WILD TURKEY GOBBLING CHRONOLOGY
IN NORTH CAROLINA

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NORTH CAROLINA WILDLIFE RESOURCES COMMISSION
WILDLIFE MANAGEMENT DIVISION

EXECUTIVE SUMMARY

Thousands of hunters pursue wild turkeys in North Carolina each spring, with annual harvests of more than 15,000 birds in recent years. The North Carolina Wildlife Resources Commission (NCWRC) regulates spring hunting seasons with the goal of maintaining high-quality hunting while allowing the population to increase. The NCWRC's regulatory framework is based on the idea that gobbling activity follows a bimodal pattern and that the second gobbling peak is the ideal time for hunting. Thus, gobbling information is critical to understanding hunter satisfaction as well as the biology of wild turkeys, but this type of data is lacking in North Carolina. Fortunately, Autonomous Recording Units (ARUs) can be used to collect thousands of hours of audio files from which to study wild turkey gobbling chronology across wide geographic areas. For these reasons, in 2016 we began a project to investigate gobbling activity in North Carolina to:

1. determine the best methods for using ARUs to research gobbling chronology and
2. use ARUs to collect gobbling chronology data to evaluate current timing of spring hunting seasons.

We extensively tested ARUs to evaluate how they performed at detecting turkey gobbles. We identified several factors that affect their performance, with topography and spring green-up being the most notable, but also found that those factors can be accounted for in data analyses. Furthermore, we learned that ARUs, in combination with automated software programs, are capable of identifying approximately 34% of the total gobbles that could be heard by human observers and that they are capable of correctly identifying trends in gobbling activity.

We deployed ARUs on unhunted properties across North Carolina during the springs of 2016-2019. These ARUs collected 53,943 hours of audio files from 94 locations, which when processed by automated software yielded 113,737 gobbles. Examining the timing of these gobbles revealed that year-to-year variation in gobbling activity was much greater than the amount of variation across regions. Gobbling activity did not occur earlier in the coastal region than in other regions of the state. Furthermore, examination of the timing of these gobbles revealed no evidence to suggest that gobbling activity follows a clear bimodal pattern. Rather, our study found that gobbling chronology follows a more complicated pattern with multiple peaks. As such, we suggest that identifying peaks in gobbling activity may not be the ideal way to inform regulatory decisions. A better way may be to examine how much gobbling activity occurs before, during, and after hunting seasons. In our study, we found that 25%, 60%, and 15% of gobbling activity occurs before, during, and

Autonomous Recording Unit

after North Carolina's spring turkey hunting seasons. Thus, we conclude that the current spring turkey hunting seasons likely increase hunter satisfaction by offering the chance to pursue turkeys at a time when substantial gobbling occurs (i.e., 60%), but do not know whether ample breeding opportunity is afforded the turkey population before the hunting seasons begin.

Based on results of our study, we recommend that the NCWRC:

- Maintain a statewide framework for turkey hunting seasons, with uniform opening and closing dates for all parts of the state.
- Maintain current opening and closing dates for the youth and regular turkey hunting seasons, through at least 2024. At that time use gobbling chronology information reported herein, along with nesting chronology information from final results of the ongoing study "*Multi-scale Assessment of Wild Turkey Ecology in North Carolina*" and recommendations by Isabelle et al. (2018) [1] to inform decisions about the best time to open and close the spring hunting seasons.
- Continue research to better understand the drivers of annual variation in wild turkey ecology, including gobbling activity, and the utility of ARUs.

[1] REFERENCES are indicated numerically throughout this report. Full details for these references are provide on pages 23-24.

INTRODUCTION

Wild turkeys are a valuable public trust resource in North Carolina. They are beloved by hunters and non-hunters alike. In recent years, more than 60,000 hunters pursued turkeys each spring and annually harvested more than 15,000 birds. Since 2006, the North Carolina Wildlife Resources Commission's (NCWRC) goal for wild turkey management has been to emphasize spring gobbler hunting by managing the population below the maximum sustained yield in order to maintain high quality spring hunting and maximize continued increases in population size and distribution [2].

The NCWRC has regulated spring turkey hunting with minimal variations for several decades. Prior to this relative stability notable changes established earlier opening dates and statewide, rather than regional, season structure. The NCWRC continues to receive numerous hunter requests for earlier opening dates, presumably because hunters have a strong desire to hunt as soon as turkey gobbling activity begins. The frequency and timing of these requests vary across the state, suggesting there may be within-state variation (e.g., ecoregions) in gobbling chronology. As such, the timing of gobbling activity, the timing of the spring turkey seasons, hunter success, and hunter satisfaction are all intertwined. This makes an understanding of gobbling chronology paramount to successful turkey management. Appropriate timing (i.e. opening and closing dates) of spring hunting seasons is a key factor in achieving hunter satisfaction, with earlier and longer seasons generally desired by turkey hunters, 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 [1, 3-7].

Springtime patterns of gobbling activity have been investigated by researchers in other states for many years, but studies have provided mixed results as to conclusions about the underlying biology. Several studies have identified a bimodal pattern in gobbling activity through the spring, with one peak occurring just after winter flocks break up and a second peak after females begin incubating nests [8-11]. These studies investigated gobbling chronology on relatively small scales (i.e., specific Wildlife Management Areas or regions) and by human observers. Interestingly, no support for bimodal gobbling activity has been found when analyzed at much larger scales (i.e., state-level) or when using newer technology such as Autonomous Recording Units (ARUs) [5, 7, 12-15].

Science-based gobbling chronology data in North Carolina have been lacking. Furthermore, gobbling chronology may vary across the state. It is generally recognized that gobbling activity varies with respect to latitude in North America, with gobbling occurring earlier in southern latitudes. In some cases, peak gobbling activity may vary by as much as two weeks within individual states [15]. 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 [16-19]. Regional or annual variation in gobbling and nesting chronology can complicate the ability to identify appropriate opening and closing dates for spring turkey hunting seasons. Therefore, in 2015, we began to work with Autonomous Recording Units (ARUs) and collect gobbling chronology data specific to North Carolina so that we could better inform regulatory decisions about turkey management.

ARUs hold tremendous potential for wildlife research, especially for wild turkeys and other birds. Chief among their advantages is the opportunity to survey for vocalizing birds over much greater time spans than can typically be achieved using traditional human-based survey techniques [7, 13, 20]. They also reduce the potential bias associated with multiple human observers and eliminate the influence of the presence of humans carrying out surveys [20].

However, ARUs have potential drawbacks and limitations. Surveying across large geographic areas may not be feasible without high costs associated with having many ARUs. When using species recognition software, ARU-based studies may detect fewer species' occurrences and at shorter distances than human observers [20]. ARUs 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 because of microphone deterioration or potentially from weather or other changing environmental factors [21].

Thus, while ARUs offer the opportunity to examine gobbling chronology at large scales, their limitations and potential biases under different field conditions must be critically evaluated. Most notably is the assumption that ARU detection probability does not change over space and time during the sampling period, especially as spring green-up occurs. Additionally, it is important to understand ARU performance in comparison to human observers and in different habitat types. Furthermore, North Carolina's turkey hunting regulations assume an underlying bimodal pattern of gobbling activity, but little state-specific information exists to support this assumption. A more thorough understanding of gobbling chronology from data collected within the state will provide more confidence in regulatory decisions, ultimately resulting in more robust turkey populations and higher levels of hunter satisfaction. Given all this information, we began this project in 2016 to evaluate ARUs and to investigate gobbling activity in North Carolina.

Our objectives were to:

1. Determine the best methods for using ARUs to research gobbling chronology in North Carolina. We wanted to train field staff in the use of ARUs and associated software and learn first-hand of their potential for studying wild turkeys, including their potential biases and limitations.
2. Use ARUs to collect gobbling chronology data across North Carolina to evaluate the timing and structure of spring hunting seasons.

METHODS

As described herein, we used several approaches to achieve our objectives.

1. ***Field Testing of ARUs*** – We tested ARUs in the field to evaluate how well they performed at detecting turkey gobbles. These tests allowed us to understand how ARUs perform in different conditions and how their performance compares to a human observer. As described in detail in the Appendix, we conducted these evaluations by playing recorded gobbles in the field through Fox Pro® speakers and determining 1) how many gobbles were recorded by the ARUs, 2) how many gobbles could be found by automated software, and 3) how many gobbles could be heard in the field by human observers.

2. ***Automated Review*** – In order to investigate gobbling activity patterns across the state, we used ARUs to record an extensive set of audio files. We processed the full set of audio files with automated Raven Pro software, which allowed many hours of audio files to be processed quickly. Because this automated review was of the entire data set, we relied on these results to answer questions about patterns in gobbling chronology and whether differences in gobbling activity occurred between years or regions. We completed this automated review using a Band Limited Energy Detector (BLED; see Appendix for further details) in Raven Pro. Raven Pro's automated review is essentially a two-step process. The first step is for the BLED to auto-identify sounds in the recordings that meet the basic parameters of a turkey gobble. The second step is for us to listen to all the sounds and verify which ones were actually turkey gobbles. This automated process is an efficient way to find many gobbles in the recordings. However, it is imperfect and does not find all the gobbles. Also, many of the auto-identified sounds turn out to be something other than gobbles (i.e., crows, woodpeckers, etc.), which are then removed from the data set.

