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Research Article

Gobbling Chronology of Eastern Wild Turkeys in South Carolina

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ABSTRACT Eastern wild turkeys (*Meleagris gallopavo silvestris*) use a polygynous-promiscuous mating system, wherein males compete for mating opportunities and communicate with females via courtship behaviors. One courtship behavior is vocalization (gobbling), which attracts females and signals dominance to other males. However, temporal variation in gobbling activity may be influenced by external stimuli, environmental variation, and hunter activity. Gobbling activity is a key determinant of hunter satisfaction, and gobbling chronology is often used by state agencies to inform regulatory processes. To identify factors influencing gobbling activity, we evaluated daily gobbling chronology on 3 sites in South Carolina, USA (Webb Wildlife Management Area [WMA] Complex, Savannah River Site, Crackerneck WMA) with different levels of hunter activity. We used autonomous recording units (ARUs; $n = 45$) across 8,280 days to collect 53,937 hours of ambient sound recordings and identified 68,426 gobbles. Gobbling activity varied daily and site interacting with minutes since sunrise best predicted daily gobbling activity. We noted distinct differences in predicted numbers of gobbles between hunted sites and an unhunted site, suggesting that hunting may be an important determinant of gobbling activity. Across our study sites, we observed that $\geq$72% of gobbling activity occurred between 30 minutes before and 60 minutes after sunrise. We found no clear evidence of well-defined unimodal or bimodal peaks in daily or weekly gobbling activity. Across sites, $<$44% of gobbling activity occurred during legal hunting seasons in South Carolina, with between 30% and 48% of gobbling activity occurring after legal hunting seasons. Because hunter satisfaction is primarily influenced by gobbling activity, wildlife managers in South Carolina may consider adjusting dates of turkey hunting seasons to correspond hunting with periods when most gobbling occurs. © 2018 The Wildlife Society.

KEY WORDS gobbling chronology, hunting, hunting regulations, *Meleagris gallopavo*, season timing, wild turkey.

Eastern wild turkeys (*Meleagris gallopavo silvestris*) use a polygynous-promiscuous mating system, wherein males compete for mating opportunities and communicate with females via courtship behaviors (Healy 1992). Males use courtship behaviors to attract females (Bailey and Rinell 1967, Healy 1992), including visual displaying (e.g., strutting) combined with vocalizations (e.g., gobbling; Schleidt 1968, Williams 1984). Gobbling is often elicited by a stimulus or in response to female vocalizations (Hale et al. 1969, Scott and Boeker 1972). Although patterns in gobbling activity across the reproductive season are associated with increases in testosterone levels (Schleidt 1968, 1970; Lisano and Kennamer 1977), factors that influence variation in gobbling activity vary considerably. Specifically, previous studies have suggested that gobbling activity was influenced by female receptivity (Bevill 1973, Miller et al. 1997*a*, Norman et al. 2001), changes in weather (Bevill 1973, Porter and Ludwig 1980, Vangilder et al. 1987, Hoffman 1990, Kienzler et al. 1996), and hunting pressure (Kienzler et al. 1996, Norman et al. 2001, Lehman et al. 2005).

Because gobbling activity is a key determinant of turkey hunter satisfaction (Hoffman 1990, Kurzejeski and Vangilder 1992, Kienzler et al. 1996, Little et al. 2001, Oleson and He 2004), gobbling chronology has played a significant role in setting hunting regulations. Historically, wildlife managers attempted to identify peaks (local maxima) when

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gobbling activity was occurring to set season dates (Bevill 1975, Miller 1984, Kennamer 1986) because the distribution of gobbling activity was thought to be influenced by female reproductive activities (Bevill 1975, Porter and Ludwig 1980, Hoffman 1990). Managers assumed that by setting hunting season dates that excluded the first peak in gobbling activity, females would have initiated nesting. Presumably, timing hunts when females were nesting would reduce vulnerability of females to accidental harvest while maintaining hunter satisfaction, if males would more actively gobble when females were less available on the landscape (Bevill 1975, Hoffman 1990, Kurzejeski and Vangilder 1992, Oleson and He 2004). Regulatory timing of seasons is important because improperly timed dates may result in excessive disturbance to breeding females or removal of dominant males before breeding, which can negatively affect reproductive success and recruitment (Kimmel and Kurzejeski 1985, Vangilder and Kurzejeski 1995, Healy and Powell 1999, Norman et al. 2001, Whitaker et al. 2005).

Spring hunting for male wild turkeys occurs during the reproductive period; hence, hunting pressure may influence gobbling activity, either via removal of gobbling males or suppression of gobbling due to hunter-based disturbance (Kienzler et al. 1996). The effect of hunting activities on gobbling chronology is uncertain because studies incorporating sites with and without presence of hunters are rare (Lehman et al. 2005, Colbert 2013), and hunting has been reported to have negative (Norman et al. 2001, Lehman et al. 2005), neutral (Palmer et al. 1990), or even positive (Miller et al. 1997*b*) relationships to gobbling activity. Notably, previous efforts to describe gobbling chronology have primarily relied on roadside surveys repeated over time, but the availability of autonomous recording units (ARUs) allows researchers to efficiently collect detailed information on gobbling chronology at a finer temporal scale (Scott and Boeker 1972, Porter and Ludwig 1980, Kienzler et al. 1996, Healy and Powell 1999, Lehman et al. 2005). Our objectives were to provide a detailed evaluation of gobbling chronology relative to hunting season timing and to describe factors influencing gobbling activity in South Carolina. Secondarily, we evaluated how gobbling activity varied across multiple study sites with varying levels of hunter activity.

