

Efficacy of autonomous recording units to evaluate wild turkey gobbling chronology in North Carolina, USA

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Abstract

Wild turkey (*Meleagris gallopavo*) gobbling is a key component of hunter satisfaction, also providing insight into the underlying reproductive ecology of wild turkeys that can inform regulatory decisions. However, monitoring gobbling chronology over large geographic areas can be logistically challenging and identifying efficient monitoring schemes can help wildlife agencies better manage the species. We evaluated the efficacy and utility of autonomous recording units (ARUs) to detect wild turkey gobbles and deployed 51 ARUs to monitor gobbling chronology in North Carolina, USA. We conducted controlled field-tests at 20 locations to compare how detection of gobbles differed by ARU software, manual review of ARUs, and in-field human observers. Autonomous detections had the lowest probability, with detection probabilities approaching 0 at 300 m from the ARU. Autonomous detections of gobbles were affected by leaf-on conditions and topographical interference while vegetation type surrounding ARUs had minimal and inconsistent effects on detection. We deployed ARUs on properties with little or no turkey hunting across North Carolina from March–May during 2016 through 2019 to explore annual and regional variation in gobbling chronology. We used ARUs to monitor gobbling chronology and recorded 53,943 hours of audio files from which we confirmed 113,737 gobbles out of a total of 602,053 possible sound events

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identified. We identified multimodal gobbling chronology across 3 primary physiographic regions in North Carolina. We also found comparable timing of gobbling chronology across the 3 regions, with 57–61% of gobbling occurring during the weeks in which hunting seasons occur. We recommend that researchers validate ARU performance to calibrate monitoring of gobbling chronology. Additionally, our gobbling chronology data suggest that a statewide framework, rather than a regionally split framework, is appropriate for wild turkey hunting in North Carolina.

KEYWORDS

Autonomous recording unit, gobbling chronology, *Meleagris gallopavo*, North Carolina, wild turkey

The timing of male wild turkey (*Meleagris gallopavo*) gobbling (i.e., gobbling chronology) is vital to proper regulatory management by state wildlife agencies, as it can provide insight to wild turkey biology and hunter satisfaction. Hunters generally desire earlier and longer seasons, but season timing must also safeguard the population against potential impacts of overharvesting males, harvesting males before breeding occurs, and the illegal or inadvertent harvest of hens (Kimmel and Kurzejeski 1985, Norman et al. 2001, Whitaker et al. 2005, Isabelle et al. 2018, Wightman et al. 2019).

Regional and seasonal variation in gobbling and nesting chronology can complicate the ability to identify appropriate opening and closing dates for spring turkey hunting seasons. Though springtime patterns of gobbling activity have been investigated for many years, the underlying mechanism driving variation remains unclear and can limit regulatory management. Some support exists for environmental factors such as weather (Kienzler et al. 1996, Palumbo et al. 2019) and hunting pressure (Miller et al. 1997b, Lehman et al. 2005, Wightman et al. 2019) as drivers of gobbling, but these may not be the only factors causing variation in gobbling chronology. Across the United States, there tends to be regional variation in opening and closing dates for the spring hunting season, where seasons in northern states (e.g., Maine) are later than southern states (e.g., Florida), presumably as a result of phenological differences (e.g., later gobbling and breeding) as well as hunter interest (Whitaker et al. 2005, Isabelle et al. 2018). Palumbo et al. (2019) identified substantial within-state differences in gobbling chronology with respect to latitude within Mississippi, USA, suggesting there is evidence of variation in gobbling chronology across smaller geographic areas.

Several studies investigated gobbling chronology on relatively small scales (i.e., specific Wildlife Management Areas [WMAs] or within-state regions) and by human observers and have identified a bimodal pattern in gobbling chronology through the spring (Bevill 1973, Bevill 1975, Hoffman 1990, Lehman et al. 2005), with 1 peak occurring just after winter flocks break up and a second peak after females begin incubating nests. Interestingly, no support for bimodal chronology has been found when analyzed at much larger scales (i.e. state-level) or when using newer technology such as autonomous recording units (ARUs; Kienzler et al. 1996, Norman et al. 2001, Chamberlain et al. 2018, Palumbo et al. 2019, Wightman et al. 2019). Wild turkey research conducted in North Carolina has provided some information about nesting chronology, with information indicating peak female incubation dates occurring in late April (Reed 1988, Davis 1992, Cobb et al. 1993, Kilburg et al. 2014), but state-specific gobbling chronology data are lacking and could be an important component for determining proper timing of hunting regulations.

Autonomous recording units provide considerable potential for wildlife research, especially for avian ecology, and can readily be used to provide state-specific gobbling chronology information (Colbert et al. 2015, Schonfield and Bayne 2017,

Chamberlain et al. 2018, Wightman et al. 2019). Chief among ARU advantages is the opportunity to survey for vocalizing birds over much greater time spans than logistically feasible via traditional human-based survey techniques (Colbert et al. 2015, Schonfield and Bayne 2017, Wightman et al. 2019). Also, ARUs offer the opportunity to detect an equal or greater number of bird species compared to traditional human surveys (Chimchome 2004) and can provide insight into optimal survey dates and times (Thompson et al. 2017). Autonomous recording units provide an opportunity to reduce potential bias associated with multiple human observers and eliminate the influence of the presence of humans carrying out surveys in the field (Schonfield and Bayne 2017).

Although ARUs have many advantages, there are potential drawbacks and limitations. Surveying across large geographic areas may not be feasible due to financial and logistical challenges associated with ARUs. When using species recognition software, ARU-based studies may detect fewer species' occurrences and at shorter distances (Schonfield and Bayne 2017). Autonomous recording units and associated equipment can be costly, and time and effort required to develop species recognition software can add appreciably to overall study costs. When ARUs are deployed for long periods of time, detection probabilities may decline as a result of microphone deterioration (Turgeon et al. 2017) or potentially from weather or other changing environmental factors. Researchers must consider whether ARU detection probability is consistent over space and time during the sampling period, especially in spring when leaf-on conditions occur, and under different field conditions.

