	$P = 0$ (10N, 25C)	$P = 0.028$ (3N, 4C)	-	$P = 1$
Stump 1 2016	$P = 0.0082$ (2N, 2C)	$P < 0.0001$ (5N, 5C)	$P = 1$ (1N, 1C)	$P < 0.0001$ (2N, 8C)	-	-	$P = 0$ (4N, 18C)	-	-
Ram Pasture 2016	$P = 0$ (98N, 2125C)	$P = 0$ (23N, 132C)	$P = 1$ (31N, 156C)	$P = 0$ (109N, 1363C)	$P = 0$ (65N, 223C)	$P = 0$ (93N, 779C)	$P = 0$ (122N, 6764C)	$P = 1$ (75N, 249C)	$P = 1$ (29N, 65C)
West Hummock 2016	$P = 0$ (6N, 14C)	$P = 0$ (6N, 15C)	$P = 1$ (2N, 2C)	$P = 0.0091$ (4N, 6C)	$P = 0.030$ (1N, 1C)	$P = 1$ (1N, 1C)	$P = 0$ (15N, 24C)	-	$P = 0.\ 20$ (2N, 2C)
Lost Farm 2016	$P = 0$ (12N, 34C)	$P = 0.17$ (1N, 2C)	$P = 1$ (4N, 5C)	$P = 0$ (15N, 26C)	$P < 0.0001$ (3N, 4C)	$P < 0.0001$ (17N, 37C)	$P = 0$ (27N, 341C)	$P = 1$ (9N, 10C)	$P = 0.0003$ (3N, 4C)
Sconset 2016	$P < 0.00001$ (4N, 6C)	$P < 0.0001$ (2N, 4C)	-	-	-	-	-	-	$P = 0.38$ (1N, 1C)
Pout Pond 2016	$P = 0$ (29N, 110C)	-	$P = 0.012$ (2N, 3C)	$P = 1$ (1N, 1C)	$P = 0.28$ (1N, 1C)	$P = 0.073$ (14N, 19C)	$P = 0$ (22N, 30C)	$P = 0.18$ (6N, 6C)	$P < 0.0001$ (7N, 11C)
Beatties 2016	$P = 0.041$ (1N, 1C)	-	-	-	-	-	-	-	-

detected by EchoClass software, was identified ($P < 0.05$) at 4 stations. The Northern Long-eared Bat was identified at 8 stations ($P < 0.05$).

Manual vetting confirmed the presence of Northern Long-eared Bats, Eastern Red Bats, Hoary Bats, Silver-haired Bats, Tricolored Bats, and Big Brown Bats on Nantucket. There is significant overlap in the parameters differentiating calls of *Myotis* species, and expert review did not identify any candidate calls as definitive evidence of Little Brown Bats, Indiana Bats, or Eastern Small-footed Bats.

Seasonal variation in detection rates

We detected bat calls from 30 April through 11 November 2015 and 2 May to 12 December 2016. Bats were present on 19–84% of nights surveyed at each station, with lower detection-rates during late fall (Fig. 2). We demonstrated a significant effect of season on likelihood of bat detection ($F_{(4,54)} = 2.81$, $P = 0.034$), with detection rates significantly lower on nights in the late season compared to the volancy period ($P_{adj} = 0.013$). There was no effect of season on likelihood of detection ($P > 0.05$) of any individual species or *Myotis* spp. as identified by KaleidoscopePro. This result was likely due to low identification rates by the auto-classification software, resulting in low detection-rates for species at most stations across all seasons.

Based on manual vetting, *Myotis* spp. were present from 30 April–21 October 2015, and on most warm nights between 2 May–26 November 2016, with particularly