STUDY AREA

We conducted research on 3 sites along the Savannah River in the Atlantic Coastal Plain Region of South Carolina, USA, including the Savannah River Site (SRS), Crackerneck Wildlife Management Area and Ecological Reserve (CWMA), and the Webb Wildlife Management Complex (Webb WMA Complex; Fig. 1), 2015–2016. Elevation on these sites ranged from 8 m to 85 m above sea level. The climate in the Atlantic Coastal Plain was subtropical, temperature ranged from −8°C in January to 38°C in July, and mean annual rainfall was approximately 127 cm. The Webb WMA Complex was a conglomerate of 3 contiguous Wildlife Management Areas (WMAs; Webb, Palachacola, and Hamilton Ridge) owned and managed by the South Carolina Department of Natural Resources (SCDNR). The

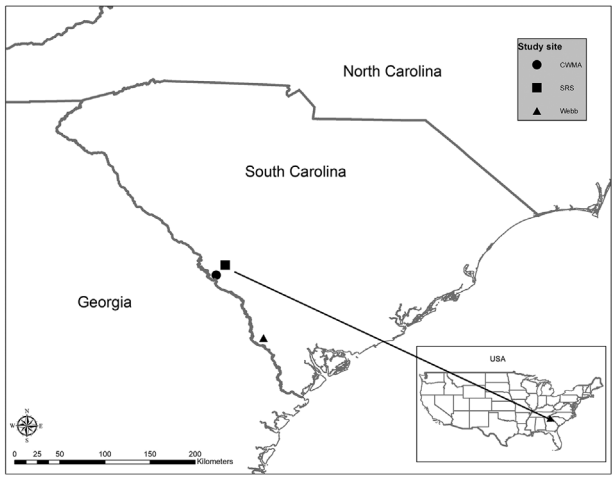

Figure 1. Location of Crackerneck Wildlife Management Area (CWMA), Savannah River Site (SRS), and Webb Wildlife Management Area Complex (Webb) in South Carolina, USA, where we evaluated eastern wild turkey gobbling chronology during 2015–2016.

Webb WMA Complex was 10,483 ha located in Hampton and Jasper counties, and consisted of mostly bottomland hardwoods with upland hardwood stands along drainages, which accounted for 4,673 ha. Planted and managed upland pines, primarily loblolly (*Pinus taeda*) and longleaf pine (*Pinus palustris*), comprised approximately 3,346 ha. The remaining 2,464 ha were composed of mixed-pine hardwoods, wildlife openings, and wetlands. Management activities included prescribed fire, timber management, fallow field management, and maintaining agricultural food plots focused on enhancing habitat for wildlife species such as white-tailed deer (*Odocoileus virginianus*), wild turkey, red-cockaded woodpeckers (*Picoides borealis*), and northern bobwhite (*Colinus virginianus*). Hunting season for male turkey opened 1 April in 2015 and 2016. The season ended on 30 April during 2015 and on 5 May in 2016. Hunting was permitted Monday–Saturdays on the Webb WMA Complex.

The Crackerneck Wildlife Management Area and Ecological Reserve (CWMA) was a 4,400-ha portion of SRS on its western border in Aiken County, and was managed and operated by the SCDNR. Habitats on CWMA were dominated by upland and bottomland hardwoods, mixed pine-hardwoods, and planted pine stand, with wildlife openings managed for white-tailed deer, wild turkey, mourning dove (*Zenaida macroura*), and northern bobwhite. A male turkey season was initiated on CWMA for the public during spring 1983 and was still in place during our study. The hunting season opened 1 April and closed 1 May and hunts occurred only on Fridays and Saturdays.

The SRS was a 78,000-ha tract in Aiken and Barnwell counties owned by the United States Department of Energy. More than 90% of the SRS was forested and consisted of upland and bottomland hardwoods, mixed-pine hardwoods, and planted stands of longleaf pine, loblolly pine, and slash pine (*P. elliottii*). Depending on site-specific management objectives, pine forests were managed on 50- to 120-year

rotations and primarily for wood fiber production. Non-forested areas were primarily marshes, grassland open areas, and utility rights-of-way. Approximately 30% of SRS was managed for red cockaded woodpeckers, with prescribed fire applied on a 3–5-year burn rotation. Turkey hunting pressure on SRS since 1951 was limited, only occurring during an annual 2-day event for 25 mobility-impaired hunters. This hunt began in 2002, usually occurred during the third weekend of April, and resulted in an annual harvest of 25–40 turkeys.