Since 2006, the North Carolina Wildlife Resources Commission's (NCWRC) goal for wild turkey management has been to emphasize spring hunting by managing the population below maximum sustained yield to maintain high quality spring hunting and maximize continued increases in population size and distribution (Seamster 2016). The NCWRC continues to receive numerous hunter requests for earlier opening dates, and the frequency and timing of these requests varies across the state, suggesting there may be within-state variation in gobbling chronology. The NCWRC has implemented relatively consistent spring turkey hunting regulations for several decades, but until 1980 afforded hunting seasons that opened 1 week earlier in the southeastern part of North Carolina than the rest of the state. North Carolina's turkey hunting regulations have assumed an underlying bimodal pattern of gobbling activity, but little data exists to support this contention. A more thorough understanding of gobbling chronology, from data collected within the state, may provide more confidence in regulatory decisions, which may ultimately result in more robust turkey populations and higher levels of hunter satisfaction. Likewise, a critical evaluation of the limitations and potential biases of ARUs under different field conditions is needed to support confident regulatory decisions that rely on ARU-derived data. Our objectives were to 1) evaluate the efficacy and utility of ARUs and autonomous software to detect wild turkey gobbles under a variety of conditions including how they compare to human observers and 2) use ARUs to explore spatial and temporal variation in gobbling chronology across North Carolina and determine if gobbling peaks earlier in eastern North Carolina where the spring hunting season historically opened earlier.

STUDY AREA

We deployed ARUs at 94 locations on 60 properties in 41 counties across North Carolina's 3 physiographic regions (Figure 1). North Carolina spans approximately 800 km from east to west and 300 km from north to south, with elevations ranging from sea level to >1,800 m in the mountain region. The coastal region, comprised of 55,412 km², is characterized by southern pine (*Pinus* spp.) forests, large agricultural fields, and forested wetlands. The piedmont region, comprised of 48,842 km², is characterized by a mix of agriculture and pine and hardwood forests. The mountain region, comprised of 24,374 km², is characterized by hardwood forests and climatic conditions characteristic of more northern regions. To the greatest extent possible, we selected properties that were large, had robust turkey populations, and received little to no turkey hunting pressure. Sixty-three sampling locations were on privately-owned properties and the remaining 31 on publicly-owned lands (North Carolina State Parks, North Carolina State Forests, North Carolina Zoo land, North Carolina Department of Agriculture lands, Orange Sewer and Water Authority). On all properties, turkey hunting was either prohibited or not a primary activity of the landowner.

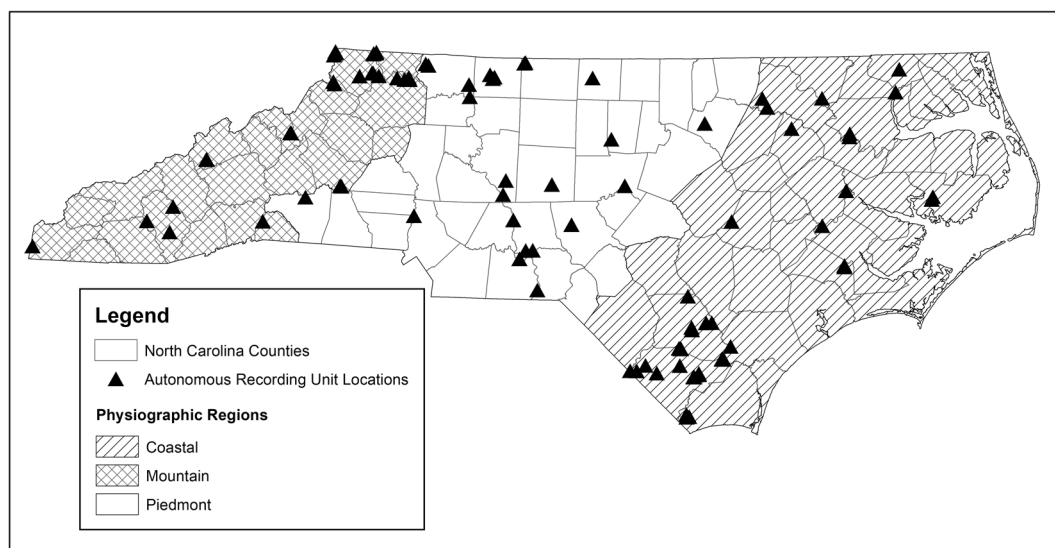


FIGURE 1 Locations in North Carolina, USA, where we deployed autonomous recording units to evaluate their utility and efficacy for detecting wild turkey gobbles during 2016–2019.

We did not include any properties enrolled in North Carolina's Game Land program. Property size varied from several hundred hectares to smaller parcels nested within areas where the surrounding landscape exhibited the low hunting pressure we desired. Properties were distributed equally among NCWRC's 9 administrative districts so that each of North Carolina's 3 physiographic regions were well represented.

METHODS

ARU evaluation

We conducted controlled field tests at 20 of the 94 ARU locations to evaluate how human detection of turkey gobbles (field listener) differed from ARUs, where ARUs were evaluated both autonomously through software (automatic detection) and manual review of ARU sound recordings (manual review). To do so, we used playback devices and a pre-recorded sound file of wild turkey gobbles. We selected 10 clear, representative gobbles from audio files recorded on ARUs in 2016. We condensed these 10 gobbles into a single 1-minute file that would systematically play a gobble every 3 seconds, such that the set of 10 gobbles played twice. We loaded the sound file into FoxPro Spitfire and Patriot game calls equipped with an SP70 external speaker (FoxPro Inc., Lewistown, PA, USA) and played the recording in the field with settings adjusted so that gobbles played at 65 decibels when measured 9 meters directly in front of the speaker (Colbert et al. 2015).

At each ARU, we chose a 300 m, straight-line transect that would extend well beyond the maximum distance previously reported for ARU detection of gobbles (Colbert et al. 2015), beginning at the tree to which the ARU was attached. Starting 50 m from the ARU, we played the gobble recording, with the speaker held 1 m above ground, 1 time each at 50-meter increments in distance from the ARU, for a total of 6 times per transect. We determined the 50 m increments by pacing. When time and personnel allowed, at 11 of the 20 ARU locations, we chose a second 300 m straight line transect from the same ARU, and again played the gobble file at 50 m increments. In order to evaluate potential effects of leaf-on conditions occurring in spring, we played the gobble recording along each transect before leaf-on conditions occurred in February or March and again along each transect in June after

leaf-on conditions were present. Each time the gobble recording was played, we recorded several pieces of information: distance from ARU, whether vegetation interrupted the line of sight from ARU to the player, whether topography blocked a straight line from ARU to player, and estimated wind on Beaufort scale. A human observer (field listener) stood by the ARU and recorded the number of played gobbles heard, except in a few cases (4.8%) when personnel were not available, with 10 different observers used throughout our study. In total, we played 7,440 gobbles to evaluate ARU efficiency and 7,080 of these could be used to evaluate human observers. We used Raven Pro 1.5 software (Cornell Laboratory of Ornithology, Ithaca, NY, USA) to determine the number of played gobbles that were detected autonomously with the Band Limited Energy Detector procedures described below. We also determined the number of gobbles detected through a manual review of listening to the audio file and examining the spectrogram with Raven Pro 1.5, with all manual reviews completed by C. Kreh.