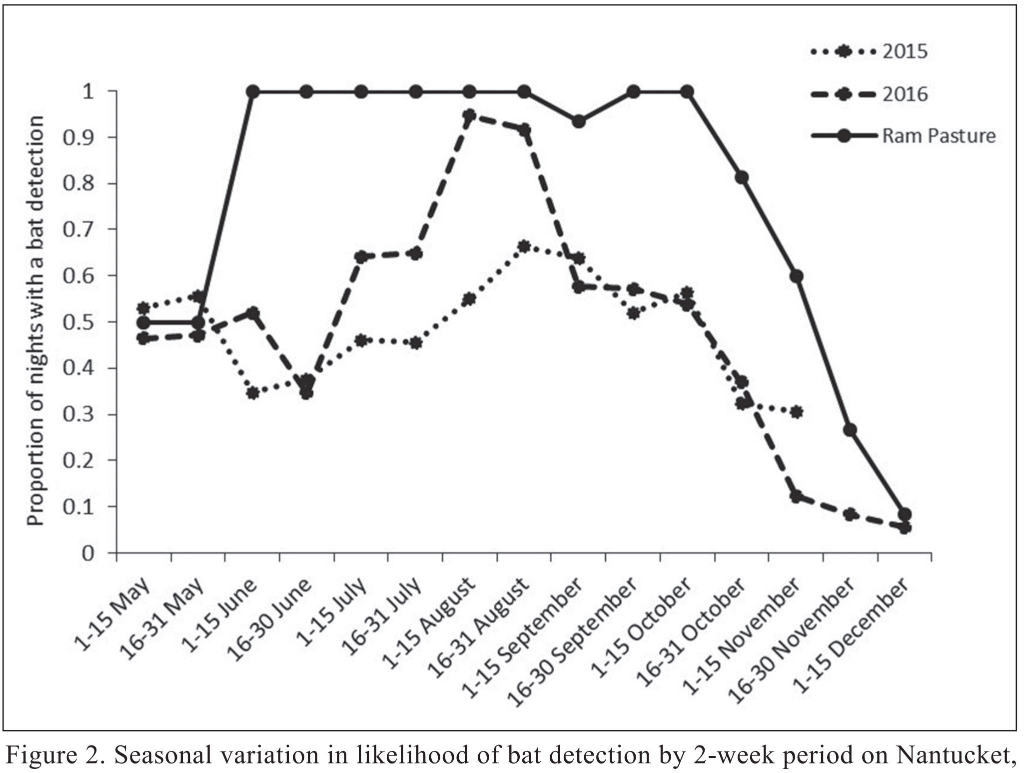

Figure 2. Seasonal variation in likelihood of bat detection by 2-week period on Nantucket, MA, in 2015 and 2016. Values are summed across all stations by year, except Ram Pasture (sampled 2016) is displayed separately, due to unusually high detection rates.

high detection rates at the Ram Pasture and Lost Farm sites in 2016. We detected Tri-colored Bats on 29 July 2016, on several isolated nights in September and October 2015, and on 8–9 November 2016; a final call was recorded 12 December 2016 at the Lost Farm site, following an unseasonably warm day (high of 12 °C, 7 °C at dusk). Manual vetting also confirmed that Eastern Red Bats were widespread, and they were recorded frequently every month from 15 May–15 November 2015 and 2 May–27 November 2016. Hoary Bat calls were primarily recorded during the migration seasons (2015: 9–29 May, 9 August–13 October; 2016: 12 August–25 September), but there were isolated detections during the maternity period in June 2015 and early July 2016. We detected Silver-haired Bats in 2015 from 27 October to 5 November, with 2 distinct peaks (27 August–1 September, and 14–16 September), whereas in 2016, we detected Silver-haired Bats from 26 July to 30 October with no peaks in activity. There were several confirmed calls in June.

Bat capture, tagging, and tracking

We caught a total of 13 bats on Nantucket in 2016, all of which were Northern Long-eared Bats (Table 4). We captured 9 bats in 2.25 h of trapping on 20 July 2016, and radio-tagged 3 lactating females. We relocated 2 tagged bats for 2 days each before they dropped their tags. One tagged bat utilized a roost at a private residence ~1.9 km from the capture site on 22 July and 23 July, where it appeared to be roosting on the side of a house under a trim board. We tracked a second bat to a *Pinus rigida* Mill. (Pitch Pine) snag ~200 m from the capture site in a pine stand on 21 July. That evening, we observed 11 bats emerging from a long crack in the tree. On 22 July, we tracked the bat to a second roost in a live Pitch Pine ~130 m from the first tree and ~140 m from the capture site. Two observers saw 9 and 20 bats, respectively, in the vicinity of the tree on the night of 22 July, but they could not identify the emergence location.

Table 4. Morphological data and tracking information for Northern Long-eared Bats captured on Nantucket, MA.

