Factors impacting gobbling chronology and activity of male wild turkeys (*Meleagris gallopavo*) in Alabama

by

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Abstract

Eastern wild turkeys (*Meleagris gallopavo silvestris*) are the second most pursued game species in the United States and hold significant cultural and economic value across the Southeast. Recent declines have raised concerns regarding population sustainability. Consequently, many Southeastern states (e.g., Alabama) have adjusted season frameworks through delayed seasons and reduced bag limits in an effort to reverse these trends. The potential impacts to wild turkey populations and hunter satisfaction within Alabama have not been investigated. Further, little is known regarding the relationship between landscape composition and gobbling activity, which is an important determinant of hunter satisfaction. Thus, we deployed 91 autonomous recording units (ARUs) on public and private study sites across Alabama to investigate how different factors impacted gobbling activity and chronology of male wild turkeys. We deployed ARUs from 1 March to 30 June during 2022 and 2023 and recorded all ambient sound from 1 hr before sunrise to 5 hr after. A small, 6-day difference in peak gobbling occurred from north to south Alabama, but the difference was likely inadequate to warrant region-specific hunting seasons. Gobbling activity was suppressed on transitional and moist days. Gobbling activity was positively associated with cumulative male removal, but not to other measures of hunting activity. The proportion of gobbling activity captured by the hunting season was greater on private land, where the season started one-week earlier than on public land. In general, our results showed that later seasons captured less gobbling activity. Gobble detection rates increased with the amount of early successional and mature bottomland forest cover at the landscape level, and were positively associated with forb ground cover at the local (ARU) scale. Overall, our research provides state agencies and managers with important

information on the impact of changes in season frameworks, along with how latitude, humidity, hunting, and habitat characteristics affect gobbling in wild turkey populations.

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CHAPTER 1

THE EFFECTS OF HUNTING, LATITUDE, AND WEATHER ON STATEWIDE GOBBLING CHRONOLOGY OF MALE WILD TURKEYS IN ALABAMA, USA

ABSTRACT

Eastern wild turkeys (*Meleagris gallopavo silvestris*) are an economically and socially important game bird within the southeastern United States. Gobbling activity by male wild turkeys is a key component of the species' reproductive ecology and hunter satisfaction. Therefore, understanding the timing of gobbling and how various factors influence it can be critical to optimizing sustainable harvest and hunter satisfaction in hunted populations. We deployed autonomous recording units (ARUs) on publicly and privately owned study sites across three regions of Alabama. The units recorded from 1 h before sunrise to 5 h after. We used a convolutional neural network to flag potential gobbles and manually verified each selection. We monitored 68 and 91 ARUs during 1 March–30 June 2022 and 2023, respectively. The hunting season opened on March 25 on private land and April 1 on public land. There was a six-day difference in peak gobbling between north and south Alabama. Under existing season structures, 57% of gobbling occurred during the private land hunting season and 41% of gobbling occurred during the public land hunting season, with most of the remaining gobbling activity happening before the season. Gobbling activity was positively related to the cumulative number of males removed throughout the season ($P = 4.16 \times 10^{-4}$) but was not related to other measures of hunting activity. Although we found a 6-day difference in the peak of gobbling activity from north to south Alabama, weekly gobbling activity was likely too similar among regions of the state to justify region-specific seasons. Our data helps turkey managers better understand latitudinal variation in gobbling chronology and how season timing affects the amount of gobbling heard by hunters, an important element of their satisfaction.

INTRODUCTION

Eastern wild turkeys (*Meleagris gallopavo silvestris*, hereafter; turkey) have a profound economic and social influence in the Southeastern U.S. (Dickson 2001, Isabelle et al. 2018). With 2 million hunters hunting 13 million days annually, turkeys are second only to white-tailed deer (*Odocoileus virginianus*) as the most pursued game species in North America (Dickson 2001, Aiken 2016, Isabelle et al. 2018). Accordingly, turkey hunting generates millions of dollars in economic revenue across the U.S. and supports hundreds of jobs (Grado et al. 1997, Chapagain et al. 2020). However, following successful restocking of wild turkeys, populations began declining as early as 2004 (Tapley et al. 2011, Ericksen et al. 2015), and now data from multiple state agencies across the Southeast indicate declines in both estimated harvest and poult-per-hen ratios (Danks 2021; Chamberlain et al. 2022). This has led some state agencies to change season timing to minimize potential disruptions to breeding activity, but this may negatively impact hunter satisfaction.

Turkeys are hunted during their breeding season, primarily due to the gobbling activity associated with breeding behavior (Isabelle et al. 2018), which heavily influences turkey hunter satisfaction (Bevill Jr. 1975). Seeing, hearing, or having the opportunity to shoot a male turkey are major factors impacting the quality of a hunting experience (Wynveen et al. 2005). More specifically, Little (2001) found that hearing and seeing male turkeys greatly impacted perceived quality of a hunt, with hunters expressing greater satisfaction from hunts with increased gobbling activity. In fact, failure to hear sufficient gobbling activity causes dissatisfaction among hunters (Schroeder et al 2018).