METHODS

We deployed ARUs (Song meter model SM2+; Wildlife Acoustics, Concord, MA, USA) on each site to collect ambient acoustic recordings from 1 March through 31 May in 2015 and 2016. We placed ARUs ≥3 m off the ground to minimize potential human or animal interference. We connected a microphone to the ARU and attached the microphone to the same tree at a height between 6 m and 9 m, which allowed for a greater sampling range away from the recorder because microphones were above ground story vegetation (Colbert et al. 2015).

We deployed 45 ARUs during 2015–2016, with 20 on SRS, 15 on the Webb WMA Complex, and 10 on CWMA. We placed ARUs at sites with turkey activity based on field observations and global positioning system (GPS) locations of wild turkeys collected during previous research (Collier et al. 2017, Wightman et al. 2018). All ARUs were separated by ≥600 m to avoid multiple units recording the same gobble (Colbert et al. 2015). We programmed ARUs at SRS and CWMA to continuously record data beginning 30 minutes before sunrise until 2 hours and 30 minutes after sunrise. We programmed ARUs on the Webb WMA Complex to record ambient sound from 0500 to 2000 for additional research evaluating gobbling chronology relative to female reproductive ecology. Because data collection was more intensive on the Webb WMA Complex, we checked each ARU on the Webb WMA Complex every 2 weeks, replacing batteries and secure digital (SD) cards, whereas we checked ARUs, replaced batteries, and downloaded data on SRS and CWMA ≥2 times during the monitoring period. All turkey capture, handling, and marking procedures were approved by the Institutional Animal Care and Use Committee at Louisiana State University Agricultural Center (protocol A2014-013 and A2015-07).

We autonomously searched audio files for gobbles using Raven version 1.4 (Cornell Laboratory of Ornithology, Ithaca, NY, USA). We created a test identification set based on gobble recordings and used that set to parameterize Raven for gobble identification (700–1,275 Hz, 0.2–2.0-sec duration, 0.018-sec minimum separation, 20% minimum occupancy, 10% sound noise ratio threshold) for the Limited Band Energy detector function. The Limited Band Energy detector function uses the above parameter settings to identify sound signatures that match those of the parameters. The signature for turkey gobbles occurred on the sound spectrum between 700–1,275 Hz; hence, we set the Limited Band Energy detector to select sounds created in this frequency range. However, a suite of animal vocalizations (crows, owls, etc.) and human activities (gunshots) overlap this frequency range and can cause false positives during the search process. Thus, once selection of potential gobbles was completed, we visually and auditorily evaluated each selection to identify gobbles. We also attempted to identify any additional gobbles that were not selected by Raven 1.4 during our evaluation of the spectrogram. For each frequency identified as a gobble, we denoted the record as a 1, recorded date and time, and archived all audio files. We summarized general temporal trends in gobbling chronology by summarizing gobbling activity daily and weekly across sites, and used the findPeaks function in package quantmod (Ryan and Ulrich 2017) to identify local maxima (Table 1). Because agencies setting regulatory frameworks typically adjust hunting regulations on short time frames (e.g., days, weeks), these aggregations of gobbling data were informative.

Table 1. Number of peaks detected in daily and weekly eastern wild turkey gobbling activity on Savannah River Site (SRS), Crackerneck Wildlife Management Area (CWMA), and Webb Wildlife Management Area Complex (Webb), South Carolina, USA, 2015 and 2016.

Site[a]	Year	Local maxima (daily samples)	Local maxima (weekly samples)
SRS	2015	31	4
SRS	2016	31	5
CWMA	2015	29	5
CWMA	2016	30	4
Webb	2015	29	3
Webb	2016	31	3
Webb[2]	2015	27	5
Webb[2]	2016	30	4

[a] Webb[2] does not contain data collected past 150 minutes after sunrise.

To evaluate effects of hunting activity on gobbling activity, we summarized numbers of hunters present each day during the hunting season, which were collected via mandatory check-in cards on the Webb WMA Complex and CWMA. We defined a hunter day as number of hunters/day present on the WMA. We considered SRS as essentially unhunted and did not include a measure of hunter activity in our analysis. For comparative analysis, we reduced recordings at the Webb WMA Complex to 30 minutes before sunrise to 150 minutes after sunrise to match the time frame recorded at SRS and CWMA. We defined the hunting season according to season dates used by the Webb WMA Complex (1 Apr opening) because SRS is split along county lines with variable season frameworks.

We used generalized linear modeling in R (R Core Team 2017) to model counts of gobbles within 30-minute intervals from sunrise to 150 minutes after sunrise. Because our count data were over-dispersed, we used negative binomial regression (Lawless 1987, White and Bennets 1996). Our candidate model set (Table 2) included counts of gobbles as the response variable relative to time of year, minutes from sunrise, and hunting activity. We investigated effect of time of year by modeling days since 1 March as a predictor of gobbling because previous authors noted that gobbling activity increased or decreased as the reproductive season

Table 2. *A priori* model selection table with number of parameters (K), −2 log-likelihood (−2LL), second-order Akaike's Information Criterion (AIC_c), difference from lowest AIC_c value (ΔAIC_c), and Akaike's model weights (w_i) for models explaining effects of daily number of hunters, site, year, days since 1 March, and 30-minute intervals from sunrise on eastern wild turkey gobbles at the Webb Wildlife Management Area Complex, Savannah River Site, and Crackerneck Wildlife Management Area, South Carolina, USA, 2015 and 2016.