3. ***Manual Review*** – To ensure that we could rely on the automated review process to accurately identify trends in gobbling activity, we also manually reviewed a subset of the ARU recordings to determine the number of gobbles that were missed by the automated process described above. The manual review was a slow, exhaustive process that involved listening to the audio recordings as well as visually inspecting the spectrogram to find gobbles that were missed by the BLED. A manual review would not be an efficient way to process the entire set of recordings; however, we processed

a subset of recordings in this fashion to ensure the validity of the automated process. The subset came from ARU recordings made throughout the course of our study. In 2016, we manually reviewed a 20-minute period (around sunrise) of recordings from three ARUs during part or all of the season. In 2017, we manually reviewed a 5-minute period immediately before sunrise for every ARU on every day. In 2018 and 2019, we manually reviewed a 2-minute period immediately before sunrise for every ARU on every day.

Deploying ARUs Statewide

We deployed ARUs at 94 locations on 60 properties in 41 counties across North Carolina (Figure 1). To the greatest extent possible, we selected properties that were large, had robust turkey populations, and received little to no turkey hunting pressure. It was important to focus on this type of property because we wanted to learn about gobbling patterns that had not been unduly influenced by hunters harvesting or pressuring turkeys. Sixty-three locations were on privately-owned properties while the remaining 31 were publicly owned. On all properties, turkey hunting was either prohibited or not a primary activity of the landowner. Property size varied from more than a thousand acres to smaller parcels that were nested within low hunting pressure zones. Recorders were housed in security boxes and bolted to trees approximately 6 feet above ground, except for a few sites where potential theft or prescribed fire necessitated placing them approximately 15 feet above ground.

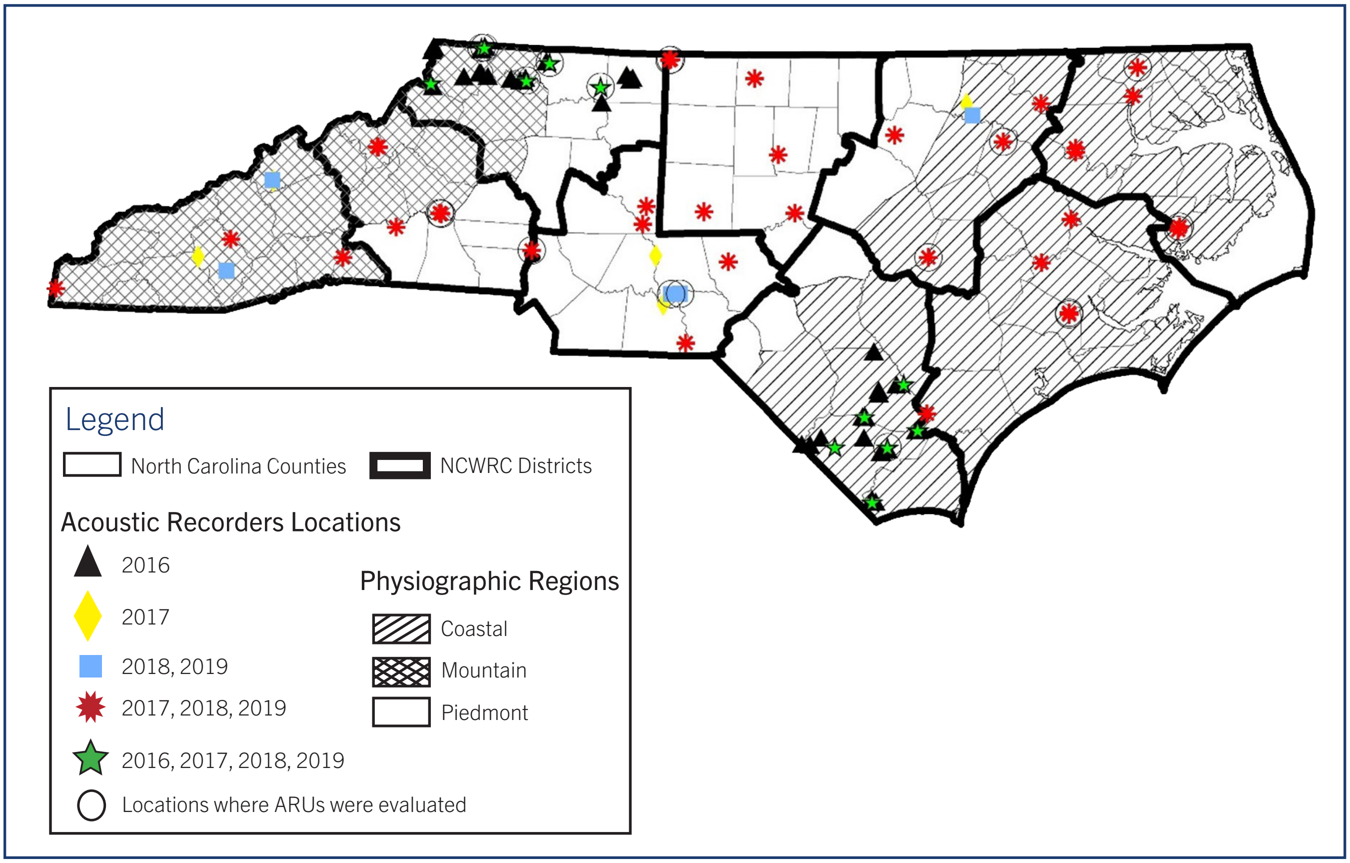


Figure 1. General locations of Autonomous Recording Units, 2016-2019

We deployed ARUs from late February through early June of 2016 through 2019. In 2016, we deployed 25 ARUs in northwestern North Carolina and 25 ARUs in southeastern North Carolina. We programmed the ARUs to record five hours each morning, beginning one hour before sunrise. This was the first year of our study and this approach provided data from two regions where factors thought to influence the timing of gobbling chronology are most different (e.g., latitude, elevation). This approach also allowed staff to become familiar with using the equipment. During the remainder of the study, 2017-2019, we deployed ARUs across the entire state so that each physiographic region was well represented. In these years, we programmed ARUs to record 2.5 hours each morning, beginning 30 minutes before sunrise.

Habitat Assessment

Because one of our primary objectives was to determine the best methods for using ARUs, it was important for us to understand how they performed in different habitat types. Therefore, we categorized the habitat types within 200 meters (219 yds) of each location where we deployed an ARU. Forests were categorized as "deciduous" or "non-deciduous". Pastures, crop fields, and other areas with vegetation less than six feet high were categorized as "open". We made these assessments visually in the field, rather than by objective vegetative measurements. We later used ArcMap to calculate the percentages of each habitat type at each location so the information could be included in our analysis.

Sampling Period and Recording Time

Our primary period of interest was March through May of each year. Some data were recorded in late February and early June as units were being deployed and retrieved, but we omitted data from those times from analyses. To simplify data analysis and reporting, we pooled data into 13 weekly periods, with the first week beginning on March 1st and the 13th week ending May 30, omitting data from May 31 (Table 1). North Carolina's spring turkey hunting seasons (youth and regular) occurred each year during portions of Weeks 5-11, though our project deployed ARUs on properties where turkeys experienced little or no hunting pressure.

Table 1. Weekly periods used for data analyses and reporting

Week Number	Dates
1	March 1-7
2	March 8-14
3	March 15-21
4	March 22-28
5	March 29-April 4
6	April 5-1
7	April 12-18
8	April 19-25
9	April 26-May 2
10	May 3-9
11	May 10-16
12	May 17-23
13	May 24-30

DATA ANALYSIS

Several different analyses were necessary to meet our study objectives:

- The first step was to evaluate the performance of ARUs, such that we would be able to reliably incorporate ARU recordings from many different locations.
- The second step was to evaluate the results of the manual review to determine whether we could rely on the automated software to correctly identify patterns in gobbling chronology.
- We then incorporated information from these two steps to analyze patterns in gobbling chronology in the entire set of recordings made by the ARUs, such that we could understand patterns in gobbling activity across the state and between years.

Evaluating Performance of the ARUs

We performed a rigorous statistical analysis of the data collected during Field Testing of ARUs. Specifically, we modeled detection probability as a function of the variables we thought would affect the ability of ARUs and humans in detecting gobbles. The variables we included in this analysis were: distance from ARU, whether spring green-up had occurred, whether vegetation or topography obstructed the line between the ARU and where gobbles were played, the habitat type (i.e., forest-type or open categories) around the ARU, and estimated wind and background noise. We analyzed data for each of the three ways we determined the number of gobbles: human listener, automated review, and manual review (see Appendix for additional details).

Evaluating the Manual Review

First, we identified all the gobbles that occurred during the subset of audio files that we manually reviewed. Next, we determined which of those gobbles could be found with automated review and determined which ones were missed. Finally, we examined the gobbling patterns in this subset of recordings to see if the automated review provided an accurate picture of gobbling activity.