Although timing hunting to maximize overlap between the season and peaks in gobbling activity would likely maximize hunter satisfaction, state agencies must also consider population sustainability (Isabelle et al. 2018). For example, the Alabama Department of Conservation and Natural Resources (hereafter; ADCNR) recently made changes to the spring turkey season in Alabama, namely delaying the spring season opening from 20 March to 25 March on private lands. In total, 10 states nationwide have moved their spring hunting season ≥5 days later since 2017, with six of those being in the Southeast (Quehl et al. 2023a). These changes were made in response to a hypothesis outlined by Isabelle et al. (2018) that intensive early harvest of male turkeys during spring may disrupt natural breeding behaviors, decreasing productivity in the population. However, little is known regarding the effects of such delays on wild turkey vital rates or hunter satisfaction.

Several biological and environmental factors interact to affect gobbling activity. Given that gobbling is directly associated with reproductive behavior, it is most affected by time of year, with most gobbling activity constrained to the reproductive season (Healy 1992). Additionally, research has shown that weather conditions can affect daily gobbling activity (Bevill Jr 1973, Kienzler et al. 1995, Palumbo et al. 2019, Wightman et al. 2022*a*). Specifically, wetter conditions suppress gobbling activity, while drier conditions are associated with higher rates of gobbling. We also know that time of day can influence gobbling activity, with most gobbling occurring just before and a few hours after sunrise (Wightman et al. 2019). Thus, the impacts of these factors are well documented.

The onset of the reproductive season and associated gobbling is primarily driven by an increase in photoperiod (Healy 1992). This increase follows a latitudinal gradient, which influences the onset of breeding behavior, including gobbling (Palumbo et al. 2019). The influence of latitude and photoperiod can be observed in numerous avian species' seasonal behaviors, like singing (Da Silva and Kempenaers 2017). Accordingly, Palumbo et al. (2019)

reported an approximate 10–14-day difference in peak gobbling activity between southern and northern Mississippi. Given the connection between latitude and photoperiod, latitude could be used to predict variation in the onset and peak of gobbling activity across broad areas (Whitaker et al. 2005, Palumbo 2010, Isabelle et al. 2018). However, data resolution of older studies may be limited due to the number of personnel required to collect data across large spatial scales simultaneously (Colbert et al. 2015, Palumbo et al. 2019).

Hunting activity may also influence gobbling activity. More broadly, hunting influences wildlife activities and behaviors across taxa and can cause avoidance of humans, decreasing hunter success (Verdade 1996, Burcham et al. 1999, Johnson et al. 2004, Drimaj et al. 2021, Sergeyev 2022). Research on the effects of hunting pressure on gobbling activity has been somewhat inconclusive. Specifically, Wakefield et al. (2020) found that hunter activity and male removal suppressed gobbling activity. They hypothesized that this relationship is a part of the risk allocation hypothesis that suggests animals would allocate more effort to antipredator behavior during times of increased predation risk (i.e., hunting). Also, they suggested that hunting removed vocal males, resulting in a decrease in gobbling activity by remaining males. Accordingly, some have reported greater gobbling activity on non-hunted sites (Lehman et al. 2005, Wightman et al. 2019). Thus, if gobbling activity is negatively affected by hunting, any negative affect of a season delay may be, at least partially, counteracted by the accompanying delay in hunting activity. However, it is somewhat unclear whether this is true, as Palmer et al. (1990), Lint et al. (1995), and Miller et al. (1997) all found a positive effect of hunting activity on gobbling. Palmer et al. (1990) suggested this was the result of hunters expending greater effort in times when males were gobbling more frequently.

Because many states are currently restructuring spring turkey hunting seasons, coupled with the uncertainty related to how shifting seasons may affect gobbling activity and, in turn, hunter satisfaction, we conducted a study to examine the impact of latitude, hunting, and weather on gobbling activity throughout Alabama, USA. We hypothesized there would be latitudinal variation in gobbling across the state. Additionally, we hypothesized that gobbling activity would be negatively affected by one or more aspects of hunting activity (e.g., hours hunted, male removal, etc.). Finally, we hypothesized that gobbling activity would be greater during periods of dry weather.

STUDY AREA

Data were collected during March–June 2022 and 2023 on publicly and privately owned study sites across three primary ecoregions of Alabama (Figure 1.1). Alabama's climate was subtropical, with long, hot, humid summers and mild, cool winters (Runkle et al. 2022). Most of the state received all its precipitation in the form of rain, and the total annual rainfall averaged 141 cm (Runkle et al. 2022). Of our study sites, eight fell within the Coastal Plain, one was within the Ridge and Valley, and the remaining two were within the southwest Appalachia ecoregion. Land cover is slightly different across ecoregions (Miller and Robinson 1994). Our study sites within the northern region of the state had steeper topography and greater coverage of hardwood forests (e.g., oaks [*Quercus* spp.]). Our study sites within the central and southern region of the state had flatter topography and a greater coverage of pine (*Pinus* spp.) than in the northern region. All regions had open and agricultural cover types present. Our study sites included 3 public land sites and 5 private land sites in 2022, and 4 public and 7 private land sites in 2023. All sites south of 32.5° N were classified as southern sites, all sites north of 32.5° N and south of 34° N were classified as central sites, and all sites north of 34°N were classified as northern sites. Publicly owned study sites were selected based on size and consultation with state and federal agency biologists, and included Barbour (11,418 ha), Oakmulgee (18,009 ha), and Skyline (25,495 ha) Wildlife Management Areas (WMAs). All privately owned sites were ≥404 ha in area. The spring turkey hunting season began on March 25 on private and federally owned study sites, and on April 1 on public land sites. The season ended on May 8 across ownerships, resulting in a 45-day season on private and federal land and a 38-day season on WMAs. Legal hunting hours lasted from daylight to dark on private and federal lands and daylight to 1:00 pm on WMAs. Additionally, all study areas had a youth hunting season one week before the start of the regular spring hunting season.