Detecting spatial and temporal trends in North Carolina

We deployed ARUs (Song meter model SM3, Wildlife Acoustics, Concord, MA, USA) from late February through early June 2016–2019 across North Carolina, USA to explore spatial and temporal variation in gobbling chronology. In 2016, trained NCWRC biologists deployed 25 recorders in 6 counties in northwestern North Carolina and 25 recorders in 3 counties in southeastern North Carolina. We used preliminary data from 2016 to identify 6 locations in southeastern North Carolina and 6 locations in northwestern North Carolina that yielded the highest number of gobbles and again deployed ARUs on those sites in 2017. During 2017, we deployed 39 ARUs such that each of the NCWRC's 9 administrative districts had at least 5 ARUs. In 2018 and 2019, we again deployed ARUs at the locations used in 2017, except for 5 locations that had yielded fewer than 100 gobbles in 2017. We selected new locations for the 5 ARUs, from 0.6 kilometers to 29 kilometers from the previous locations, in areas where we expected to collect substantially more gobbles. Later examination of ARU data revealed a maximum detection distance of 300 m, thus we omitted 1 ARU that was within 500 meters from another unit to avoid double counting. All remaining ARUs were located more than 600 m from neighboring ARU devices. We created buffers with a radius of 200 m (Colbert et al. 2015) around each ARU location and categorized vegetation conditions as forest-deciduous when a forest was composed of 50% or more deciduous vegetation, as forest-non-deciduous when forests were composed of less than 50% deciduous vegetation, and as open to describe non-forested areas such as fields, pastures, and other situations where vegetation was less than 2 meters high. Habitat assessments were made subjectively by field biologists and did not involve quantitative vegetative measurements. We used ArcMap 10.2 (ESRI, Redlands, CA, USA) to calculate the proportion of each habitat type within 200 m of each ARU.

We programmed ARUs with SM3 Configurator software (Wildlife Acoustics, Concord, MA, USA) to record on both external microphones with high pass filter set to off, gain set to automatic, file type set to .wav format, and sampling rate of 16 kHz. Zero-crossing and trigger levels were not used. In 2016, ARUs recorded 5 hours each day, beginning 1 hour before sunrise, with each ARU checked in April of 2016 to replenish SDHC cards and batteries. Preliminary data from 2016 led us to adjust the program so that ARUs deployed 2017 through 2019 recorded 2.5 hours each day, beginning 30 minutes before sunrise, with no requirement to replace SDHC cards or batteries in April of those years. Autonomous recording units were placed inside metal security boxes and bolted to trees approximately 2 m above ground, except for a few sites where potential theft or prescribed fire necessitated placing them approximately 4 m above ground.

We used Raven Pro 1.5 to identify potential gobbles in ARU recordings via a Band Limited Energy Detector (BLED) using the following settings: 775–1050 Hz, minimum duration 0.49806 seconds, maximum duration 1.18769 seconds, minimum separation 0.26819 seconds, minimum occupancy 40%, signal to noise threshold 10 dB, block size 5.01894 seconds, hop size 1.99225 seconds, percentile 20, screen resolution 1225. Other parameters for the BLED setting were unchanged from default settings or not used. The BLED was used to select sounds matching the parameters of gobbles occurring in audio files recorded by either of the ARUs external microphones. We used

Microsoft Excel (Microsoft, Redmond, WA, USA) to examine the BLED results and remove duplicate selections that occurred when sounds were identified on both channels. We verified the BLED results by visually and aurally examining the selected sounds and categorized them as either true positives (i.e., gobbles) or false positives (i.e., woodpeckers, crows, or other background sounds). We used the full set of gobbles found autonomously by Raven Pro's BLED and verified by employees to examine patterns in gobbling chronology.

Evaluating ARU detectability

We modeled detection probability as a function of main effects thought to affect the detection process of ARUs and human field observers (Table 1). All main effects were factors (i.e., categorical predictors) and modeled as additive effects, each interacting with distance to reflect that the strength of these main effects was dependent on distance from the ARU. We modeled each observation type (field listener, manual review, or automatic detection) separately to simplify the interpretation of the results. We assumed that the number of gobbling detections y detected at distance d at site i was distributed as a binomial random variable, the intercept represents the mean detection probability for a given observation type at the reference level of all factor covariates, and subsequent parameter estimates (i.e., regression coefficients) represent the difference between the reference group and each level of a factor. We used corner constraints so that the effect of the reference group for each factor is set to 0.

Spatial and temporal trends of gobbling chronology in North Carolina

There are 2 common approaches for identifying peaks (i.e., modes) in distributions: (1) Gaussian mixture models and (2) kernel density estimation (KDE), with the latter removing the parametric assumptions imposed by the first approach (Mukhopadhyay 2017). Here we used KDE to describe gobbling chronology across physiographic regions within the state of North Carolina and among years surveyed. Kernel density estimation is a distance weighted function (i.e., uses distances between a given observation and the other observations in a sample) that returns the probability density function for a given random variable, and depends on 1 user-supplied parameter, bandwidth, to determine the smoothness of the distribution. To determine bandwidth in our estimator, we used methods described by Silverman (1981), later refined by Hall and York (2001), to determine region- and year-specific critical bandwidths for each KDE; critical bandwidths describe bandwidth values in KDEs that are between transitions in

TABLE 1 List of main effect factors and associated levels that were used to model the probability of detecting wild turkey gobbles by autonomous recording units (ARU) and human observers. All main effects were factors and modeled as additive effects, each interacting with distance to reflect that the strength of the main effects was dependent on distance. These effects were modeled from data derived from playing recorded wild turkey gobbles in the field in North Carolina, USA during 2016–2019.