Model	K	−2LL	AIC_c	ΔAIC_c	w_i
Site × minutes from sunrise	19	2,2146.6	2,2184.8	0.0	1
Minutes from sunrise × days since 1 Mar × site	37	2,2124.0	2,2198.9	14.1	0
Hunters × minutes from sunrise	13	2,2451.2	2,2463.4	278.6	0
Minutes from sunrise × days since 1 Mar	13	2,2484.2	2,2510.3	325.5	0
Minutes from sunrise	7	2,2497.4	2,2511.5	326.7	0
Year × minutes from sunrise	13	2,2488.6	2,2514.7	329.9	0
Site	4	2,2764.4	2,2772.4	587.6	0
Site × days since 1 Mar	7	2,2762.4	2,2776.5	591.7	0
Site × year	7	2,2762.4	2,2776.5	591.7	0
Hunters	3	2,2921.4	2,2927.4	742.6	0
Hunters × year	5	2,2919.8	2,2929.9	745.1	0
Year × days since 1 Mar	5	2,2938.4	2,2948.4	763.6	0
Days since 1 Mar	3	2,2946.0	2,2956.0	771.2	0
Year	3	2,2951.4	2,2957.3	772.5	0

progressed (Bailey and Rinell 1967, Bevill 1975, Porter and Ludwig 1980, Hoffman 1990). Because most gobbling occurs immediately before and after sunrise, we modeled gobbling activity in 30-minute intervals from sunrise and expected activity to decline over time (Bevill 1975, Hoffman 1990, Colbert 2013). We expected variation in gobbling activity across sites because of differences in hunting activity across sites, so we modeled effect of site (Webb WMA Complex, SRS, CWMA) and year (2015, 2106) on gobbling activity. Previous studies noted that hunting activity could positively or negatively affect gobbling activity (Palmer et al. 1990, Kienzler et al. 1996, Miller et al. 1997*b*, Norman et al. 2001, Lehman et al. 2005), so we modeled gobbling activity as a function of daily number of hunters present and expected a negative effect of hunter numbers on gobbling activity. For all candidate models, we calculated the second-order Akaike's Information Criterion (AIC_c) to determine which model was best supported by the data based on AIC_c ranking (Burnham and Anderson 2002).

RESULTS

We collected approximately 53,937 hours of ambient sound recordings, identified 2,438,841 potential gobbles, and positively identified 68,426 recordings as gobbles (Table 3). We had 300 recorder days out of 8,280 (3%) when data were not collected because of dead batteries, faulty secure digital cards, or malfunctioning microphones. Average gobbles per ARU were 27% greater on SRS than CWMA and 45% greater than the Webb WMA Complex (Table 3).

Numbers of gobbles collected by each ARU on the Webb WMA Complex was variable (15–2,266), with 2 ARUs accounting for nearly 43% of gobbles in 2015. Likewise, numbers of gobbles in 2016 were variable across ARUs (6–1,622), with 3 of 15 ARUs accounting for 44% of gobbles. Numbers of gobbles across ARUs on CWMA also varied during 2015 and 2016 (39–1,798), with the same 2 ARUs collecting 48% of gobbles in 2015 and 47% in 2016. Finally, numbers of gobbles collected across ARUs on SRS during both years also varied (9–4,488).

Most (64%) gobbling on the Webb WMA Complex occurred between 30 minutes prior to and 60 minutes after sunrise with 80% of gobbling occurring between 30 minutes prior to and 150 minutes after sunrise. On SRS and CWMA, 72–84% of gobbling occurred 30 minutes before sunrise until 60 minutes after sunrise and 16–28% occurred between 60 and 150 minutes after sunrise. Daily gobbling activity was variable over our monitoring period, and we found no clear evidence of well-defined unimodal or bimodal peaks in daily or weekly gobbling activity (Table 1; Fig. 2; Appendix A, available online in Supporting Information).

Table 3. False detections from autonomously searching audio files for gobbles using Raven v1.4, and actual number of eastern wild turkey gobbles identified using autonomous recording units (ARUs) on the Savanah River Site (SRS), Crackerneck Wildlife Management Area (CWMA), and Webb Wildlife Management Area Complex (Webb), South Carolina, USA, 2015–2016.

Site[a]	Year	False detections	Gobbles	Total	Gobbles (%)	False detections (%)	Gobbles/unit ($\bar{x}$)
SRS	2015	211,142	16,287	227,429	7.2	92.8	814
SRS	2016	295,901	18,877	316,026	6.3	93.7	1,006
CWMA	2015	187,126	6,589	193,715	3.4	96.6	659
CWMA	2016	198,409	6,348	205,172	3.3	96.7	676
Webb	2015	648,398	9,546	658,722	1.5	98.5	688
Webb	2016	897,865	9,580	908,185	1.1	98.9	688
Webb[2]	2015	158,250	7,308	165,558	4.4	95.6	487
Webb[2]	2016	164,597	7,606	172,240	4.4	95.6	509

[a] Webb[2] does not contain data collected past 150 minutes after sunrise.