METHODS

Data Collection

We used Song Meter SM4 acoustic recorders with 10-m SM4 microphone cables and external A2 acoustic microphones (Wildlife Acoustics, Inc., Concord, MA) to collect gobbling data. Each ARU was placed in a tree 3-m above the ground via a climbing tree stand. Each external A2 microphone rested on top of a 15x15 cm corner bracket that was screwed into the tree and attached to the corner bracket by two zip ties. A total of 68 ARUs were deployed across 9 study areas during the 2022 field season and 95 ARUs were deployed across 11 study areas during the 2023 field season. Each ARU recorded daily from 1-hr before sunrise to 5-hrs after, starting 1 March and ending on 30 June for a total of 122 days annually. Each ARU had a 64 GB SD card to store data during recordings. We replaced batteries and SD cards in each ARU monthly. We deployed ARUs on each study area based on its size and the number of available ARUs. Within each site, 4–10 units were spaced >600 m apart to avoid overlap in area sampled (Chamberlain et al. 2018). ARU placement was based on based on recommendations of wildlife managers and landowners as to areas regularly frequented by turkeys, with the intent of capturing an adequate number of gobbles to assess gobbling chronology throughout the reproductive season.

At the end of the survey period, recordings were processed through a convolutional neural network (CNN) to obtain selections of possible turkey gobbles (Wightman et al. 2022*b*). Although the specificity of CNNs has decreased the number of false positives (e.g., crow calls), researcher review of each selection is still required (Wightman et al. 2022*b*). Thus, each selection was auditorily verified to censor false positives from the dataset.

We obtained hunter activity data on private study sites from cooperating landowners who recorded all hunting activity during the 45-day spring turkey season. This dataset included date and number of males harvested, daily start and end times for each hunter, and the number of participating hunters. Hunter activity data on public study sites was collected using a mandatory hunter check-in system and included identical data to our private land sites.

We used categories from the Spatial Synoptic Classification (SSC) system (Sheridan 2002) to account for the influence of daily weather conditions on gobbling activity. This system uses surface-based data to create air-mass types for a nearby area. Because Palumbo et al. (2019) found no relationship between SSC temperature categories and gobbling activity, we only used SSC-derived humidity conditions in our analyses. The SSC humidity categories include dry (D), moist (M), and transitional (TR). We used the measure tool in ArcGIS Pro (Esri, v 3.3) to locate the nearest SSC station to each study site, which averaged 41 km. We used data from the next closest available station when daily data was missing from the nearest SSC station.

Analysis

Gobbling activity over the course of the breeding season is non-linear, and it is not uncommon to fail to detect gobbles at several units on any given day. Thus, we used a Generalized Additive Mixed Model (GAMM) to examine the effects of our independent variables on daily gobble counts (COUNT) for each site and region. GAMMs are a semi-parametric approach that uses smoothing terms and a negative-binomial distribution to allow researchers to examine empirical distribution functions (Wood 2006). We used the mgcv package in R version 4.3.1 (R Development Core Team 2023) to develop a GAMM with a negative binomial distribution that included what we determined to be biologically important variables. We developed a model that investigated the relationship of our dependent variable (COUNT) to our independent fixed effects (JULIAN and HUMIDITY). Once our variables were selected, we then included a smoothing term for the interaction of JULIAN by REGION that would separate the model output by our 3 designated regions within the state. We then log transformed the number of ARUs that were recording at each SITE for a given day and included an offset of this variable to account for different levels of recording effort across sites. Finally, we then included a random effect of SITE within the model. We also tested for potential autocorrelation associated with time-series analyses using the ACF and pACF function within base R. We found minimal autocorrelation; therefore, we did not include an AR(1) structured correlation within the model. We also used the concurvity function within the mgcv package to measure the concurvity between components of our GAMM. Results from this function indicated our smoothing term was identifiable and not approximated by other terms within the model. Additionally, we tested the model's goodness-of-fit using the rootogram function in R to test the observed values of the response compared to those expected from the fitted model (Kleiber and Zeileis 2016). The model without the random effect of SITE somewhat underpredicted the number of zeros and conversely overpredicted the number of small nonzero counts, but since this only affected the exact fitted values at small (0-4) counts, we proceeded with the model rather than adding the complexity of modeling zero-inflation explicitly. Further, we investigated the timing of peak gobbling activity on public and private lands across each region using the previously described model and included an interaction of JULIAN by REGION separated by ownership type.