Main effects	Levels					
Distance (meters)	50	100	150	200	250	300
Cover type	Forest-Non deciduous	Forest-Deciduous	Open			
Vegetation	Leaf off	Leaf on				
ARU Visibility due to vegetation	Yes	No				
ARU visibility due to topography	Yes	No				
Wind (categories)	0	1	2	3	4	5

the number of peaks (e.g., a bandwidth value right before the transition from 2 to 3 peaks). We used an excess mass test to determine whether gobbling activities exhibited multimodality (i.e., a distribution of activity with greater than 1 peak; Ameijeiras-Alonso et al. 2019); this tests a null hypothesis of the true number of modes being equal to 1. For the excess mass test, we used the week an observation occurred as our response variable. We included gobbling data from the 13 complete weeks from 1 March through 30 May each year. Data collected before and after the 13-week period were censored from our analysis. Detection of gobbles, however, was likely observed imperfectly (i.e., false negative detections), thus we corrected the count of observations during a given week to acknowledge a priori differences in environmental conditions and seasonality.

We estimated an ARU detection probability during our survey period based on our results from the ARU evaluation (described above). Again, we modeled the number of gobbles detected y at site i as a binomial random variable:

$$y_i \sim \text{Binomial}(\mu_i, N)$$

$$\text{logit}(\mu_i) = \beta_0 + \beta_1 * \text{Region}_i + \beta_2 * \text{Leaf}_i + \beta_3 * \text{Cover}_i$$

where β_0 represents the mean detection probability at the reference level of all factors, and subsequent parameter estimates represent the difference between the reference group and each level of a factor. Region is a categorical predictor describing the North Carolina ecoregion in which an ARU was deployed. Leaf is a binary predictor representing whether deciduous shrub and tree species were in leaf-on conditions. For each location at which we deployed an ARU, we determined the average 2014–2019 first bloom date from the National Phenology Network (Schwartz et al. 2012) as an estimate of when ARUs began to be affected by leaf-on conditions occurring in spring. We used the average first bloom date from 2014–2019 for each site, rather than a unique date each year, since we were missing first bloom data at some sites and years. Cover is also a categorical predictor based on our categorization of vegetation conditions surrounding the ARU. To determine the vegetation conditions surrounding an ARU, we used 200 m buffers and calculated the proportion of open, deciduous forest, and coniferous forest within the buffer. If the value was greater than or equal to 0.5, that ARU was categorized with the cover type meeting that criterion. Categorizing each ARU in this fashion allowed us to obtain a detection probability for each combination of main effects described above which was used to correct the number of gobbles detected (i.e., multiply the count of gobbles during a given week by the detection probability). Following this correction, our primary interests were whether the range of gobbling was constant across space and time and whether there was variation in peak gobbling.

We estimated parameters in all ARU evaluation analyses using a Bayesian approach with Markov chain Monte Carlo (MCMC) implemented in JAGS (Plummer 2003) accessed through program R (R Core Team 2019) using package JagsUI (Kellner 2015). Additional file and data manipulation was done using packages data.table (Dowle and Srinivasan 2019), abind (Plate and Heiberger 2016), and here (Müller 2017). Data visualization was done using packages ggplot2 (Wickham 2016). We generated 3 chains of 10,000 iterations after a burn-in of 10,000 iterations with no thinning. Convergence was evaluated by inspecting trace plots and checking whether the Gelman-Rubin statistic was less than 1.1. We used a beta distribution with both shape parameters set to 1 for uninformative conjugate priors across all covariate effects. We evaluated strength of effects by whether the 95% credible intervals overlapped 0.

RESULTS

ARU testing

Overall, field observers had the highest probability of detecting a gobbler across all distances, although manual review of ARUs had comparable detection probabilities (Figure 2). Automatic software detection of ARUs had the lowest detection probabilities across all distances, with probability of detecting a gobbler approaching 0 at 300 m

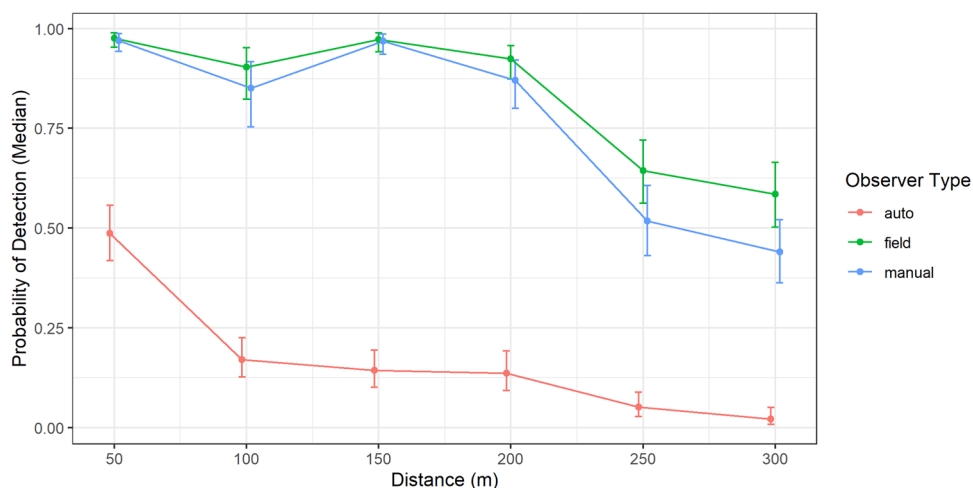


FIGURE 2 Estimated probabilities of detecting recorded wild turkey gobbles played in the field, by three different methods of observation in North Carolina, USA. Methods were human observers listening in the field, a manual review by a human of recordings made by autonomous recording units, and automated software review of recordings made by autonomous recording units.

from an ARU device. Specifically, mean detection probability at 50 m was 0.97 (95% CI = 0.95–0.99) for field observers, 0.97 (95% CI = 0.94–0.99) for manual review, and 0.49 (95% CI = 0.42–0.56) for automatic software detection.

We found mixed effects of field conditions on detecting gobbles. Leaf-off or on conditions had the most consistent, negative impact on field observers' probability of detecting a gobbler at nearly all distance bins, but magnitude of change in detection during leaf-on conditions was negligible (Figure 3). Leaf-on conditions decreased automatic software detections at distances greater than 150 m but had no measurable effect on manual review of detections (Figure 3). In general, vegetation type surrounding an ARU had minimal and inconsistent effects of the detection process with a majority of 95% credible intervals overlapping across all observer types and distance bins (Figure 4). Field observers tended to better detect gobblers in coniferous vegetation, but this was only apparent at distances less than 200 m, whereas automatic software detections increased in open conditions, although this again was most notable at distances less than 150 m (Figure 4). We found greater effects of topography-obstructed line-of-sight than vegetation-obstructed line-of-sight on whether a gobbler was detected (Figures 5 and 6). Topography negatively affected the detection process for distances up to 150 m for automatic detection by software, whereas we observed a negative effect on field observers for all distance bins tested (Figure 6).