Capture date	Capture location	Bat ID	Age	Sex	Reproductive status	Forearm length (mm)	Body mass (g)	Days tracked	Roosts
20 July 2016	Ram Pasture	F259	A	F	Lactating	36.9	7.6	2	2
20 July 2016	Ram Pasture	n/a	J	F	Non-reproductive	36.2	5.7	-	-
20 July 2016	Ram Pasture	n/a	J	F	Non-reproductive	37.5	6.4	-	-
20 July 2016	Ram Pasture	F264	A	F	Lactating	36.5	7.1	2	1
20 July 2016	Ram Pasture	n/a	J	F	Non-reproductive	36.7	6.4	-	-
20 July 2016	Ram Pasture	n/a	J	F	Non-reproductive	37.0	6.4	-	-
20 July 2016	Ram Pasture	F247	A	F	Lactating	37.0	6.7	<1	0
20 July 2016	Ram Pasture	n/a	J	M	Non-reproductive	35.8	5.8	-	-
20 July 2016	Ram Pasture	n/a	A	F	Lactating	36.4	7.0	-	-
30 Oct 2016	Ram Pasture	M269	A	M	Non-reproductive	36.1	9.0	12	1
1 Nov 2016	Crawl space	F272	A	F	Non-reproductive	35.3	7.2	7	1
1 Nov 2016	Crawl space	F260	A	F	Post-lactating	36.8	8.7	24	1
1 Nov 2016	Crawl space	M257	A	M	Non-reproductive	35.2	8.4	20	1

We captured and tagged 1 male Northern Long-eared Bat in 2 h of trapping on 30 October 2016 at Ram Pasture. We tracked this bat to a crawl space beneath a house located ~2.4 km from the capture site, where we found it was roosting in association with 4 other Northern Long-eared Bats in narrow (~1 cm) cracks between wooden, sistered floor joists. On 1 November, we hand-captured and radio-tagged 1 additional male and 2 female Northern Long-eared Bats roosting in the crawl space (Table 4). Radio-tags remained on all 4 bats at least through 8 November, when we observed torpid and unresponsive bats in the crawl space. Three of the 4 tagged bats were also intermittently recorded by the nearby automated telemetry station, with variation in signal strength demonstrating tags remained on these bats for at least 12–24 days after tagging. Manual tracking further indicated tags of all 4 bats were located in the crawl space through the end of radio-tag battery life on 8 December, and no tagged bats were recorded by coastal or off-island telemetry stations. Based on variations in signal strength recorded by the local automated telemetry station, bats were active in the evening hours (16:00–19:00) following relatively warm days in early–mid November, but it was not clear if bats were simply changing positions within the roost or making short forays outside. No bats exited the roost during an emergence survey on 1 warm (>10 °C) evening (3 November). The crawl space was open to the outside via a ~0.6 m x 1.0 m hole which was closed on 27 November, but small (~2-cm wide) cracks along boards covering basement window holes remained, providing potential points of egress. On 24 February 2017, a researcher re-entered the crawl space and found 1 torpid Northern Long-eared Bat with no visible signs of disease. Relative humidity within the crawl space remained above 85% throughout the hibernation season (15 November 2016 to 15 April 2017), and recorded temperatures remained between 6.5 °C to 15 °C (Fig. 3). The crawl space was warmed by water pipes running beneath the house, and the dirt floor may have helped maintain humid conditions.

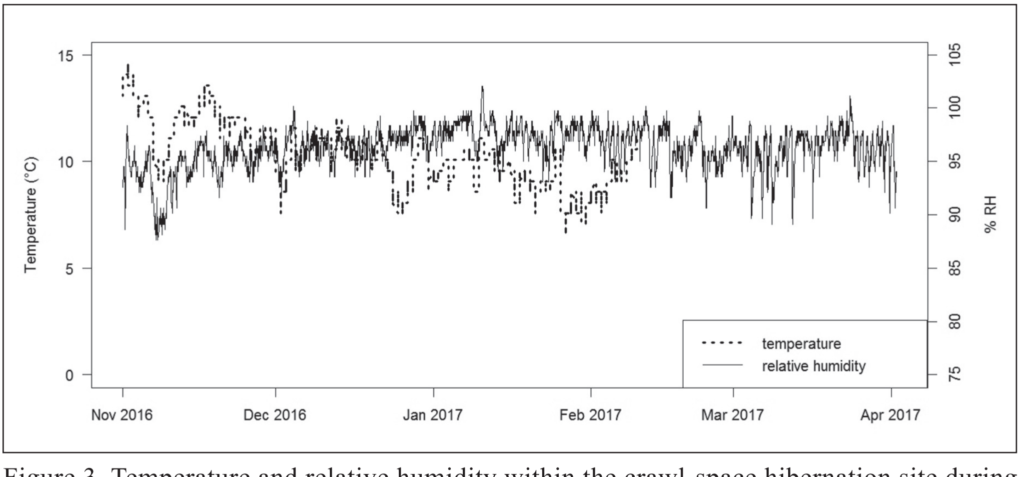

Figure 3. Temperature and relative humidity within the crawl-space hibernation site during the hibernation period (15 November 2016–15 April 2017). Temperature logger failed to collect data after 24 February 2017.