Analyzing Patterns in Gobbling Chronology

We used Kernel Density Estimation (KDE) to describe patterns in gobbling activity across regions and years. Kernel Density Estimation is a weighted function (i.e., it considers how close observations are to one another) that returns the probability density function for a given random variable, and depends on one user-supplied parameter, bandwidth, to determine the smoothness of the distribution. We incorporated the results of the “evaluation of ARU performance” described above into the KDE analysis. The KDE analysis was able to account for the influence of some of the important variables that we found affected ARU performance. Because spring green-up was found to be an important variable, we relied on “First Bloom” information from the National Phenology Network to determine when spring green-up occurred at each ARU location [22] (see Appendix for additional details).

RESULTS

Evaluating Performance of ARUs and Human Observers

There were substantial differences in the three methods of detecting gobbles. Automated review of acoustic recordings detected substantially fewer gobbles, at all measured distances, than either a manual review of the recordings or when compared to a human observer listening to gobbles at the field sites (Figure 2). At 50 meters (55 yds), an automated review detected 50% of gobbles, and declined sharply by 100 meters (109 yds) and then declined steadily with distance to less than 10% probability of detecting gobbles at 300 meters (328 yds). A manual review of acoustic recordings had comparable detection of gobbles when compared to the number heard by a human observer listening in the field, with each of these methods detecting most of the gobbles played within 200 meters (219 yds). At distances of 250 or greater human observers performed somewhat better than a manual review of the audio files.

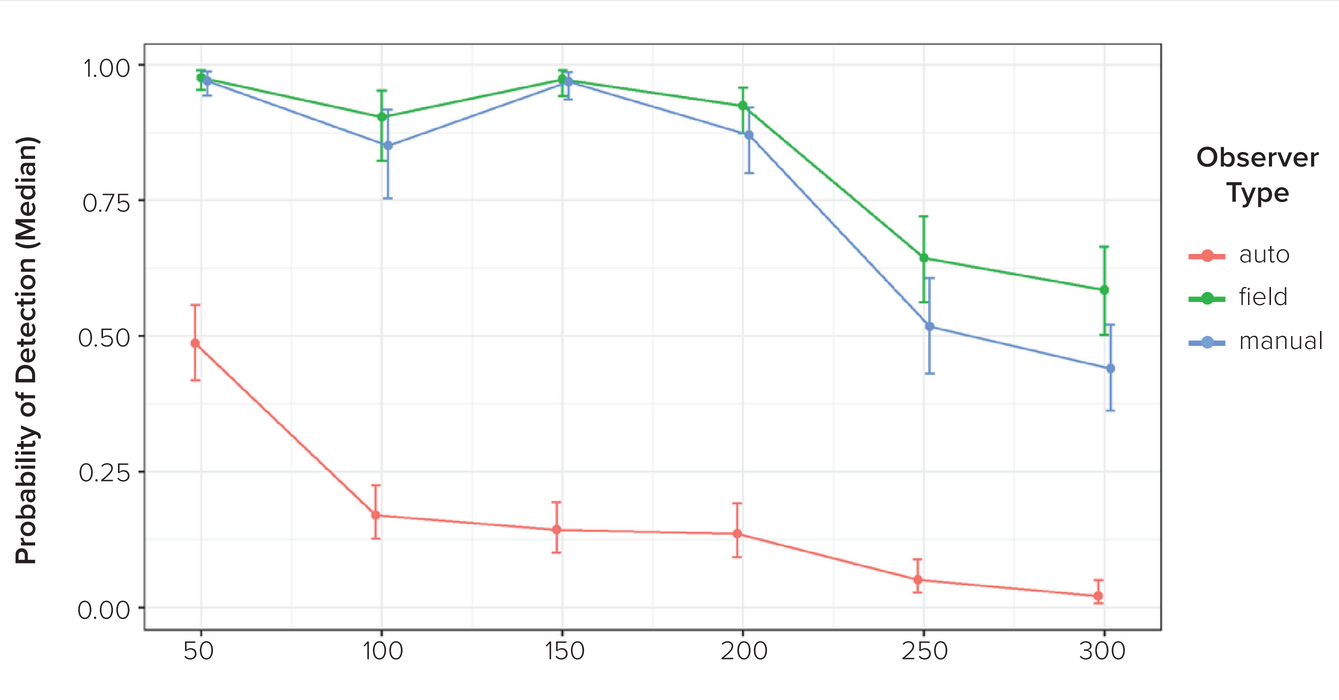


Figure 2. Estimated detection probabilities based on testing of ARUs*. These estimates are for reference levels of all factors of leaf conditions, forest type, clear line of sight, topographical interference, wind interference, and background noise.*

Spring green-up substantially impacted the probability of automated procedures detecting gobbles (Figure 3). While the overall detection probabilities for leaf-off and leaf-on conditions are roughly comparable, the effect of distance is noteworthy. At close distances (100 meters (109 yds) or less) our automated procedures had the highest detection probabilities during leaf-on conditions. However, at greater distances, the higher detection probabilities occurred during leaf-off conditions. Given that a much greater proportion of the sampled area is beyond 150 meters (164 yds), the overall effect of spring green-up is that the number of gobbles detected by automated procedures is reduced. When averaged across all 94 locations at which we deployed ARUs, the effect of leaf-on conditions was to decrease the number of gobbles that ARUs could detect by 25%. Also, our analysis revealed that topography had a substantial effect on detection probability. Other variables in our analysis had only a small effect on detecting gobbles. The effect of wind noise and background noise on detection probability was negligible in our analysis. Region and forest type influenced detection probabilities, though the effect was of a much smaller magnitude than those of topography, distance, and green-up.

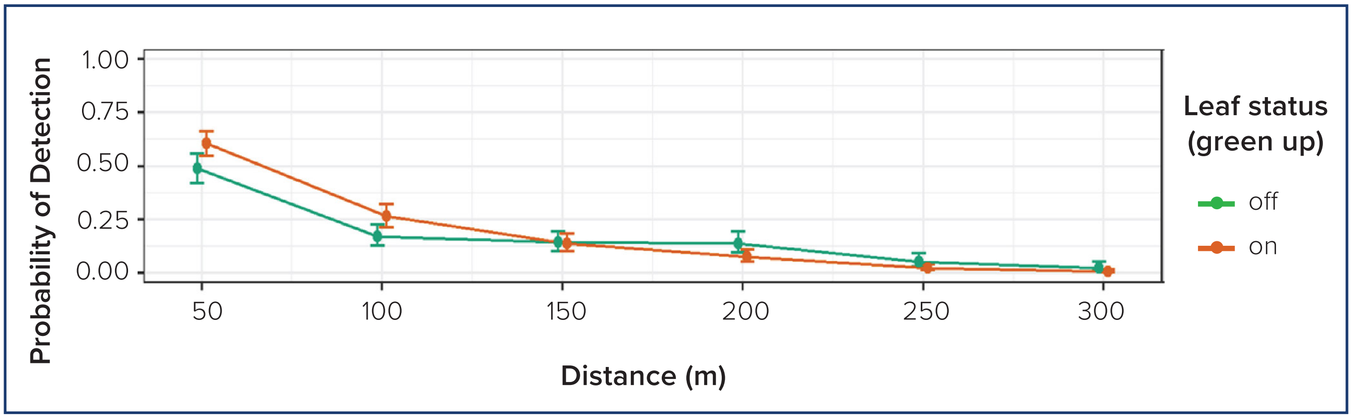


Figure 3. Detection probability of automated review for leaf-off and leaf-on conditions. *These estimates are for reference levels of all factors of leaf conditions, forest type, clear line of sight, topographical interference, wind interference, and background noise.*

ARU during leaf-off and leaf-on conditions

Manual Review

We manually reviewed a subset of the ARU recordings, totaling 43,593 minutes, and determined that this subset contained a total of 16,859 gobbles. Of this total, 5,702 gobbles (33.8%) had been identified by the automated review process, and the remaining 11,157 gobbles (66.2%) were identified only by the manual review. In general, the gobbles that were identified only by the manual review tended to be faint (presumably from a more distant bird) or occurred at a time when other sounds partially obscured the gobble. We found very similar patterns in gobbling activity (based only on this subset of recordings) from gobbles identified by automated procedures when compared to the manually identified methods (Figure 4). Though the manual review yielded more gobbles, both methods pointed to increasing gobbling activity prior to weeks 4-7, and then overall declining gobbling after that time.