Once our GAMM for the relationship between gobbling activity, humidity, and latitude was developed, we used this as a base to develop a model that would identify any potential relationships between gobbling activity and hunting pressure. Data on hunting pressure was available for all public sites and two of the private study sites during 2022 and 2023. Thus, not all study sites were included in the hunting pressure analysis. Our hunting pressure variables included HUNTERS (hunters/day), HUNTHRS (total hours hunted/day), and MALES (males removed/day). We also included a cumulative version of each variable. To adjust for differences in study area size, we divided each variable by the area of the site to standardize each variable on a square kilometer basis (e.g., hunters/day/km^2). We then used a correlation matrix to determine if any variables were strongly correlated (>0.7), and removed those from further analysis. Due to the large combination of potential variables available, we used R package MuMIn (Barton 2009) to rank models by Akaike's information criterion adjusted for small sample sizes (AICc). To perform model selection, we dropped the random effect from the GAMM model. From our model ranking, we observed ΔAIC <2.0 in 4 competing models (Table 1.1). Accordingly, we used HUNTERS, cumulative HUNTERS, and cumulative MALES in our final model, which also included the random effect of site.

RESULTS

We recorded and verified a total of 186,548 gobbles across approximately 111,840 hours of ambient sound recordings across years. Of those gobbles, 85,482 (46%) were in 2022 and 101,066 (54%) in 2023. During the 2022 breeding season, a total of 48,960 (44%) hours of ambient sound recordings were collected across 68 ARUs. A total of 62,880 (56%) hours across 91 ARUs were collected during the 2023 breeding season. During the 2023 season, 5 ARUs across 3 study sites failed to record at any point during our survey window causing a loss of 3,660 (3%) hours of ambient sound recordings. Additionally, due to ARU malfunctions for units that did record at some point during the season, we lost approximately 4,548 (4%) hours of ambient sound recordings across both years.

Average gobbling activity was 25 gobbles/ARU/day on public land and 176 gobbles/ARU/day on private land, and ranged from 0–364 gobbles/ARU/day. A total of 45,761 (54%) and 59,485 (59%) gobbles occurred during the 2022 and 2023 spring hunting season, respectively. On the 3 WMAs in our study with a season start date of April 1, 41% of all gobbles were recorded during the hunting season across both years, with 51% of gobbles occurring before the start of the hunting season and 8% after. Conversely, the hunting season started March 25 on the remaining sites, and 57% of gobbling occurred during the hunting season, with 30% of gobbles occurring before and 13% after. Most (65.9%) gobbling occurred between 30 minutes prior to sunrise and 60 minutes after. Another 17.1% of gobbles occurred between 60 minutes and 120 minutes after sunrise.

We pooled across both years of data to examine latitudinal trends in gobbling chronology. We observed different trends in gobbling across the 3 regions (Figure 1.2). Specifically, there was a unimodal influence of Julian date on gobbling chronology for the northern and central regions. In north Alabama, gobbling activity peaked on 1 April, while gobbling peaked on 27

March for central Alabama. Gobbling peaked on 26 March for south Alabama, but there was a secondary peak in gobbling activity on 27 April. We also observed a significant relationship between gobbling activity and humidity within our model (adjusted $R^2 = 0.138$; Figure 1.3; Table 1.3). Specifically, we observed 1.56 (95% CL = 1.33–1.83; $P = 3.84 \times 10^{-8}$) times as many gobbles on dry days compared to moist days. Additionally, there were 2.02 (95% CL = 1.56–2.62; $P = 1.49 \times 10^{-7}$) times as many gobbles observed on dry days compared to transitional days. There was not a significant difference in the number of gobbles observed between moist and transitional days (95% CL = 0.59–1.01; $P = 0.058$). Further, we observed gobbling activity peaking earlier on public lands compared to private lands (Figure 1.5). In north Alabama, gobbling peaked on 2 April on public land and 29 March on private land. In central Alabama, gobbling peaked on 27 March and 31 March for public and private land, respectively. Finally, in south Alabama, gobbling peaked on 24 March and 29 March for public and private land, respectively. There was a secondary peak in gobbling activity on private land in south Alabama on 27 April.

We included all public and 2 private sites for both years in the hunting pressure analysis. Cumulative hunter density ranged from 0.73–9.01 hunters/km^2 and averaged 4.5 hunters/km^2. Maximum daily hunter density ranged from 0.29–1.22 hunters/km^2. Average hunter density on public land was 0.14 hunters/km2, average cumulative hunter density was 3.83 hunters/km^2, and the average male removal was 0.15 males/km^2. Comparatively, average hunter density on private land was 0.05 hunters/km^2, average cumulative hunter density was 1.74 hunters/km^2, and the average male removal was 0.22 males/km^2. We did not observe a significant relationship between gobbling activity and HUNTERS ($P = 0.177$). We also did not observe a significant relationship between gobbling activity and cumulative HUNTERS ($P = 0.451$). Cumulative male removal ranged from 0–0.75 males/km^2. We observed 2.38 (95% CL = 0.55–10.26; P = 4.16 x 10^{-4}) times as many gobbles for every 0.17 unit increase in the cumulative number of males removed per square kilometer, per season (Figure 1.4).