Discussion

Species presence

This is the first inventory of bat species on Nantucket. Using acoustic detection, we documented the presence of 3 long-distance migratory tree-bat species at multiple locations on the island. These 3 species were previously collected on Nantucket during the spring and fall in the 1950s–1970s (Maria Mitchell Association 2017), and existing evidence suggests that these migratory species use coastal and island areas along the Eastern Seaboard during migration (Cryan and Brown 2007; Johnson et al. 2011a; Peterson et al. 2014, 2016; Sjollema et al. 2014; Smith and McWilliams 2016). We detected Silver-haired and Hoary Bats primarily during the spring and fall migration seasons, but Eastern Red Bats were detected frequently throughout the active season from early May to late November. Previous studies describe peaks of migratory activity in which high capture-rates in mist-nets, bats roosting in visible numbers, or high numbers of calls indicate waves of migration, possibly associated with favorable weather conditions (e.g., Cryan 2003; Cryan and Brown 2007; Divoll 2012; McGuire et al. 2012; Peterson et al. 2014, 2016). We observed qualitative evidence for this behavior in 2015 among Silver-haired Bats, with peaks of activity that spanned multiple sites from 27 August to 1 September, and again during 14–19 September. We did not observe similar peaks of activity in 2016 among Silver-haired Bats, or among Hoary Bats or Eastern Red Bats in either year. The presence of Eastern Red Bats during the maternity and volancy periods suggests they could be forming maternity colonies on the island. Cryan (2003) documented both sexes moving into New England in the summer based on analysis of museum-specimen collections, and the species has been recorded in inland Massachusetts during summer (Brooks 2011).

Through acoustics, we also documented the presence of *Myotis* species on Nantucket, including the federally threatened Northern Long-eared Bat. Auto-classification software identified Little Brown Bats, Indiana Bats and Eastern Small-footed Bats as present at multiple sites on the island, but we did not identify any definitive calls of these species in the manual vetting process. The last known observation of the Indiana Bat in Massachusetts was in 1939 (MANHESP 2012). The historic summer range of this species is poorly known; there are no records from southeastern Massachusetts (Thomson 1982). Formerly, the species was known to hibernate at sites in Berkshire and Hampden counties (MANHESP 2012). Further mist-netting efforts may reveal whether other *Myotis* spp. are present on Nantucket. We also recorded Big Brown Bats and Tricolored Bats on Nantucket. The final acoustic detection of a Tricolored Bat was in mid-December, which indicates this species may over-winter on Nantucket.

Northern Long-eared Bats

Northern Long-eared Bats appear to be successfully reproducing and hibernating on the island. We captured 9 Northern Long-eared Bats in summer 2016 and 4 Northern Long-eared Bats in the fall. Bats captured in July included both lactating females and volant juveniles of both sexes. Based on emergence counts, the maternity colony we identified comprised at least 11 individuals, and may have included 20 or more. Capture rates at the Ram Pasture site were high compared to other locations in the Northeast, with 4.0 Northern Long-eared Bats per hour in July, and 0.5 per hour in October. Acoustic activity suggests that Northern Long-eared Bats were present at the capture site through much of the active season, from early May into early December. Northern Long-eared Bats were also detected at other stations on the island from the time acoustic detectors were first deployed in late April through early December.

In the fall, Northern Long-eared Bats captured at a hibernation site in a crawl space included males and females of healthy weight (7.2–9.0 g). Although bats appeared torpid during an inspection of the hibernaculum on 8 November, automated tracking data suggests that bats were intermittently active within the hibernaculum on seasonably warm evenings through mid-November. Final automated detections were 12–24 d after tagging, but we manually detected the tags in the hibernation site through early December, presumably through the end of tag-battery life. Conditions within the hibernation site fell within the range suitable for hibernating *Myotis* spp. (Brack 2007, Johnson et al. 2016, Thomas and Cloutier 1992, Webb et al. 1996). The relatively mild temperatures could promote the growth of *Pseudogymnoascus destructans* Gargus (White-nose Fungus), which grows optimally at 12.5–15.8 °C (Verant et al. 2012); however, there were no visible signs of disease on the bat we observed in the hibernaculum on 24 February 2017. The persistence of Northern Long-eared Bats on Nantucket and at other coastal locations could indicate some bats may be hibernating locally in habitat not conducive to the spread of WNS, rather than travelling to infected inland hibernacula. If coastal areas are serving as refugia from WNS, persistent populations in these areas could be a focus for conservation of cave-hibernating bats.