ARU deployment across North Carolina

From 53,943 hours of ARU recordings from 1 March through 30 May of 2016–2019, our BLED identified a total of 602,053 sound events meeting the criteria of settings we used in Raven Pro's BLED (Table 2). We visually and aurally confirmed 113,737 (18.9%) of those sound events as gobblers. Autonomous recording units were deployed for a total of 18,463 recorder-days during the 1 March through 30 May time period and recorded audio files as programmed on 17,509 (94.8%) of those recorder-days. Autonomous recording units failed to record properly on 363 recorder-days in District 3 because of improper deployment and failed to record properly on 591 recorder-days at a variety of sites due to battery failure or equipment malfunction.

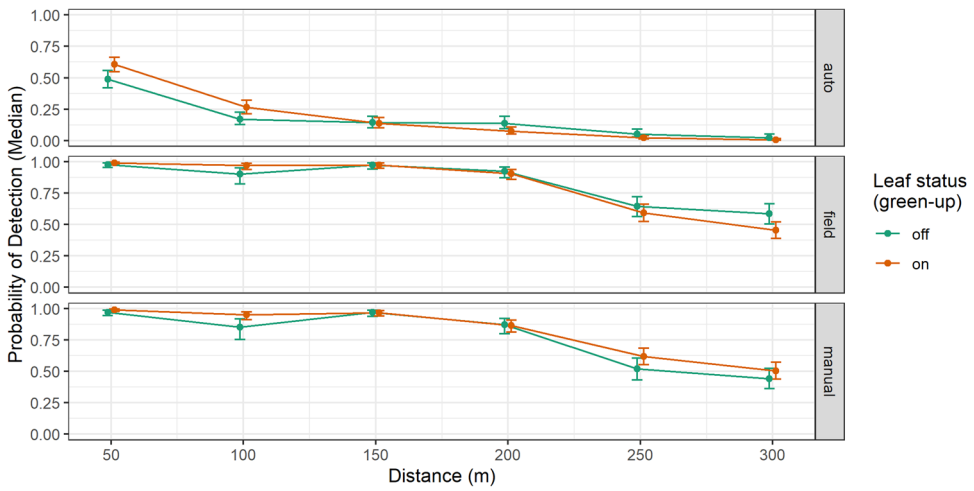


FIGURE 3 Estimated probabilities of detecting recorded wild turkey gobblers played in the field by three different methods of observation in North Carolina, USA, for leaf-on and leaf-off conditions. Methods were human observers listening in the field, a manual review by a human of recordings made by autonomous recording units, and automated software review of recordings made by autonomous recording units.

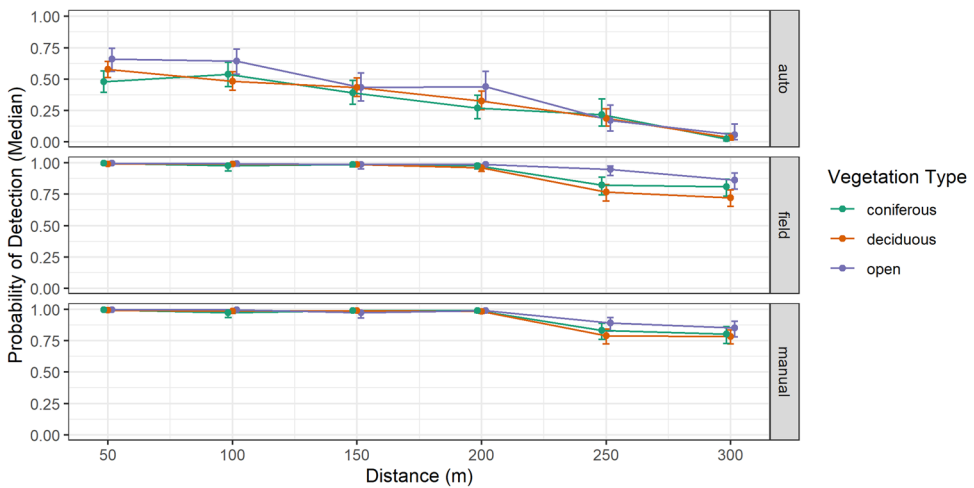


FIGURE 4 Estimated probabilities of detecting recorded wild turkey gobblers played in the field by three different methods of observation in North Carolina, USA, for differing vegetation types. Methods were human observers listening in the field, a manual review by a human of recordings made by autonomous recording units, and automated software review of recordings made by autonomous recording units.

Temporal and regional variation in gobbling

There was support for the true number of modes being greater than 1 (statewide, excess mass test statistic = 0.005, $p < 0.001$). Each individual region also exhibited multimodality (mountains, excess mass test statistic = 0.014, p -value < 0.001 ; piedmont, excess mass test statistic = 0.11, p -value < 0.001 ; coast excess mass test statistic = 0.01, p -value < 0.001). Since there was support for the true number of modes being greater than 1, when generating critical bandwidths, we specified the number of modes equal to 2 for all analyses.

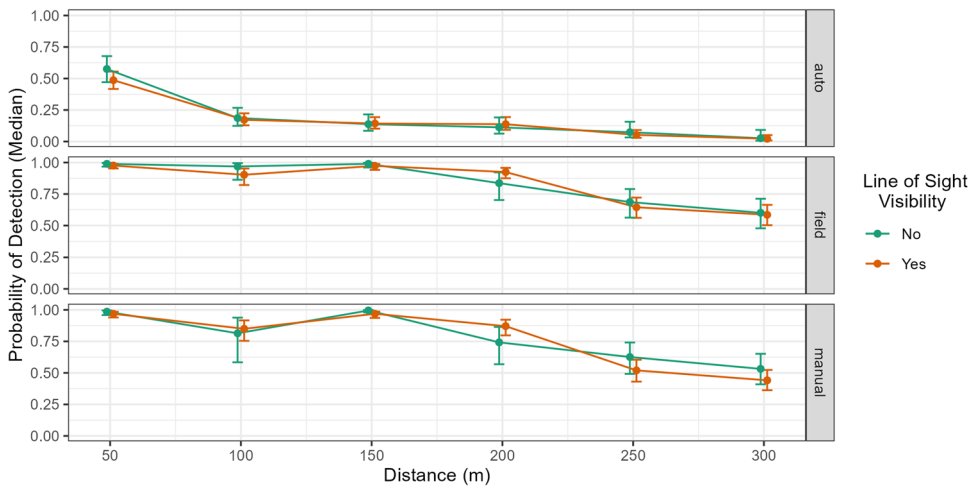


FIGURE 5 Estimated probabilities of detecting recorded wild turkey gobbles played in the field by three different methods of observation in North Carolina, USA, with respect to whether vegetation restricts line of sight visibility. Methods were human observers listening in the field, a manual review by a human of recordings made by autonomous recording units, and automated software review of recordings made by autonomous recording units.