DISCUSSION

Based on previous studies (Whitaker et al. 2005, Palumbo et al. 2019), we expected temporal trends in gobbling activity would vary by latitude, especially given that Alabama was >500 km from its northern to southern boundary. Our results partially support this. We observed a 6-day difference in the peak magnitude of gobbling activity from southern to northern Alabama. Similarly, Palumbo et al. (2019) observed a 10–14-day difference in gobbling from northern to southern Mississippi with a coarser dataset collected using point count surveys rather than ARUs. Whitaker et al. (2005) also reported an effect of latitude on nest incubation, which is related to gobbling activity (Wakefield et al. 2020). Our findings are comparable and suggest that gobbling activity is influenced by latitude, even within state boundaries. This is further reinforced by Hopkin's bioclimatic law. This law states that phenological events change by an estimated 4 days for every 5° change in latitude northward or longitude eastward. Given that Alabama varies latitudinally by about 5° from north to south, the 6-day difference in peak gobbling we observed closely aligns with that prediction. Conversely, Kreh et al. (2023) used ARUs across 3 longitudinal different regions of North Carolina and found that 57−61% of gobbling activity occurred within the hunting season across regions, similar to our finding, and little regional variation. Similarly, Gonnerman et al. (2022) found no effect of latitude on timing of nest initiation by hens in Maine. Compared to Alabama, however, those states have significantly less latitudinal variation. Overall, previous research suggests that breeding behavior (e.g., gobbling activity and nest initiation) can vary from a few days to two weeks at the state scale, likely depending on the size and latitudinal variation within the state. The variation in gobbling activity we observed falls within this range, but is likely too small to warrant regional seasons within Alabama.

Our data suggests the current season structure on public lands in Alabama results in hunters missing 59% of gobbling activity, with most of that missed activity (51%) occurring before the season. The intent of the current start date of 1 April on public lands is to follow Isabelle et al. (2018)'s suggestion that moving the season closer to nest initiation or incubation would decrease disruption to breeding activities. The most conservative approach outlined in that paper is to delay opening the season until peak incubation. Based on our data, gobbling activity decreased <10% from the earliest prospective start date we examined (15 March) to the current private lands start date (25 March). However, delaying the season to peak nest initiation would hypothetically reduce the amount of gobbling activity captured by the season to 44%, while delaying the season to peak incubation would reduce it to 27%, assuming no shift in gobbling activity accompanied the season change.

Nonetheless, some have posited that delaying the season would result in no net reduction in gobbling activity observed by hunters due to a negative relationship between the onset of hunting and gobbling activity. Indeed, several have observed greater gobbling activity on non-hunted sites compared to hunted ones (Norman et al. 2001, Lehman et al. 2005, Wightman et al. 2019), although Colbert (2013) found no difference in gobbling between a hunted and non-hunted site. However, Palmer et al. (1990), Lint et al. (1995), and Miller et al. (1997b) all found a positive correlation between gobbling activity and hunting. Palmer et al. (1990) obtained data from mandatory hunter check-ins and estimated harvest rates from the percentage of tagged males harvested. They observed an average annual harvest of 0.2 males/km^2, an average hunter density of 0.08 hunters/day/km^2 and a maximum hunter density of 0.4 hunters/day/km^2. Lint et al. (1995) collected data in a similar manner and reported a maximum site-level harvest of 59 males and an average of 12.4 males harvested/100 hunter-days.

Conversely, Wakefield et al. (2020) found that gobbling was negatively correlated with gobbling activity. However, their data suggested this threshold occurs at a harvest density ≥0.48 males/km^2, which is well below the average harvest density of 0.15 males/km^2 on public land and 0.22 males/km^2 on public land we observed. Although our models did not support an effect of hunting pressure on gobbling activity, gobbling activity consistently peaked earlier, and just before the season, on public land. In contrast, gobbling peaked well after the season opened on private land. We believe this may indicate hunting pressure is sufficient to reduce gobbling activity after season onset on public land, but not private land, in Alabama.

Nonetheless, we believe that other environmental and biological variables such as population size, weather, reproductive phenology, male age structure, and mating competition (Miller et al. 1997a, b, Lehman et al. 2005, Chamberlain et al. 2018, Wakefield et al. 2020) are more important predictors of gobbling activity than hunting pressure or male removal, below a certain threshold. However, our finding that cumulative male removal increased gobbling activity was initially unintuitive. It is logical to assume that hunters are more likely to pursue male turkeys that gobble more frequently (Cartwright and Smith 1990, Swanson et al. 2005). Thus, the positive relationship we observed may be the result of more gobbling yielding more successful hunts through hunters pursuing males that gobble more (Palmer et al. 1990). Another factor that may have led to our findings is the relationship between gobbling activity, hunter harvest, and abundance. Specifically, gobbling activity (e.g., Porter and Ludwig 1980, Gonnerman 2017) and harvest rates (e.g., Clawson et al. 2014, Davis et al. 2017) are often used as indices of relative wild turkey abundance. Thus, greater gobbling activity or hunter harvest on a site may have simply been a function of greater overall adult male abundance.