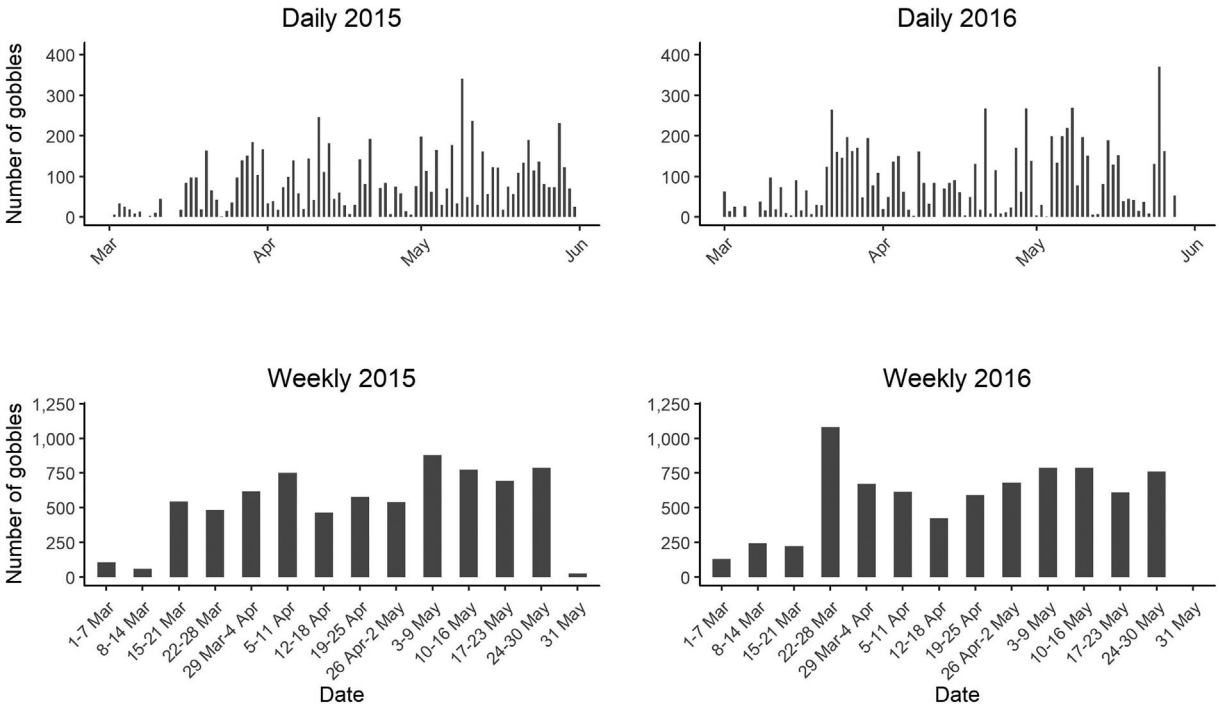

Figure 2. Daily and weekly eastern wild turkey gobbling activity on the Webb Wildlife Management Area Complex (<150 min from sunrise) South Carolina, USA, 2015–2016.

Across both years, we observed an average of 274 hunter days at CWMA and 903 at the Webb WMA Complex (Table 4). In general, gobbling activity and mean gobbles per ARU were greater outside of the hunting season (Table 4). On SRS, 32% and 30% of gobbling occurred after the hunting season closed, as did 33% and 43% on CWMA and 48% and 39% on Webb WMA Complex during 2015 and 2016, respectively. We observed more gobbles per ARU and greater mean gobbles per ARU during the hunting season on SRS than on CWMA and the Webb WMA Complex (Table 4). On CWMA, mean number of gobbles per day when hunting occurred was 9 ± 16 (SD) during 2015 (8 days of open hunting) and 23 ± 25 during 2016 (9 days of open hunting). Conversely, mean number of gobbles on days when hunting was not occurring was 91 ± 112 during 2015 (23 days of no hunting) and 74 ± 81 during 2016 (22 days of no hunting). On the Webb WMA Complex, mean number of gobbles per day when hunting occurred was 84 ± 72 during 2015 (27 days of open hunting) and 68 ± 65 during 2016 (27 days of open hunting), whereas mean number of gobbles on days with no hunting was 45 ± 53 during 2015 (4 days of no hunting) and 106 ± 24 during 2016 (4 days of no hunting). Mean number of gobbles per day on SRS was 201 ± 139 in 2015 and 256 ± 199 in 2016. On both hunted areas, gobbling activity at some ARUs essentially ceased with the onset of hunting and gobbling activity resumed after hunting ended at some ARUs (Fig. 3). Although gobbling activity resumed after hunting season at some ARUs, we also noted across all sites obvious periods when no gobbling activity was recorded at an ARU, regardless of hunting activity.