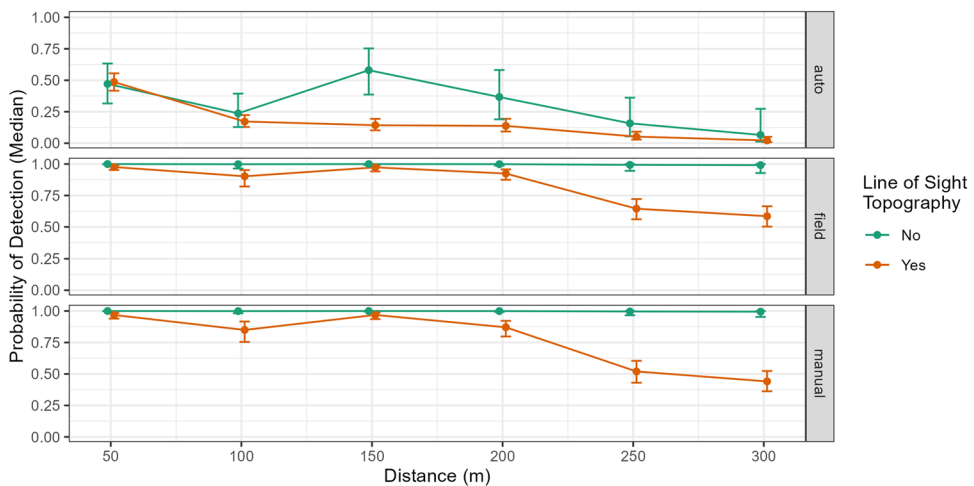


FIGURE 6 Estimated probabilities of detecting recorded wild turkey gobbles played in the field by three different methods of observation in North Carolina, USA, with respect to whether topography restricts line of sight. Methods were human observers listening in the field, a manual review by a human of recordings made by autonomous recording units, and automated software review of recordings made by autonomous recording units.

Across the 4 years of our study, we found patterns of gobbling were comparable across the primary ecoregions of North Carolina, with 57–61% of gobbling occurring during the time at which hunting season occurs (Figure 7). However, annual variation at the state-level was quite high, and even more pronounced within each ecoregion (Figures 8 and 9). Importantly, the beginning and ending of gobbling was constant across the state, with gobbling increasing in early March and tapering off in late May (Figure 7).

TABLE 2 Number of hours recorded by autonomous recording units and number of wild turkey gobbles (true positives) and false positives detected with a band limited energy detector in Raven Pro 1.5 software. These data were collected across North Carolina's three physiographic regions during 2016–2019. The detector identified sounds that matched basic parameters for a wild turkey gobbler, which were then evaluated by a human observer to determine if they were truly wild turkey gobblers.

Region	Year	Gobblers	False positives	Total detections	Number of sites	Hours recorded	Mean gobblers per site (SE)
Mountain	2016	5,423	58,772	64,195	18	7,815.0	301.3 (146.1)
	2017	6,899	22,093	28,992	13	2,920.0	530.6 (311.9)
	2018	3,822	19,541	23,363	13	2,795.0	294.0 (118.8)
	2019	2,066	10,397	12,463	13	2,825.0	158.9 (61.1)
	Subtotal	18,210	110,803	129,013	29	16,355.0	627.9 (297.9)
Piedmont	2016	822	20,446	21,268	7	3,150.0	117.4 (57.6)
	2017	9,192	43,851	53,043	17	3,788.5	540.7 (159.3)
	2018	10,990	32,035	43,025	17	3,370.0	646.5 (199.5)
	2019	10,201	31,743	41,944	17	3,847.5	600.0 (314.6)
	Subtotal	31,205	128,075	159,280	24	14,156	1,300 (462.7)
Coast	2016	13,252	72,228	85,480	25	10,130	530.1 (105.2)
	2017	19,072	66,521	85,593	21	4,735.0	908.2 (179.5)
	2018	16,230	50,407	66,637	21	3,926	772.9 (142.2)
	2019	15,768	60,282	76,050	21	4,641.0	750.9 (121.1)
	Subtotal	64,322	252,337	313,760	41	23,432.0	1598.5 (291.8)
Grand total		113,737	491,215	602,053	94	53,943.0	1,240.5 (198.6)

DISCUSSION

In our study, we demonstrated that autonomous recording units can be an effective tool for investigating gobbling chronology across large geographic areas and long time periods. This level of investigation would not have been possible for NCWRC to accomplish via traditional techniques (i.e., human observers in field). Studies that have relied on human observers in the field have generally been limited to specific WMAs or other delineated regions and have generally identified less than a few thousand gobblers (Bevill 1973, Bevill 1975, Hoffman 1990, Lehman et al. 2005, Palumbo et al. 2019). This is no fault of earlier research, but rather the reality of the vast potential of modern technology and automated software. However, review of ARU-collected data only gives the opportunity to determine the total number of gobblers, but not an indication of the number of turkeys gobbling as is the case when using human observers. Several other studies have revealed differences in detecting species richness and in detection distances (Chimchome 2004, Schonfield and Bayne 2017, Bombay et al. 2018) such that ARUs should not simply be considered as a substitute for human observers.