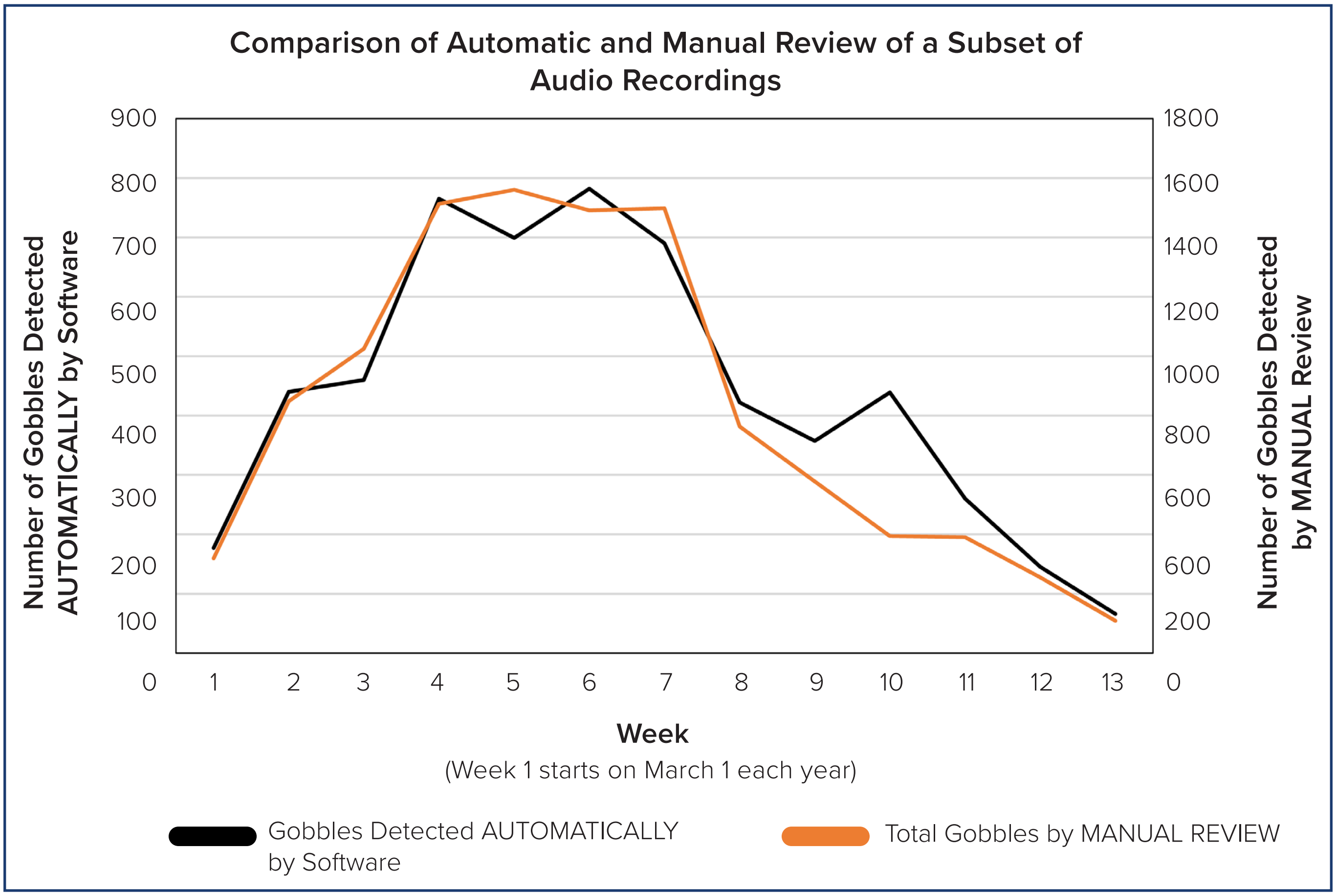


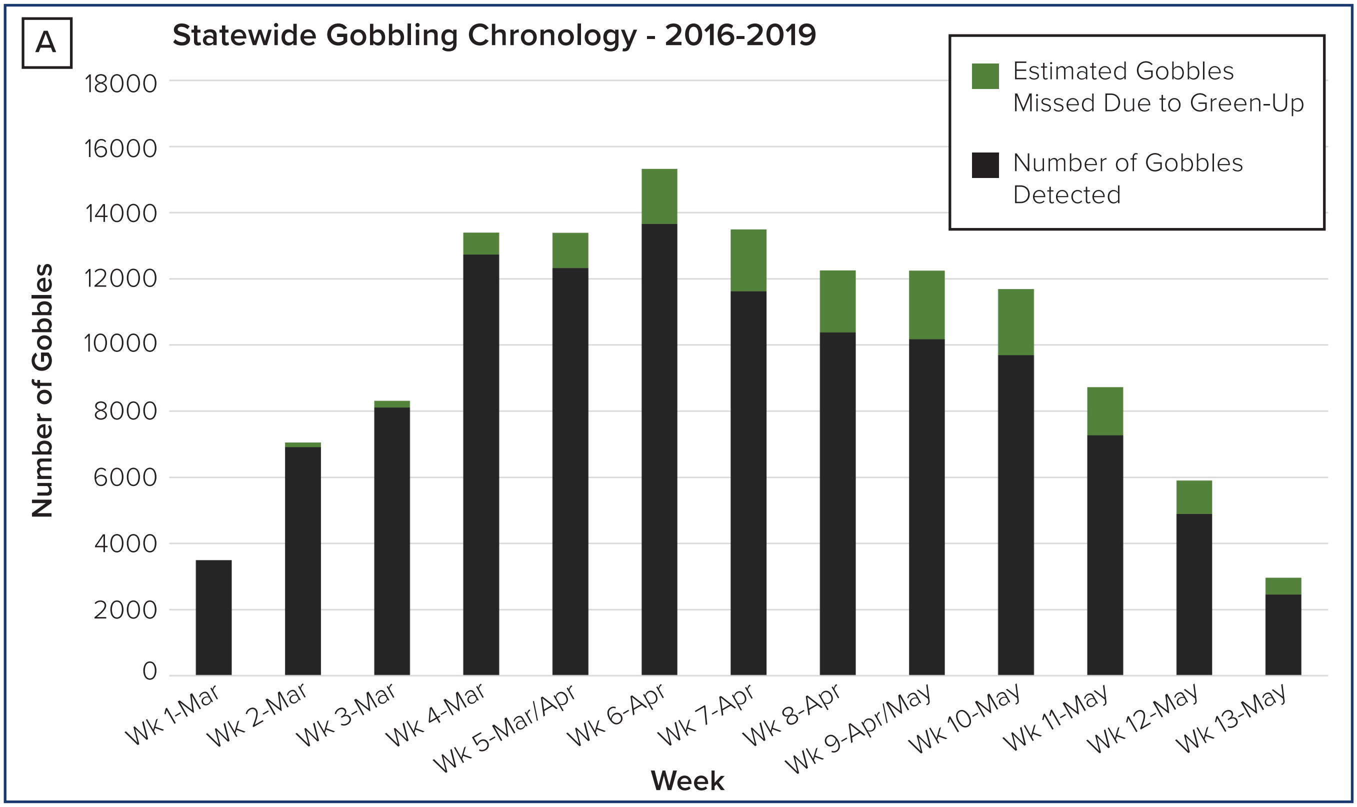
Figure 4. Comparison of the number of gobbles identified by two methods (manual and automated) from a subset of recordings made by ARUs