The model that best fit the data was where minutes from sunrise interacted with site (Table 2). Based on our top model, predicted numbers of gobbles clearly differed between both hunted sites and SRS, with more gobbling predicted on

Table 4. Summary of hunter and eastern wild turkey gobbling data on Savannah River Site (SRS), Crackerneck Wildlife Management Area (CWMA), and Webb Wildlife Management Area Complex (Webb) during the 2015 and 2016 hunting season in South Carolina, USA.

Site[a]	Year	Gobbles	Gobbles/unit outside of hunting season ($\bar{x}$)	Gobbles/unit during hunting season ($\bar{x}$)	Total hunter days	Days open	Hunters/day ($\bar{x}$)
SRS	2015	16,287	514	303	0	0	0
SRS	2016	20,125	622	384	0	0	0
CWMA	2015	6,589	441	218	295	10	30
CWMA	2016	6,763	500	176	252	11	23
Webb	2015	10,324	490	198	959	30	27
Webb	2016	10,320	503	185	847	35	21
Webb[2]	2015	7,308	342	145	959	30	27
Webb[2]	2016	7,643	351	159	847	35	21

[a] Webb[2] does not contain gobbles past 150 minutes after sunrise.

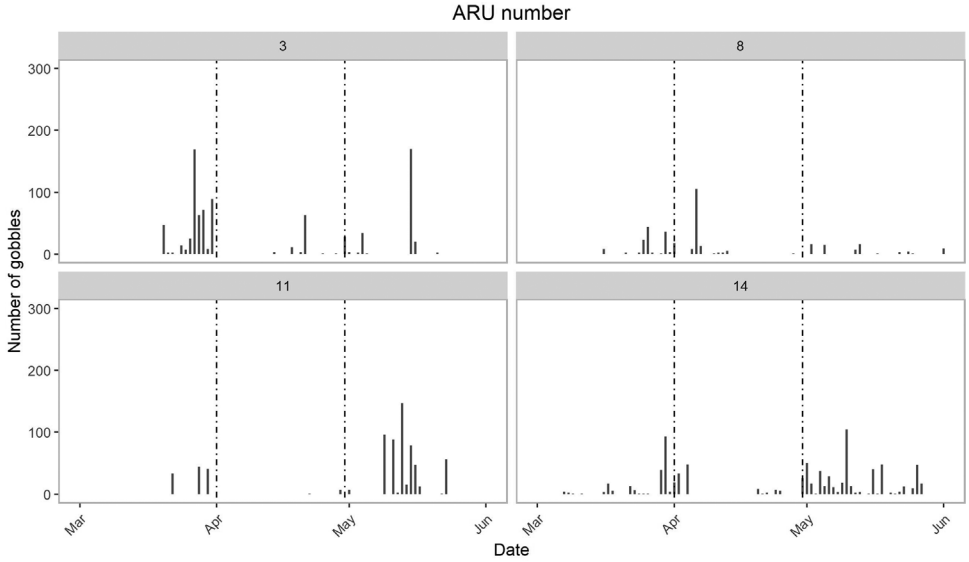

Figure 3. Daily eastern wild turkey gobbling activity for 4 autonomous recording units (ARUs) on Webb Wildlife Management Area Complex in South Carolina, USA, 2015. The first dotted line represents the start date for the spring turkey season, whereas the second denotes the date the season ended.

SRS while males were on the roost and after leaving the roost (Table 5; Fig. 4). We found no evidence that hunter activity, days since 1 March, year, or any combination of these covariates were important predictors of gobbling activity.

DISCUSSION

Previous studies categorized gobbling activity as either unimodal or bimodal (Bailey and Rinnell 1967, Bevill 1975, Hoffman 1990, Kienzler et al. 1996, Miller et al. 1997*a*), but our findings suggest that gobbling activity exhibits significant daily variation during the turkey reproductive and hunting seasons. Moreover, we failed to see either unimodality or bimodality in weekly gobbling activity, which is a notable difference between our findings and previous works (Bevill 1975, Miller 1984, Kennamer 1986). Historically, aggregation of gobbling data occurred because of small datasets, with weekly or bi-monthly aggregations being most common. However, aggregating at such coarse temporal scales ignores subtle changes in gobbling activity, and reduces the ability for managers to use gobbling activity to make meaningful changes to regulatory frameworks. Our work is the first published study to collect gobbling data at sufficient resolution to detail daily gobbling activity (Colbert 2013), hence, differences between our findings and all previously published works are likely influenced by differences in data resolution.