In our study, the overall ability to detect gobblers via software analysis of ARU recordings was greatly reduced after leaf-on conditions occur in spring, thereby requiring us to account for this in our examination of temporal gobbling trends. Turgeon et al. (2017) discussed a similar effect when detection probabilities changed over time during ARU deployments as a result of microphone deterioration, which is a factor our study did not address. At close distances, we found the automated detection process improved under leaf-on conditions, which may have

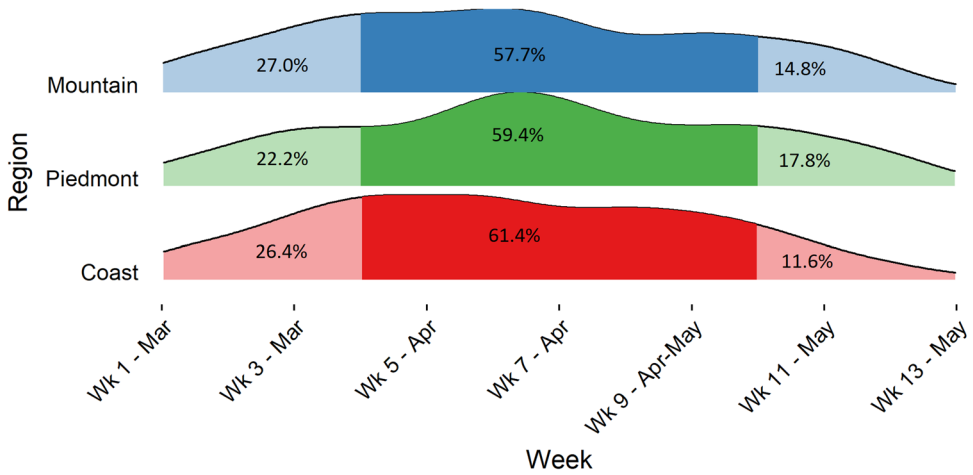


FIGURE 7 Kernel density estimates of regional variation in wild turkey gobbling activity, from autonomous recording units deployed on un hunted properties in three physiographic regions in North Carolina, USA during 2016–2019. The shaded portion of weeks 5–11 indicate the time period in which North Carolina’s wild turkey hunting season occurred each year (youth season opens on first Saturday in April and regular season closes on the fifth Saturday thereafter). The percentages listed indicate the amount of gobbling activity within each shaded time period within each region.

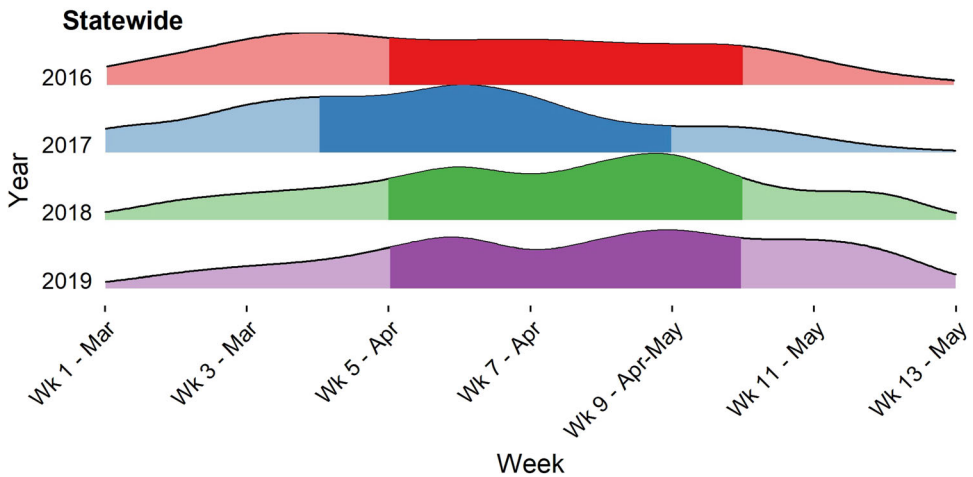


FIGURE 8 Kernel density estimates of statewide variation in wild turkey gobbling activity by year, from autonomous recording units deployed on un hunted properties in North Carolina, USA during 2016–2019. The shaded portion of weeks 5–11 indicate the time period in which North Carolina’s wild turkey hunting season occurred each year (youth season opens on first Saturday in April and regular season closes on the fifth Saturday thereafter).

resulted from leaf-on conditions reducing the volume of loud gobbles such that they fell within the parameters of our BLED. At farther distances, detection probabilities decreased. Thus, the overall detection probability is decreased substantially given that fewer turkeys will be gobbling close to ARUs than turkeys gobbling farther away, simply because the sampled area is circular and relatively little of the sampled area is within 50 m of the ARU. The effect of leaf-on conditions on the automated detection probability that we observed may be specific to our BLED’s