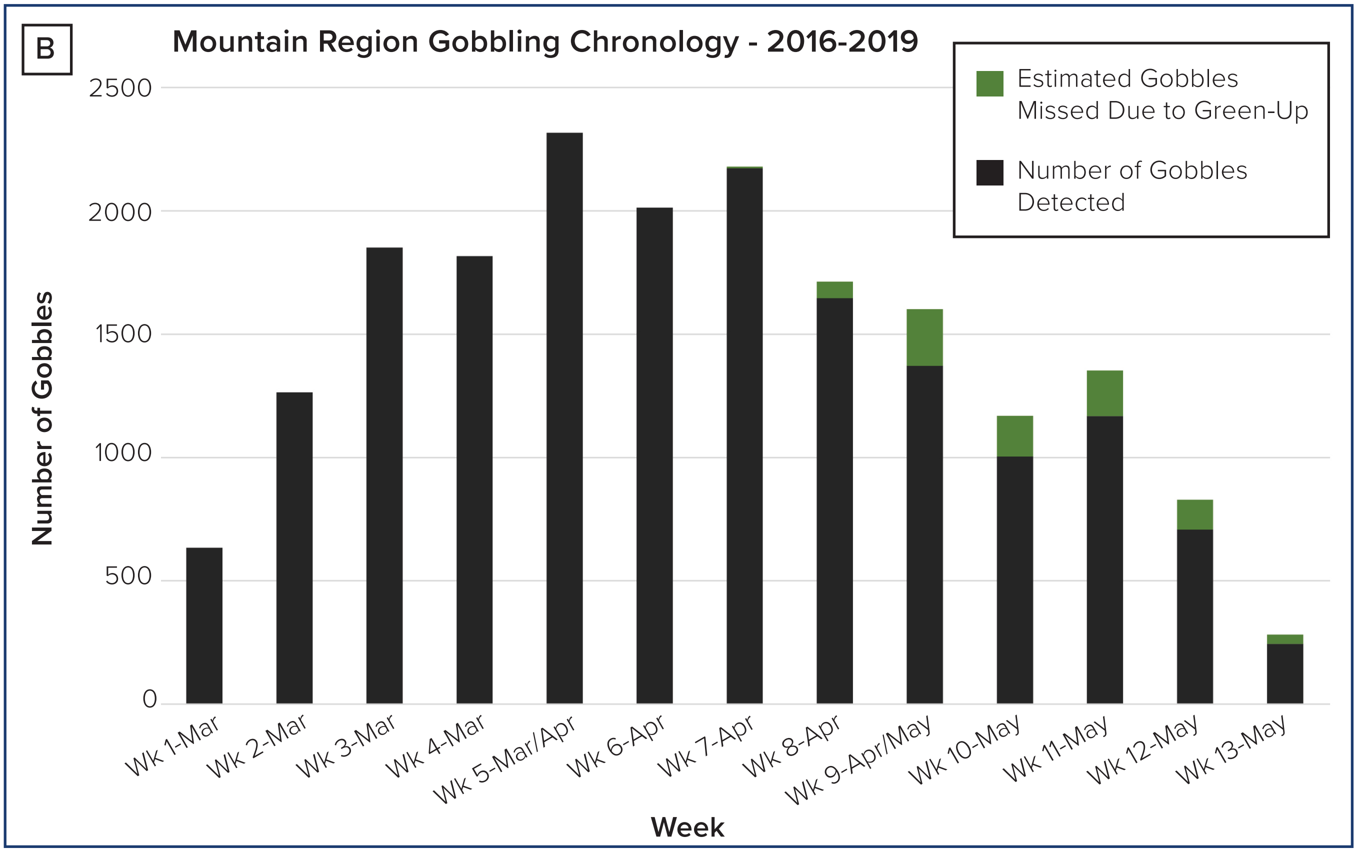
Weeks of Peak Gobbling Activity

In total, ARUs recorded 53,943 hours of audio files during our primary period of interest during March, April, and May of 2016 through 2019, and our automated review identified a total of 113,737 gobbles (Table 2). When combining all data across all three regions and all four years, the greatest number of gobbles detected occurred in Week 6 (April 5-11) (Figure 5A). When considering the data regionally, the greatest number of gobbles were detected in Week 5 (March 29-April 4) in the mountain region (Figure 5B), in Week 7 (April 12-18) in the piedmont region (Figure 5C), and in Week 6 (April 5-11) in the coastal region (Figure 5D). Incorporating estimates of the number of gobbles that may have been missed after spring green-up occurred did not change which weeks had the greatest gobbling activity for any region or at the statewide scale, though we now know there is more gobbling than we previously thought.

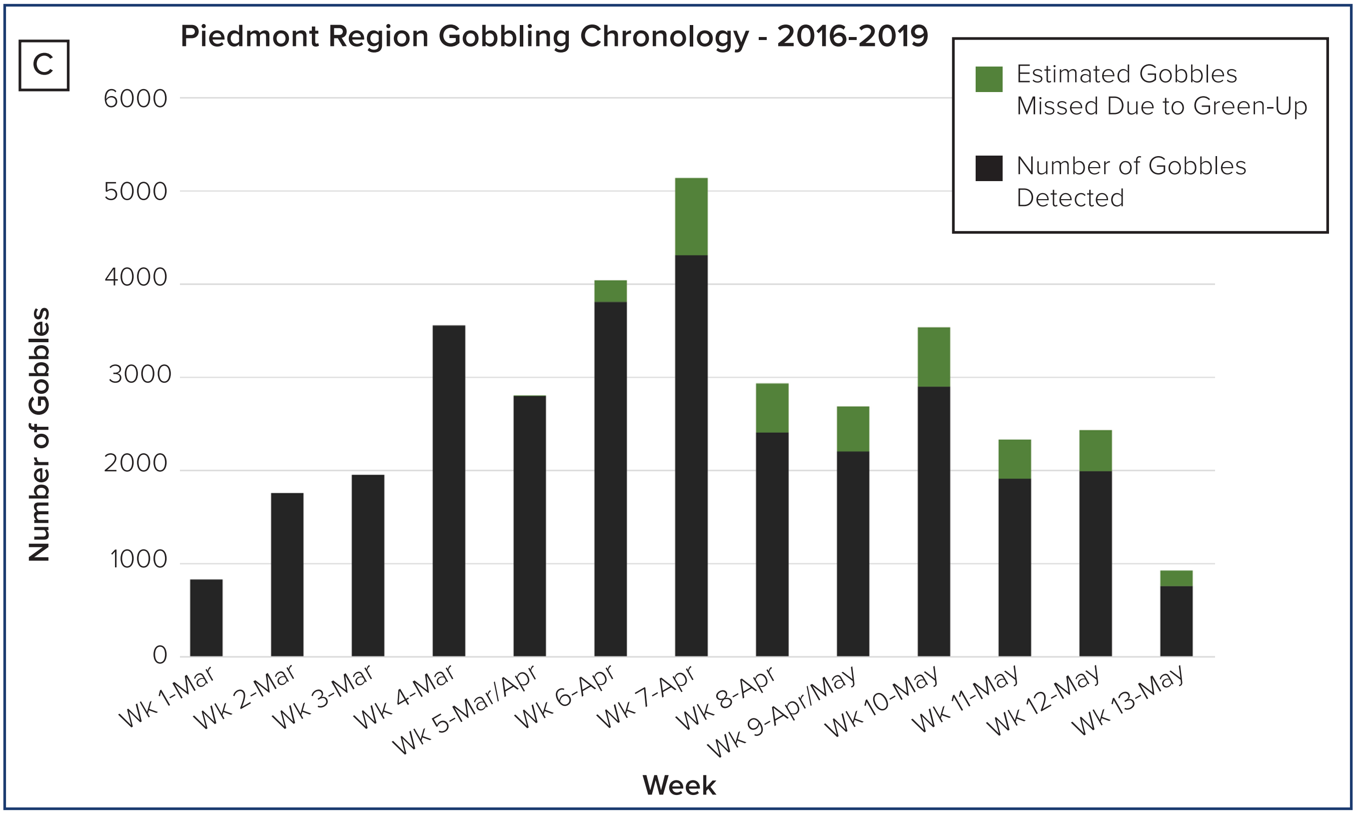
Table 2. Number of hours recorded and number of gobbles detected by turkey management regions during the 13-week period beginning March 1st each year.

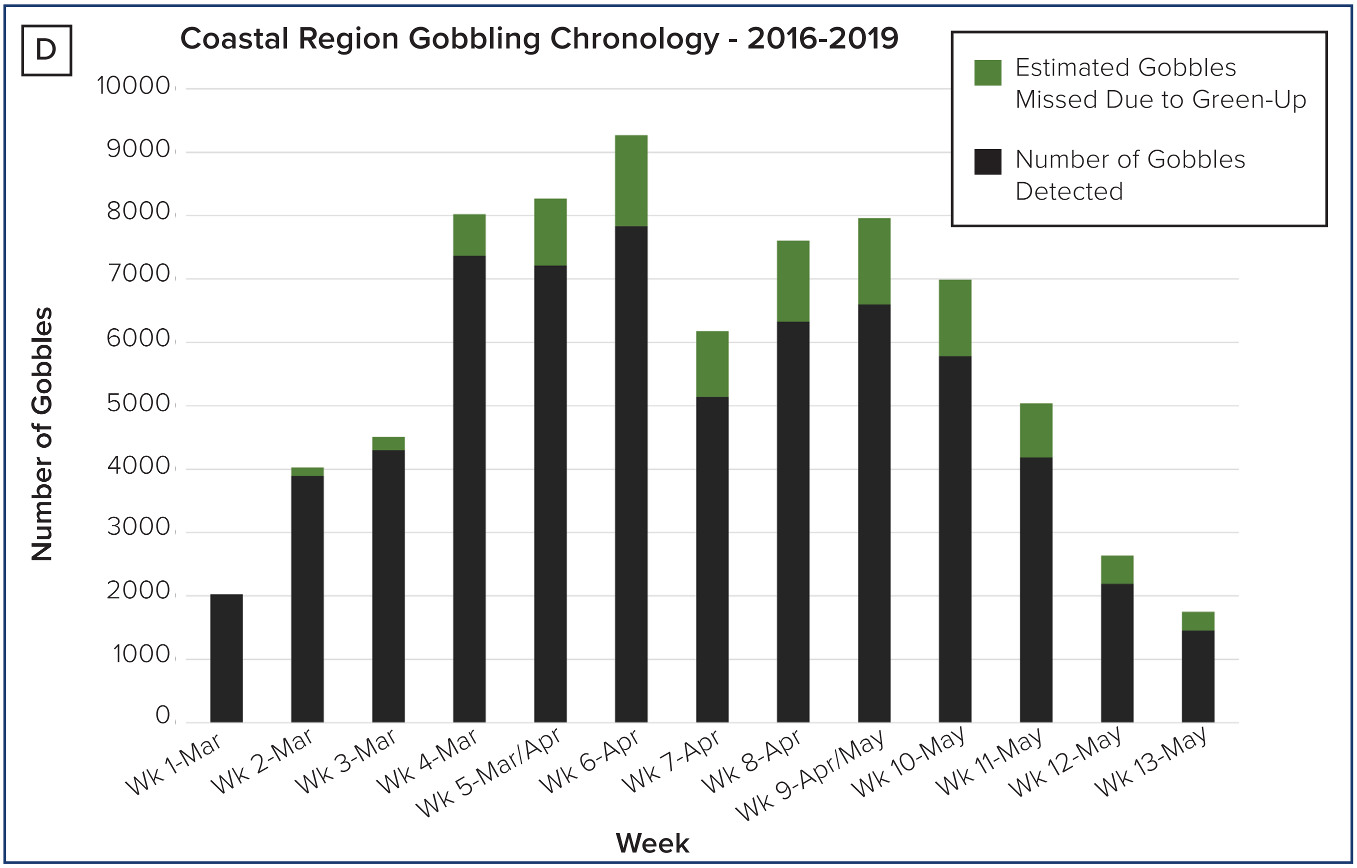
Turkey Management Region	Year	Hours Recorded	Number of Automatically Detected Gobbles	Estimated number of Gobbles Missed Due to Effect of Spring Green-up
Mountain	2016	7,815.0	5,423	140
	2017	2,920.0	6,899	252
	2018	2,795.0	3,822	315
	2019	2,825.0	2,066	105
	Mountain Total	16,355.0	18,210	812
Piedmont	2016	3,150.0	822	74
	2017	3,788.5	9,192	926
	2018	3,370.0	10,990	1,374
	2019	3,847.5	10,201	1,353
	Piedmont Total	14,156.0	31,205	3,727
Coast	2016	10,130.0	13,252	2,273
	2017	4,735.0	19,072	2,573
	2018	3,926.0	16,230	2,690
	2019	4,641.0	15,768	2,410
	Coast Total	23,432.0	64,322	9,946
	Grand Total	53,943.0	113,737	14,485