Although males use courtship displays and gobbling to attract females and maintain dominance hierarchies (Bailey and Rinell 1967, Healy 1992), gobbling can be costly by leaving the signaler vulnerable to predation (Zuk and Kolluru 1998, Jennions et al. 2001), which for male turkeys is primarily influenced by losses to hunting (Godwin et al. 1991). Hence, male turkeys that gobble are confronted with a trade-off between maximizing their mating opportunities and minimizing risk of predation (Magnhagen 1991). Previous authors have noted that considering such trade-offs, males of various species will adjust courtship behaviors to mitigate predation risks (Candolin and Voigt 1998, Hale 2004, Lohrey et al. 2009), often by changing reproductive tactics, decreasing frequency of courtship displays, or ceasing courtship completely (Hedrick 2000, Taylor et al. 2005, Moller et al. 2006, Bernal et al. 2007). We found that site interacting with minutes since sunrise best predicted daily gobbling activity, which potentially underscores these trade-offs between gobbling activity and predation risks. Male wild turkeys roost in trees primarily to minimize predation risks throughout the annual cycle (Byrne et al. 2015), but secondarily, roosting in trees and gobbling while on the roost increases sound attenuation (Boncoraglio and Saino 2007, Ey and Fischer 2009). Harvest is the most important form of

Table 5. Parameter estimates from the best approximating model predicting the number of eastern wild turkey gobbles, relative to site and 30 minutes from sunrise (MFS) at the Webb Wildlife Management Area Complex (Webb), Savannah River Site (SRS), and Crackerneck Wildlife Management Area (reference area for analysis), South Carolina, USA during 2015 and 2016.

Parameters	Estimate	SE	*z*-value	*P*-value
Intercept	3.31	0.13	26.58	<0.01
MFS(0–30)	−0.30	0.18	−1.69	0.09
MFS(30–60)	−0.97	0.18	−5.46	<0.01
MFS(60–90)	−1.42	0.18	−8.01	<0.01
MFS(90–120)	−2.12	0.18	−11.78	<0.01
MFS(120–150)	−2.53	0.18	−13.89	<0.01
SRS	0.79	0.18	4.49	<0.01
Webb	0.07	0.18	0.37	0.71
MFS(0–30) × SRS	0.04	0.25	0.18	0.86
MFS(30–60) × SRS	0.41	0.25	1.64	0.10
MFS(60–90) × SRS	0.45	0.25	1.80	0.07
MFS(90–120) × SRS	0.76	0.25	3.02	<0.01
MFS(120–150) × SRS	0.81	0.25	3.19	<0.01
MFS(0–30) × Webb	0.15	0.25	0.60	0.55
MFS(30–60) × Webb	0.08	0.25	0.30	0.76
MFS(60–90) × Webb	0.10	0.25	0.40	0.68
MFS(90–120) × Webb	0.25	0.25	0.98	0.33
MFS(120–150) × Webb	−0.06	0.26	−0.23	0.82

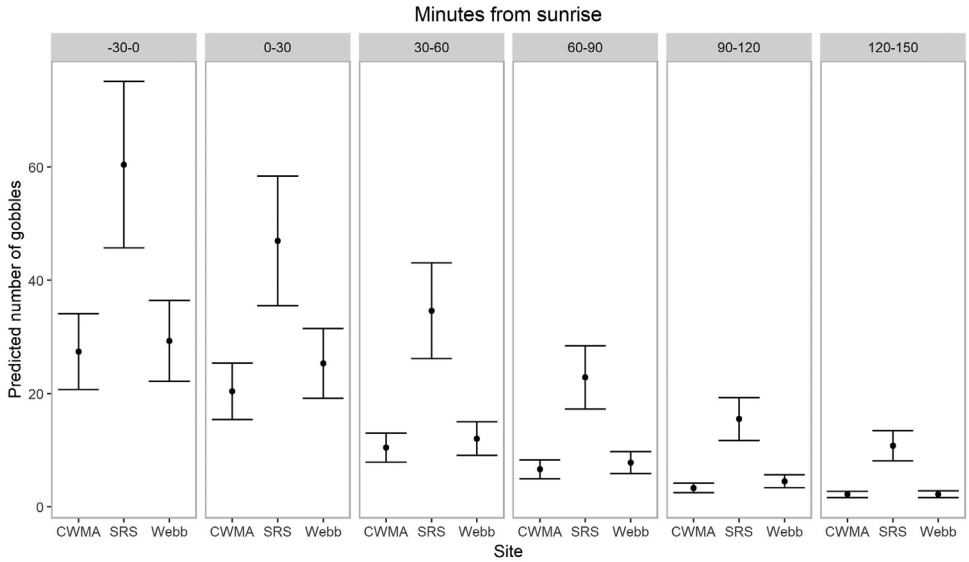

Figure 4. The predicted number of eastern wild turkey gobbles and 95% confidence intervals based on negative binomial regression of the number of gobbles in relationship to minutes from sunrise and site on Savannah River Site (SRS), Crackerneck Wildlife Management Area (CWMA), and Webb Wildlife Management Area Complex (Webb), South Carolina, USA, 2015–2016.

mortality to adult males during the breeding season (Godwin et al. 1991, Chamberlain et al. 2012) and male wild turkeys on our hunted study sites essentially used gobbling as a form of display only while roosting or soon after leaving the roost. Likewise, predicted gobbling activity differed noticeably relative to our unhunted site, suggesting that perceived predation risk from hunting could be an important determinant of gobbling activity on hunted sites (Lehman et al. 2005) or that densities of gobbling males were greater on our unhunted site.