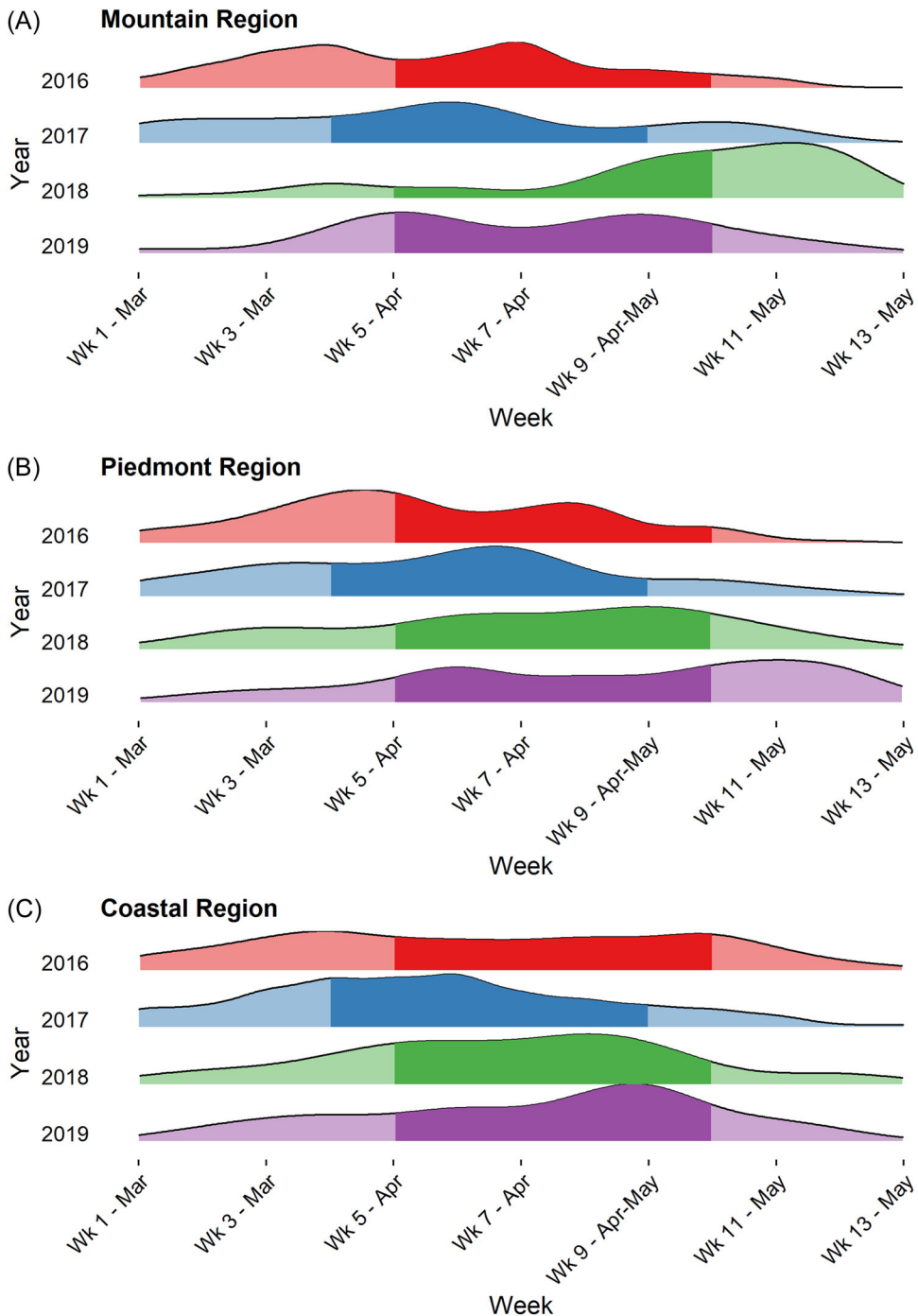


FIGURE 9 Kernel density estimates of regional variation in wild turkey gobbling activity by year in three physiographic regions in North Carolina, USA during 2016–2019. The shaded portion of weeks 5–11 indicate the time period in which North Carolina's wild turkey hunting season occurred each year (youth season opens on first Saturday in April and regular season closes on the fifth Saturday thereafter).

input parameters. As we did not evaluate different parameters, we cannot offer insight into how other BLEDs may be affected and so we urge caution in any direct comparison of our results with those of other gobbling chronology studies that have relied on ARUs or that deployed ARUs much higher above ground (Colbert et al. 2015, Chamberlain et al. 2018, Wightman et al. 2019). However, we recognize that our method of determining when leaf-on conditions occurred, and thereby of deciding when to apply a correction factor, was very coarse. Collecting specific vegetative measurements throughout the course of the study would have offered more confidence in how to correct the data for the effect of leaf-on conditions. In a similar fashion, our study showed minimal and inconsistent effects on detection probabilities as a result of vegetation type but given that this factor was estimated by a number of different field staff our methods may not have been sufficient to determine the true effect.

We realize that our evaluation of ARU efficacy and gobbling chronology is limited in several ways. Principal among the limitations is that our field evaluations were performed before and after the primary dates when gobbling typically occurs, rather than continuously through the spring. Thus, the way in which we have incorporated the effect of leaf on/off conditions on detection of gobbles is coarse. While we feel that our approach adequately describes the overall potential impact of leaf on/off conditions, it does not necessarily describe the impact throughout the various times of gobbling activity through spring. Thus, our use of ARUs to assess gobbling may not be equally evaluating all parts of the 1 March through 30 May time period. Likewise, gobbling activity follows patterns within days as well, with gobbling occurring both when birds are roosted and from the ground after birds fly down. Our methodology, playing gobbles from 1 m above ground, may be a better evaluation of detection of gobbles that occur after fly down. For these reasons, we urge caution in interpreting our data and methodology.

We did not find clear evidence that the timing of wild turkey gobbling varies across North Carolina. Rather, our findings suggest that gobbling activity begins and ends at similar times throughout the state, and that considerable variation occurs annually. It is important to note that our study took place on properties where turkey hunting pressure was minimal or nonexistent and thus minimizing the effect of hunting, which has been shown in several studies to depress gobbling activity (Miller et al. 1997b, Lehman et al. 2005, Wightman et al. 2019, Wakefield et al. 2020). As such, the amount of gobbling that we observed during April and May are likely considerably higher than what may occur on hunted properties.

Our study provides evidence that there is more than 1 peak in gobbling in North Carolina, which is a similar result to several other studies (Kienzler et al. 1996, Norman et al. 2001, Chamberlain et al. 2018, Palumbo et al. 2019, Wightman et al. 2019). A past recommendation for setting turkey hunting seasons in North Carolina and elsewhere has been to allow hunting during the second peak of gobbling (Bevill 1975, Seamster 2016). At its core, this approach would serve to ensure that 1) turkeys have ample opportunity for breeding before hunting season begins and 2) hunters are afforded opportunity to hunt when substantial turkey gobbling occurs, which would be 50% or more depending on how much gobbling occurred during the second peak as suggested by earlier studies. In our current study, we found that North Carolina's hunting seasons occur at a time when 60% of gobbling potentially occurs, and only 25% of gobbling occurs prior to the season opening. As such, our study demonstrates that the timing of North Carolina's hunting seasons appears to achieve the second tenet mentioned above (i.e., hunting allowed when 50% or more of gobbling occurs). However, we do not know whether 25% of gobbling is indicative of ample breeding opportunity before the season occurs but do note that this is far less than 50% of gobbling that might occur in a hypothesized first (of 2) peak in gobbling. It is unclear how the pattern of gobbling in our study might relate to underlying turkey biology and nesting and breeding activity of females. Conclusions from other studies are mixed, with some revealing a relationship between gobbling activity and nesting by females (Bevill 1973, Bevill 1975, Hoffman 1990, Norman et al. 2001) and others finding no evidence of a relationship (Miller et al. 1997a, Chamberlain et al. 2018). Pairing ARUs with radio-telemetered turkeys likely offers an optimal approach to understand this relationship, as it can offer insight into nesting ecology as well as gobbling chronology (Chamberlain et al. 2018).

MANAGEMENT IMPLICATIONS

Based on our results, we recommend that researchers consider validating ARU performance as well as the performance of BLEDS as a necessary part of any study to understand limitations and potential data biases. We encourage state agencies to consider ARU-derived gobbling chronology information when making decisions about when to open and close spring turkey hunting seasons and that they also consider how and when ARU data were collected. Gobbling activity is not the only factor to consider in setting spring hunting seasons and so we also encourage state agencies to rely on the information summarized by Isabelle et al. (2018) as it pertains to nesting ecology and sociological factors. We conclude that our gobbling chronology work shows that maintaining a consistent season statewide in North Carolina is appropriate.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

No ethical information provided.

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