Figures 5A-D (this page; next page). Gobbling activity by week on unhunted properties across North Carolina. *The number of gobbles detected was determined by automated procedures with Raven Pro software and verified by employees. The number of gobbles missed because of green-up was estimated via field testing of ARUs.*





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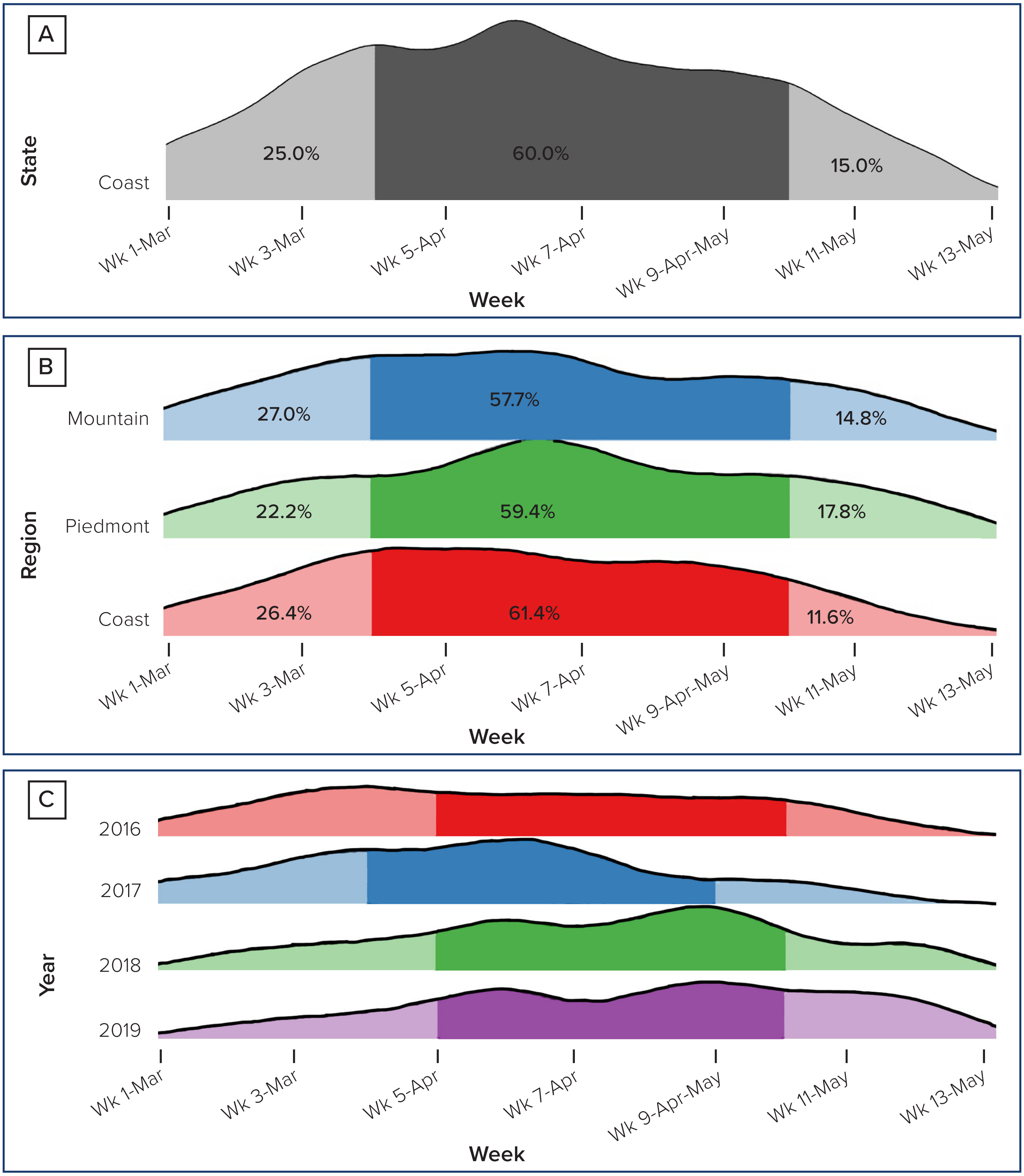
Analysis of Patterns in Gobbling Chronology – Kernel Density Estimates

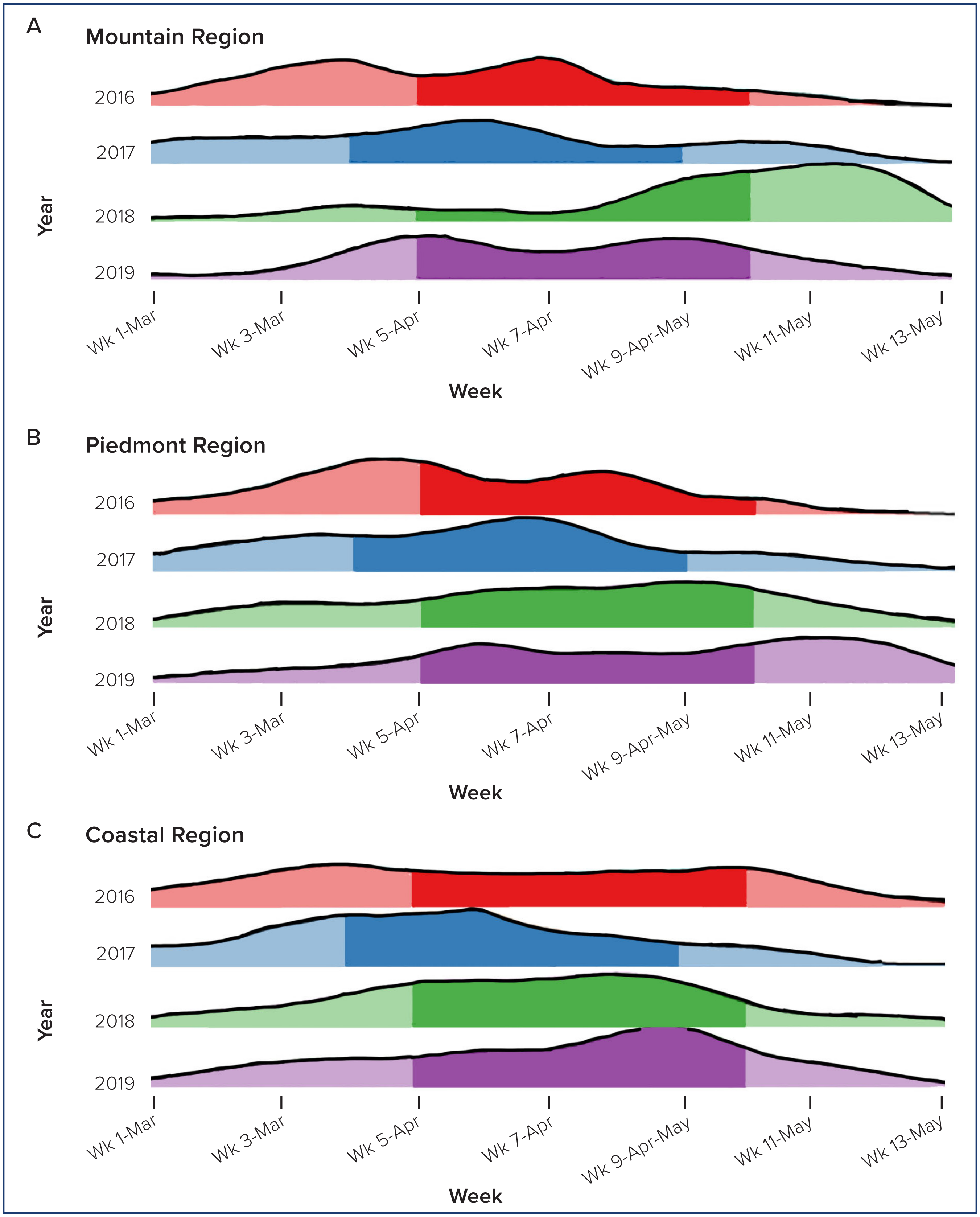
Gobbling activity peaked several times throughout the spring, whether considered at the statewide scale (Figure 6A) or by region or years (Figures 6B and 6C). Specifically, there was substantial support for the true number of modes being greater than one (statewide, excess mass test statistic = 0.005, p-value < 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). Additionally, the analysis revealed that 60.0 percent of all gobbling activity across the state occurred during the period in which the turkey hunting seasons occurred, while 25% and 15% of gobbling activity occurred before and after this time period, respectively. Within regions, the percentage of gobbling activity that occurred during the period of turkey hunting seasons ranged from 57.7% in the piedmont to 61.4% in the coast. Notably, KDE analysis also revealed substantial year to year variation in gobbling activity at the regional scale (Figures 7A-C).