Alternatively, the positive relationship we observed may also be connected to the hierarchical social system of the species. Wild turkeys are known to use a polygynous-promiscuous mating system and have strict linear dominance hierarchies (Watts and Stokes 1971, Healy 1992). Lewis and Breitenbach (1966) even suggested that subadult male reproductive development would be suppressed by the presence of a sufficient number of adult males. Similarly, Brouwer et al. (2009) studied Seychelles warblers (*Acrocephalus sechellensis*) and indicated that subordinate males are physiologically suppressed by the presence of primary males. Clutton-Brock and Huchard (2013), Tobias et al. (2004), and Crozier et al. (2006) also demonstrated reproductive behavior (e.g., calling or responding to calls from conspecifics) suppression for various species. Thus, we hypothesize that if higher ranked males were harvested from their territories early within the hunting season, it would release subordinate males from competition and increase their gobbling activity. Dominant males are more aggressive and responsible for most mating attempts, while most other males rarely get the opportunity to mate (Watts and Stokes 1971). Thus, it is logical to believe that dominant males are more likely to be harvested by hunters before subordinate males.

Our results indicated that gobbling activity varies latitudinally in Alabama, but likely not to the extent that regional seasons within the state are warranted. States with similar or greater variation in latitude should consider investigating statewide gobbling chronology to facilitate alignment of seasons with gobbling activity. We also found that the amount of gobbling captured by a season may be negatively related to season start date, dependent on timing and whether adult males modify their gobbling activity when hunters are present. However, we are uncertain what percentage of annual gobbling activity should be captured by a spring wild turkey hunting season to optimize hunter satisfaction with other objectives. Recently, Quehl et al. (2024*b*) reported that a two-week spring wild turkey hunting season delay reduced hunter satisfaction and resulted in hunters observing nearly 40% less gobbling. Accordingly, future work should focus on the interaction among season timing, vital rates, gobbling activity, and hunter satisfaction in order to optimize season timing.

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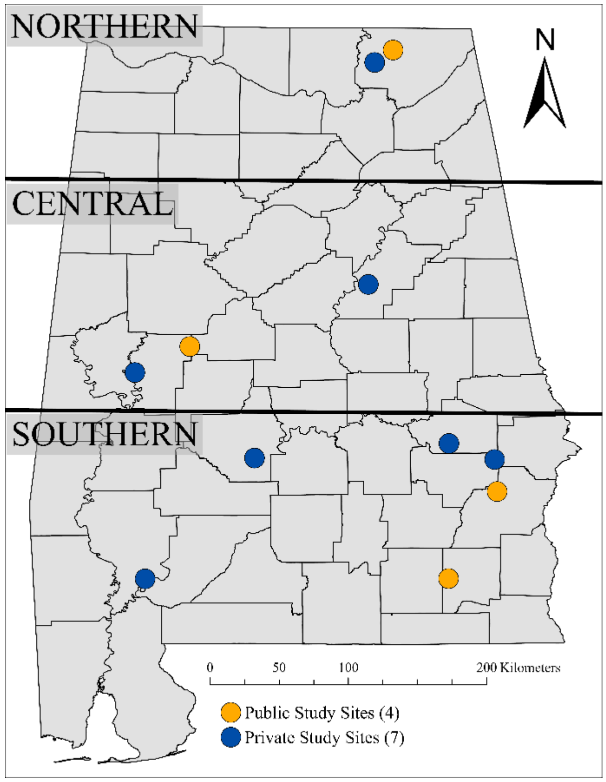

Figure 1.1. Location of study sites across the state of Alabama, where we deployed ARUs to examine the relationship between latitude, humidity, and hunting pressure on gobbling activity of male wild turkeys (*Meleagris gallopavo*) during 2022 and 2023.

Table 1.1. AICc model selection for models describing effects of hunting pressure variables on wild turkey gobbling activity across study sites in Alabama, USA during 2022 and 2023. Only models with ΔAIC <6.0 are presented.

Model	DF	logLik	AICc	ΔAIC	weight
HUNTERS Cumulative + MALES Cumulative	28	-5145.1	10365.8	0.00	0.19
HUNTERS + HUNTERS Cumulative + MALES Cumulative	28	-5153.7	10365.9	0.11	0.18
HUNTERS + HUNTERS Cumulative + MALES Cumulative + HUNTERS Cumulative * MALES Cumulative	29	-5153.7	10367.5	1.73	0.08
HUNTERS + HUNTERS Cumulative + MALES + MALES Cumulative	29	-5153.6	10367.7	1.90	0.07
HUNTERS + HUNTERS Cumulative + MALES Cumulative + HUNTERS * HUNTERS Cumulative	29	-5153.6	10367.8	2.04	0.07
HUNTERS Cumulative + MALES Cumulative + HUNTERS Cumulative * MALES Cumulative	28	-5154.3	10367.9	2.07	0.07
HUNTERS Cumulative + MALES + MALES Cumulative	29	-5154.1	10367.9	2.10	0.07
HUNTERS + HUNTERS Cumulative	28	-5154.4	10368.1	2.31	0.06
HUNTERS + HUNTERS Cumulative + MALES + MALES Cumulative + HUNTERS Cumulative * MALES Cumulative	30	-5153.6	10369.0	3.25	0.04
HUNTERS + HUNTERS Cumulative + MALES + MALES Cumulative + HUNTERS * HUNTERS Cumulative	30	-5153.5	10369.6	3.79	0.03
HUNTERS + HUNTERS Cumulative + MALES Cumulative + HUNTERS Cumulative * MALES Cumulative + HUNTERS * HUNTERS Cumulative	30	-5153.6	10369.6	3.84	0.03