Northern Long-eared Bats traditionally are considered "deep forest" bats that forage in habitats with a high level of vegetative clutter and roost in trees. However, they also utilize human-made structures as roost sites where natural roost habitat is limited (Henderson and Broders 2008). On Martha's Vineyard, 36% of Northern Long-eared Bat summer roosts were in human structures, and bats were often found roosting under rakeboards on houses, where trim boards intersected with shingles below the roof line (Baldwin et al. 2017). On Cape Cod, Northern Long-eared Bats primarily used human structures as roost sites (Curry 2016). We found bats utilizing both house and tree roosts during the maternity period. Given the common use of cedar shingles as siding on houses on Nantucket, there may be a profusion of human-made roosts on the island, which mimic natural roosts and are utilized by this species. Both tree roosts we documented were in Pitch Pines, including 1 cavity roost in a pine snag, a common roost type in pine-dominated forests (Perry and Thill 2007). Measured characteristics of maternity-roosting behavior were within the range of those documented in other studies. Colony sizes of 10–30 individuals are thought to be typical, and females in maternity colonies switch roosts on average every 2 days (Silvis et al. 2016).

Even within our small sample, we documented high variability in distances bats traveled (several hundred meters to 1.9 km) between the point of capture and maternity-roost sites, with the latter distance exceeding the maximum recorded distance for a female bat from capture site to maternity roost on Martha's Vineyard (Dowling et al. 2017). Average distances from capture site to roost recorded for Northern Long-eared Bats are <0.7 km, although longer distances have been reported in the literature (2.7 km; Silvis et al. 2016). In the Yukon, Randall et al. (2014) found that female Little Brown Bats commuted longer distances to foraging areas than males of the species and hypothesized this was due to limited roost-habitat appropriate for maternity colonies.

It is uncertain whether natural roost habitat is limited for Northern Long-eared Bats on Nantucket, but the island has relatively few stands of mature trees and only 12% forest cover (The Nature Conservancy 1998). In this respect, Nantucket represents a fairly unique habitat for this species. Numerous studies have documented a preference among Northern Long-eared Bats for large tracts of intact forest for foraging and roosting. Although these bats are known to occur in forests under a variety of management and cutting regimes (e.g., Menzel et al. 2002; Owen et al. 2001, 2003; Perry et al. 2007), they avoid clear cuts (Owen et al. 2004, Patriquin and Barclay 2003), are uncommon in open landscapes (Henderson and Broders 2008, Owen et al. 2003), and are less likely to occur in fragmented forest stands (Henderson et al. 2008, Morris et al. 2010, Yates and Muzika 2006). We detected the widespread occurrence (8 of 15 stations) of Northern Long-eared Bats on Nantucket, including where the predominant vegetation was <6-m tall *Quercus ilicifolia* Wangenh. (Scrub Oak). However, our acoustic sampling was somewhat opportunistic and focused on areas we deemed potential bat habitat; all sites where we identified Northern Long-eared Bats were within ~500 m of a forested area. Ram Pasture and Lost Farm had consistently high detection rates of Northern Long-eared Bats and were located adjacent to mature Pitch Pine stands.

If Northern Long-eared Bats on Nantucket do rely on mature-forest patches for roosting or foraging habitat, this could have significant management implications for land-conservation organizations. The island has been the focus of extensive efforts to restore and preserve coastal sandplain grassland, heathland, and scrubland. Cutting, mowing, prescribed burns, and grazing have all been used as management tools to conserve species that rely on early-successional habitats (Omand et al. 2014, Zuckerberg and Vickery 2006). Although some consider these efforts a means to maintain the natural landscape, the Cape and Islands region was likely originally dominated by forests of pine, oak, and hardwood communities, which were lost following European colonization (Foster and Motzkin 2003). Foster and Motzkin (2003) argued that this history does not invalidate the current biological and cultural value of early successional habitats, but note that management should be conducted with clear policy objectives in mind, as well as an understanding of the region's ecological history. In general, populations of woodland species are increasing across the Northeast; nevertheless, the regional decline of the Northern Long-eared Bat and other forest bats necessitates consideration of these species in management planning in places where they persist. Further research is warranted to determine whether management of protected lands in the Cape and Islands region should include maintenance of hardwood and pine forest patches for Northern Long-eared Bats.

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