Analysis revealed that 60.0 percent of all gobbling activity across the state occurred during the period in which turkey hunting seasons occurred.

NCWRC biologists tested and deployed Autonomous Recording Units across North Carolina.



Figures 6A-C. Kernel Density Estimates of gobbling activity. Though these data were collected by ARUs on unhunted properties, the shaded portion of weeks 5-11 indicates the time period in which North Carolina's wild turkey hunting seasons can occur. In 5A and 5B the percentage of total gobbling that occurred before, during, and after the period in which hunting could occur is indicated by text on the figure.



Figures 7A-C. Kernel Density Estimates of regional variation in gobbling activity by year. Though these data were collected by ARUs on unhunted properties, the shaded portion of weeks 5-11 indicates the time period in which North Carolina's wild turkey hunting seasons occurred each year.

DISCUSSION

Our work demonstrates that ARUs can be very effective tools for studying gobbling chronology, though they have some limitations which must be understood. In our study, we were able to tally more than 113,000 gobbles from nearly 54,000 hours of acoustic recordings. If these data were to have been acquired with traditional means (i.e., biologists and technicians in the field listening for gobbles) the cost would likely have exceeded $6,000,000. More importantly though, this extensive data set represents the entire state. Most gobbling chronology studies in the past have relied on far smaller data sets.

Our evaluation of ARU performance offers the opportunity to compare three different ways of studying gobbling chronology: 1) humans listening for gobbles in the field, 2) reviewing ARU audio recordings manually (i.e., listening to the recordings and viewing on a spectrogram), and 3) reviewing ARU audio recordings with automated software (which we did for our entire data set with Raven Pro 1.5 software). Manually reviewing ARU data will provide comparable results to human observers in the field. In addition, the automated review process did not limit the ability to identify patterns in gobbling activity, even though it detected fewer gobbles overall. Our specific automated review procedures yielded 33.8% of the gobbles that could be determined with a manual review (and by extension this would be the nearly the same total that would have been tallied if human observers were used). We conclude that this percentage is sufficient to correctly identify actual patterns in gobbling activity, and because this method can be performed the most efficiently (in terms of both time and expense), it is therefore ideally suited in a gobbling chronology study. Other specific automated review processes, or use of other software packages, may yield different results and so should be thoroughly tested if used in future projects.

Several factors can influence the ability to detect gobbles with ARUs. Spring green-up, topography, distance, wind, background noise, and forest-type all had some effect on ARU performance.

We found that several factors can influence the ability to detect gobbles with ARUs. Spring green-up, topography, distance, wind, background noise, and forest-type all had some effect on ARU performance. Also, ARU performance differed by region. It is important to recognize that some of these factors (such as topography, forest-type, or region) do not change during the course of the spring and therefore, while they may limit ARU performance, their impact is consistent through time and does not impact the ability to determine the pattern in gobbling activity for a given location. However, when comparing activity patterns across regions it was necessary for us to account for this effect, which we did in our KDE analysis. Other factors (such as wind or spring green-up) do change throughout the course of the spring and therefore must be given more consideration when working with ARU data. Wind and background noise change considerably, sometimes on a minute-by-minute basis and we had no way to incorporate this effect into our analysis. Time specific weather and noise data (i.e., by minute) would be the ideal way to incorporate this factor. However, we feel that deploying ARUs over four years did help to mitigate for the effect of variation in wind and background noise.

Spring green-up is perhaps the most important factor to understand, because it had a relatively large impact on detecting gobbles and changed as spring progressed. The ability of ARUs to detect gobbles after green-up is decreased by approximately 25%. This potentially could lead to incorrectly identifying patterns in gobbling activity. We were able to incorporate this effect into our analysis by using green-up dates from the Phenology Network. While we do not feel that the Phenology Network is a perfect indication of when green-up occurs, it offered a robust way to incorporate the effect into our analysis and gave us better insight into when turkey gobbling activity is greatest. Without incorporating this effect into our analysis, our results would have been biased toward suggesting lower levels of gobbling after green-up.

Year to year variation in gobbling activity was much greater than the amount of variation across the regions.

Our study provided no evidence that gobbling activity follows a clear bimodal pattern in North Carolina. This contrasts with previous studies that were relatively small and relied on human observers and in agreement with conclusions of some more recent or ARU-based studies [5, 7, 8, 11-15]. There are numerous peaks in gobbling activity within North Carolina's regions and across years. It is not clear what might be driving these peaks, but given the extensive scale of our work, we conclude that there are likely numerous (and complicated) factors involved. Weather is likely a driver of gobbling activity, as well as local turkey population density or population dynamics (e.g., sex ratio or age structure). Furthermore, in our study, we observed that year to year variation in gobbling activity was much greater than the amount of variation we observed across regions. This has significant implications for making regulatory management decisions, chiefly pointing to the need to ensure that the hunting seasons are timed appropriately to capture a large amount of yearly variation in gobbling activity.

Regardless of the drivers of gobbling activity, we suggest that identifying peaks in gobbling activity may not be the ideal way to inform regulatory decisions. However, at its core, the approach of allowing hunting during a second peak of gobbling activity would serve to ensure two chief objectives of 1) ensuring that turkeys have ample opportunity for breeding before hunting seasons begin and 2)

affording hunters the opportunity to hunt at a time with substantial turkey gobbling activity, which would be 50% or more depending on how much gobbling occurred during the second peak as suggested by earlier studies.

A better way to inform regulatory decisions may be to examine how much gobbling activity occurs before, during, and after hunting seasons. In our study, we found that North Carolina's turkey hunting seasons occur at a time when 60% of gobbling activity potentially occurs, with only 25% of gobbling activity occurring prior to the seasons. As such, our study demonstrates that the timing of North Carolina's turkey hunting seasons appears to achieve the second tenet mentioned on previous page (i.e., hunting allowed when 50% or more of gobbling activity occurs). However, we do not know whether 25% of gobbling activity is indicative of ample breeding opportunity before the seasons occur but do note that this is far less than 50% of gobbling activity that might occur in a hypothesized first (of two) peak in gobbling. State-specific information about nesting chronology is needed for a full understanding of that tenet.

It is important to remember that we deployed ARUs on properties that received little to no turkey hunting pressure. This was by design as we wanted to examine patterns of gobbling activity that have not been unduly influenced by hunters harvesting turkeys or pressuring those that were not harvested. We wanted our study to provide important baseline data from which to make decisions about the timing of the spring turkey hunting seasons. Our results would certainly have been different if ARUs had been deployed on hunted properties. It is also vitally important to recognize that our results likely differ from what many hunters experience. Recent work with ARUs on two properties in South Carolina demonstrated that turkey gobbling was decreased by 27% and 45% by hunting [7]. It is reasonable to assume that hunting pressure in North Carolina has a comparable effect, and therefore it is likely that less than 60% of gobbling activity occurs during the hunting seasons on properties that are hunted. The amount of gobbling activity that occurs during the hunting seasons will be severely curtailed because of hunting pressure, regardless of when the seasons open.

MANAGEMENT RECOMMENDATIONS

Based on results of our study, we recommend that the NCWRC:

- Maintain a statewide framework for turkey hunting seasons, with uniform opening and closing dates for all parts of the state.
- Maintain current opening and closing dates for the youth and regular turkey hunting seasons, through at least 2024. At that time use gobbling chronology information reported herein, along with nesting chronology information from final results of the ongoing study "Multi-scale Assessment of Wild Turkey Ecology in North Carolina" and recommendations by Isabelle et al. (2018)[1] to inform decisions about the best time to open and close the spring hunting seasons.
- Continue research to better understand the drivers of annual variation in wild turkey ecology, including gobbling activity, and the utility of ARUs.

FISCAL CONSIDERATIONS

Over the course of this gobbling chronology project, we spent a total of $253,751.42 (Table 3). Cost were highest during the first year of the project due to purchase of the ARUs and security boxes totaling $52,500. The North Carolina Chapter of The National Wild Turkey Federation provided $51,429.12 during the first three years of the project, allowing the remaining costs during those years to be drawn from the Wildlife and Sport Fish Restoration Program (Pittman-Robertson Funds). Most of the effort required for the project was for processing the acoustic recordings with Raven Pro software, which we accomplished by hiring temporary employees each year. Numerous permanent employees contributed to the project by deploying and testing the efficacy of ARUs in the field each year. The use of ARUs and software for automated detection made this project feasible. If we had collected the same amount of data with traditional techniques (i.e., biologists and technicians in the field each day listening for gobbling turkeys), the cost would likely have exceeded $6,000,000.

The North Carolina Chapter of The National Wild Turkey Federation provided $51,429.12 during the first three years of the project.

Table 3. Hours worked, miles driven, and cost of gobbling chronology project from October 2015 through December 2019.