HUNTERS + HUNTERS Cumulative + MALES + HUNTERS * HUNTERS Cumulative	29	-5154.2	10369.7	3.89	0.03
HUNTERS Cumulative + MALES + MALES Cumulative + HUNTERS Cumulative * MALES Cumulative	29	-5154.3	10369.9	4.17	0.02
HUNTERS + HUNTERS Cumulative + HUNTERS * HUNTERS Cumulative	30	-5154.3	10370.0	4.22	0.02
HUNTERS Cumulative	28	-5156.3	10370.0	4.25	0.02
HUNTERS + HUNTERS Cumulative + MALES + MALES Cumulative + HUNTERS Cumulative * MALES Cumulative + HUNTERS * HUNTERS Cumulative	31	-5153.5	10371.0	5.20	0.01
HUNTERS + HUNTERS Cumulative + MALES + HUNTERS * HUNTERS Cumulative	30	-5154.1	10371.5	5.76	0.01

Table 1.2. The summary output for both the latitude and hunting pressure GAMM models that was used to determine the effect of smoothing terms on gobbling activity across study sites in Alabama for 2022 and 2023.

	Latitude Model (n = 2318)				Hunting Pressure Model (n = 1341)			
Smooth Terms[a]	edf[b]	Ref.edf[c]	F-value	P-value	edf	Ref.edf	F-value	P-value
s(Julian.Date):RegionCentral	6.137	6.137	78.38	<2e-16	5.48	5.48	46.23	<2e-16
s(Julian.Date):RegionNorthern	4.803	4.803	56.63	<2e-16	4.002	4.002	30.39	<2e-16
s(Julian.Date):RegionSouthern	6.484	6.484	91.67	<2e-16	3.194	3.194	32.44	<2e-16

a. Independent variables
b. Estimated degrees of freedom
c. Reference degrees of freedom

Table 1.3. Parameter estimates (β), standard errors (SE), 95% confidence limits (LCL and UCL), T-values, and P-values predicting the effect of independent variables on gobbling in both the latitude and hunting pressure models.

	β	SE	LCL	UCL	*T*	*P*
Latitude Model						
Intercept	1.3	0.3	0.8	1.9	4.9	**<0.001**
HUMID - TR	-0.7	0.1	-1.0	-0.4	-5.5	**<0.001**
HUMID - M	-0.4	0.1	-0.6	-0.3	-5.3	**<0.001**
Hunting Pressure Model						
Intercept	0.6	0.4	-0.3	1.5	1.4	0.171
HUMID - TR	-0.7	0.1	-1.1	-0.3	-3.8	**<0.001**
HUMID - M	-0.5	0.2	-0.8	-0.2	-3.4	**<0.001**
MALES Cumulative	2.6	0.7	1.2	4.1	3.5	**<0.001**
HUNTERS	-0.9	0.7	-2.2	0.4	-1.4	0.177
HUNTERS Cumulative	-0.1	0.1	-0.2	0.1	-0.8	0.449