We observed less daily gobbling activity on hunted sites compared to a non-hunted site (SRS). Previous works detailing influences of hunting activity on gobbling (activity and chronology) have produced inconsistent conclusions with some finding negative (Norman et al. 2001, Lehman et al. 2005), neutral (Palmer et al. 1990), and even positive (Miller et al. 1997*b*) effects of hunter activity on gobbling. We noted 27% less gobbling on CMWA and 45% less gobbling on the Webb WMA Complex relative to SRS; however, we also qualitatively noted that gobbling activity essentially ceased on parts of hunted landscapes after hunting began (Fig. 3). Intuitively, cessation of gobbling after the onset of hunting could result from death of males. However, interactions with predators (e.g., humans) can alter frequency of courtship displays or displace males from environments they normally signal in (Michelangeli et al. 2015). Previous research also has demonstrated that encounters with hunters may prompt male wild turkeys to shift their core areas (Gross et al. 2015), and gobbling activity has previously been reported to be negatively affected by hunting activity (Kienzler et al. 1996, Lehman et al. 2005, Norman et al. 2001). We suspect that hunting may encourage males to move into areas lacking hunting activity (Little et al. 2014, Foley et al. 2015, Gross et al. 2015), prompt males that do not alter space use to cease gobbling (Gross et al. 2015), or simply result in death of gobbling males. The collective result would be notable reductions in gobbling activity on hunted areas as hunting seasons progress.

Numerous studies have attempted to evaluate relationships between weather variables and gobbling activity, reporting that no such relationships exist or often contradicting results (Bevill 1973, Kienzler et al. 1996, Miller et al. 1997*b*, Lehman et al. 2005). To relate daily gobbling activity to weather variables, we would have had to rely on weather data collected off-site at the nearest weather monitoring facility, which has been a common approach used in many previous studies. Hence, we did not conduct such analyses, and offer that the eventual results would not have facilitated reliable inferences. The current literature detailing potential influences of weather on gobbling activity is based entirely on road-based surveys subject to observer and sampling biases, and these surveys were often not conducted during inclement weather (Scott and Boeker 1972, Miller et al. 1997*b*, but see Porter and Ludwig 1980). Likewise, weather data collected off-site are likely not comparable in resolution, either spatially or temporally, to gobbling data collected using ARUs. We recommend future work seek to collect weather data and microclimatic data at sites where gobbling is occurring (e.g., at the ARU), rather than from local weather stations or stations on respective study sites (Kienzler et al. 1996) in hopes of more appropriately determining if weather conditions influence gobbling activity.

Spring hunting seasons for male wild turkeys have typically been set based on tradition, with the intent to maximize hunter success while minimizing vulnerability to females (Bevill 1975, Hoffman 1990, Kurzejeski and Vangilder 1992, Oleson and He 2004). Contemporary studies have reported that 67–86% of gobbling occurred during the hunting season (Palumbo 2010, Colbert 2013). However, we observed that <44% of gobbling activity occurred during legal hunting

seasons in South Carolina, with 30–48% of gobbling activity occurring after hunting season closed. Historically, season timing has been based on the expectation that gobbling chronology influences reproductive phenology, and hence that a significant amount of gobbling will occur during the hunting seasons (Bevill 1975, Porter and Ludwig 1980, Kurzejeski and Vangilder 1992, Kienzler et al. 1996, Miller et al. 1997*a*). Wild turkey hunters have regularly supported implementation of seasons that open earlier to capitalize on perceived earlier peaks in gobbling activity (Little et al. 2001, Swanson et al. 2005, Whitaker et al. 2005). Conversely, some authors have suggested hunting be restricted until after the initial peak of nesting because earlier seasons may reduce gobbling activity, decrease density of adult males before breeding, and increase incidental harvest of females, all of which could decrease reproductive success (Kimmel and Kurzejeski 1985, Hoffman 1990, Vangilder and Kurzejeski 1995, Norman et al. 2001, Whitaker et al. 2005). Hunter satisfaction is closely associated with hearing gobbling males on the landscape (Siemer et al. 1996, Little et al. 2001, Oleson and He 2004, Casalena et al. 2011). Given that a significant percentage of gobbling activity occurred after the current hunting season relative to gobbling during the hunting season, we offer that alternative season structures could potentially increase hunter satisfaction. Furthermore, adjustments to season structures could be used to ensure that seasons were more closely aligned with mean nest initiation dates of females in South Carolina (Chamberlain et al. 2018).

MANAGEMENT IMPLICATIONS

Our results indicate that most gobbling activity occurred outside of the current hunting season framework in South Carolina. We recommend that the SCDNR consider alternative season frameworks that would allow hunting to more closely coincide with gobbling activity and mean date of nest initiation. We also found that gobbling activity was primarily influenced by time relative to sunrise with additional evidence that gobbling activity varied across sites with varying levels of hunting activity. We suggest that inclusion of gobbling chronology, perhaps combined with data on nesting phenology of females, weekly harvest rates of males, and measures of hunter satisfaction, be considered by agencies when establishing season frameworks and bag limits.

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