Year	Hours Worked		Miles Driven	Total Cost
	Permanent Employees	Temporary Employees (data processing)		
Year 1 (2016)	975.5	1,696	8,151	$112,386.29
Year 2 (2017)	903.0	1,200	11,872	$49,401.17
Year 3 (2018)	462.5	1,200	11,686	$43,489.02
Year 4 (2019)	734.5	1,200	12,425	$48,474.94
Total	3,075.5	5,296	44,134	$253,751.42

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APPENDIX -- Additional Details

Equipment

We used 51 Song Meter SM3 Acoustic Recorders (Wildlife Acoustics, Inc., Maynard, MA 01754) in the course of this project. 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.

Field Tests of ARUs

We compiled a set of 10 clear, representative gobbles and set them to play through FoxPro® game calls equipped with SP70 external speakers (FoxPro Inc., Lewistown, PA, USA). We played them in the field with settings adjusted so that gobbles played at 65 decibels when measured 9 meters directly in front of the speaker [13]. We used these gobbles to evaluate the ARUs and human observers at 20 of the locations shown in Figure 1. At each of the 20 locations we chose a 300-meter, straight-line transect, beginning at the tree to which the ARU was attached, that passed through representative habitat for that location. We played the gobble set while the ARU recorded audio files. Starting 50 meters from the ARU, we played the gobble file one time each at 50-meter increments in distance from the ARU, for a total of six times per transect. When time and personnel allowed, we chose a second 300-meter straight line transect, and again played the gobble file at 50-meter increments. We played the gobble file in this fashion along each transect in February or March and again along each transect in June. Each time the gobble file was played we recorded distance from ARU, whether vegetation density or topography interrupted a straight line from ARU to the player, estimated wind on Beaufort scale, and estimated background noise interference (none, low, medium, high). A human observer stood by the ARU and recorded the number of played gobbles heard. We later used Raven Pro 1.5 software (Cornell Laboratory of Ornithology, Ithaca NY, USA) to determine the number of played gobbles that could be detected autonomously with BLED procedures described below and we also determined the number of gobbles that could be detected through a manual review of listening to the audio file and examining the spectrogram with Raven Pro 1.5. Gobbles detected by human observers were tallied from data recorded in the field. Thus, these procedures allowed us to compare the detection of gobbles by three different methods, 1) human observers, 2) manual review of audio recordings, and 3) automated review of audio files by Raven Pro 1.5 BLED software.

Automated Review

We used an automated process to determine the number of gobbles occurring throughout the spring. Specifically, we used a Band Limited Energy Detector (BLED) in Raven Pro software (version 1.5, Cornell Laboratory of Ornithology, Ithaca NY, USA) 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 10dB, 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 ARU's external microphones. We used Excel spreadsheets to examine the BLED results and remove duplicate selections that occurred when sounds were identified on both channels. Our full-time temporary employees verified the BLED results by visually and auditorily examining the selected sounds and categorizing them as either true positives (i.e., gobbles) or false positives (i.e., woodpeckers, crows, or other backgrounds sounds). We used this full set of gobbles found autonomously by Raven Pro's BLED and verified by employees to examine patterns in gobbling chronology.

Evaluating Performance of ARUs

We performed a rigorous statistical analysis of the data we collected in the "Field Testing of ARUs" section described above. Specifically, we modeled detection probability as a function of the variables we thought would affect the ability of ARUs and humans in detecting gobbles. The variables we included in this analysis were: distance from ARU, whether spring green-up had occurred, whether vegetation or topography obstructed the line between ARU and where gobbles where played, the habitat type (i.e., forest-type or open categories) around the ARU, and estimated wind and background noise. We analyzed data for each of the three ways we determined the number of gobbles (human listener, automated review, and manual review). This allowed us to compare the performance of ARU data to humans and it also allowed us to understand how the various factors affect the detection of gobbles. We included all the variables for which we collected data in the field testing. We considered the season that the field-testing data were collected (either February/March or June) as an indication as to whether or not vegetation was "leaf-on" or "leaf-off". All main effects were factors (i.e., categorical predictors) and modeled as additive effects and each with interaction with distance to reflect that the strength of these main effects was dependent on distance from the ARU. We modeled each observation type (human 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:

$$y_{-id} \sim Binomial(\mu_{id}, N)$$

$$logit(u_{id}) = \beta_0 + \beta_1 * Distance_{id} + \beta_2 * Leaf_i + \beta_3 * Cover_i + \beta_4 * Vis_i + \beta_5 * Topo_i + \beta_6 * Wind_i + \beta_7 * Distance_{id} * Leaf_i + \beta_8 * Distance_{id} * Cover_i + \beta_9 * Distance_{id} * Vis_i + \beta_{10} * Distance_{id} * Topo_i + \beta_{11} * Distance_{id} * Wind_i$$

where β_0 represents the mean detection probability for a given observation type at the reference level of all factors, and subsequent parameter estimates represent the difference between the reference group and each level of a factor. We used the "corner constraints" so that the effect of the reference group for each factor is set to zero.

Variables	
Distance	
Leaf	Leaf-on or Leaf-off based on National Phenology Network
Cover	
Vis (Visibility)	
Topo (Topography)	
Wind	Beaufort Scale

Green-up Dates

The evaluation of ARUs described above revealed that spring green-up affects ARU performance. Thus, in order to incorporate this effect into our analysis of gobbling chronology, we needed a way to determine when spring green-up occurs across North Carolina. We used "First Bloom" information from the National Phenology Network [22], which determines green-up dates annually from aerial images. Specifically, for each location at which we deployed an ARU, we determined the average 2014-2019 "First Bloom" date for a nearby city and used this to indicate when ARUs began to be affected by spring green-up. We used the average first bloom date from 2014-2019 for each site, rather than a unique date each year, since First Bloom data were missing at some sites in some years.

Distance Effect

Evaluation of ARUs revealed that detection of gobbles was highly dependent on the distance from an ARU. Furthermore, survey area in relation to distance from an ARUs is not a linear function. It was therefore necessary for our analyses to incorporate the fact there is far more area (and therefore greater likelihood of a turkey gobbling at that distance) surveyed at greater distances by ARUs. We used our field tests at the various 50-meters bands to determine the probability of detecting gobbles in the areas that occurred around those bands. For example, field tests that occurred at the 50-meter band were used to determine the detection probability for the 4.4 acres that occur within 75 meters of the ARU, and the field tests that occurred at the 100-meter band were used to determine the detection probability for the 7.8 acres that occurred between 75 meters and 125 meters from the ARU. In this fashion, the relationship of detection probability, distance, and area surveyed was incorporated into our analyses.

KDE Analysis

We performed a rigorous statistical analysis to determine if our data revealed two distinct peaks in gobbling activity. We used KDE to describe gobbling activity across regions and years. Kernel Density Estimation is a weighted function (i.e., it considers how close observations are to one another) that returns the probability density function for a given random variable, and depends on one user-supplied parameter, bandwidth, to determine the smoothness of the distribution. Our methods determined region- and year-specific critical bandwidths for each KDE to describe the transitions in the number of 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) [23]; this tests a null hypothesis of the true number of modes being equal to 1. For this test, and all analyses, we used the week a gobble occurred as our response variable. However, our evaluation of the ARUs as described above revealed that some gobbles are missed and also that the number of gobbles detected was affected by several factors. Thus, we incorporated the variables into our analysis such that we could partially "correct" the count of observations during a given week. 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:

$$y_i \sim Binomial(\mu_i, N)$$
$$logit(u_i) = \beta_0 + \beta_1 * District_i + \beta_2 * Leaf_i + \beta_3 * Cover_i$$

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. We used the corner point constraint so the effect of the reference group for each factor is set to zero. District is a categorical predictor describing the NCWRC management district in which an ARU was deployed, Leaf is a categorical predictor representing whether deciduous shrub and tree species were in leaf-on conditions, and Cover is also a categorical predictor describing the vegetation types surrounding the ARU. To determine the vegetation conditions surrounding an ARU, we used 200-meter 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. From this analysis, we obtained 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 process, our primary interests were whether the range of gobbling activity was constant across space and time and whether there was variation in peak gobbling activity.

We estimated parameters in all ARU evaluation analyses using a Bayesian approach with Markov chain Monte Carlo (MCMC) implemented in JAGS accessed through program R using package JagsUI [24-26]. Additional file and data manipulation was done using packages data.table, abind, and "here" [27-29]. Data visualization was done using packages ggplot2 [30]. 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 (i.e., R-hat) 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 zero.

Front cover from top left clockwise: ARU (Photo: Chris Kreh/NCWRC; Wild Turkey Biologist Chris Kreh checks the reading on an ARU (Photo: Chris Baranski/ NCWRC); Eastern Wild Turkey (Paul Tessier); page 2: ARU (Photo: Chris Kreh); page 3: Eastern Wild Turkeys (Photo: Bruce MacQueen; page 4 - Eastern Wild Turkey gobbling (Photo: Jim Cummings); page 11 - ARUs during leaf-off, leaf-on conditions (Photo: Chris Kreh); page 16 - testing an ARU (Photo: NCWRC); page 20 - flock of Eastern Wild Turkeys (Photo: Allen Bodenheimer); page 28: A young boy with a harvested turkey (Photo: National Wild Turkey Federation)