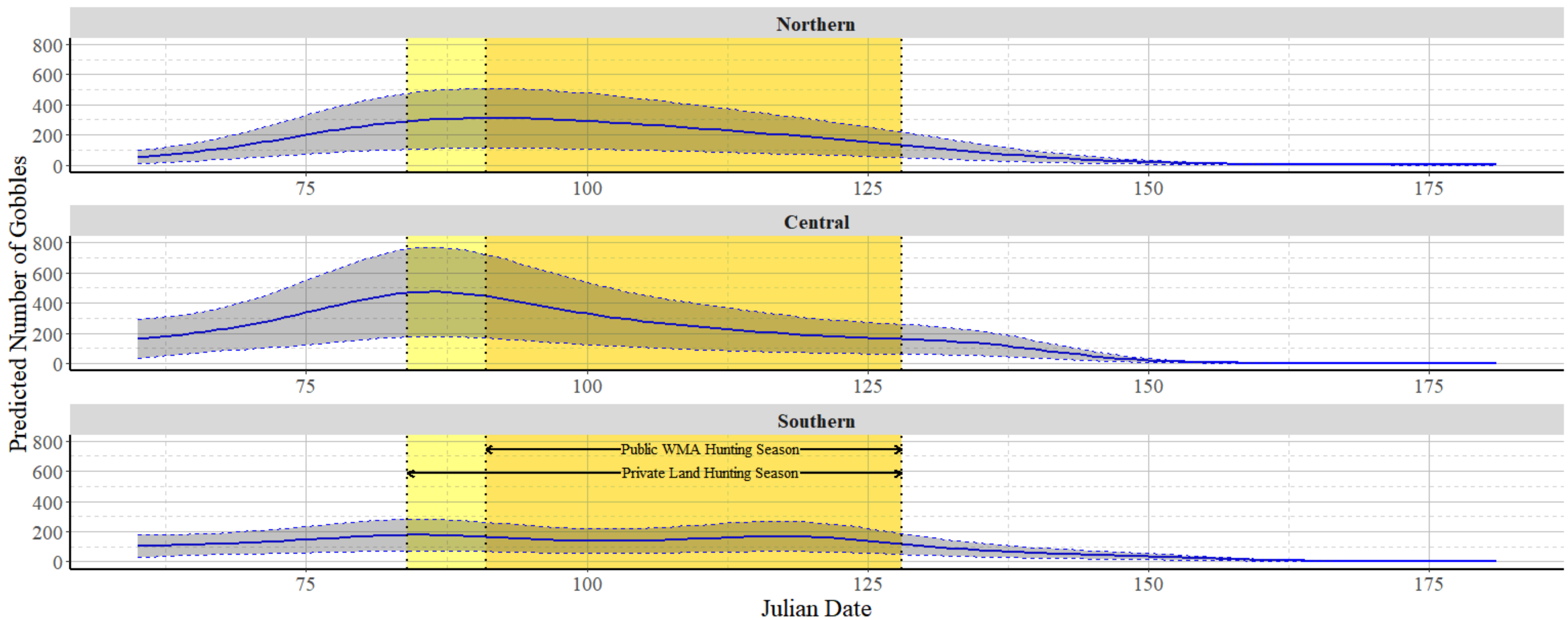

Figure 1.2. Distribution of predicted number of gobbles produced from latitude GAMM model from 1 March–30 June for the northern, central, and southern regions of Alabama for 2022 and 2023 with 95% confidence limits. Includes public (orange) and private (yellow) spring turkey hunting seasons.

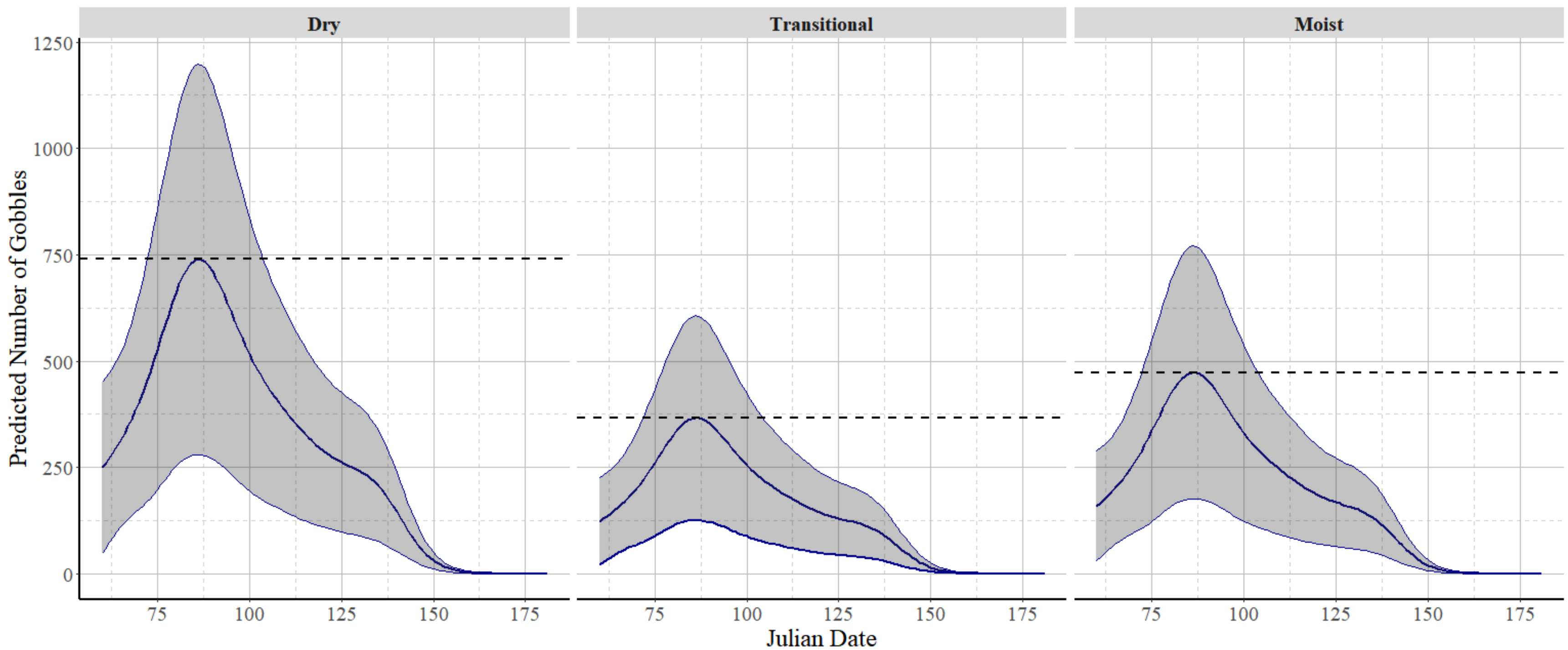

Figure 1.3. Comparison in the predicted number of gobbles through the breeding season between 3 categories of humidity conditions including a horizontal line that indicates peak magnitude of gobbling activity, as well as 95% confidence intervals.

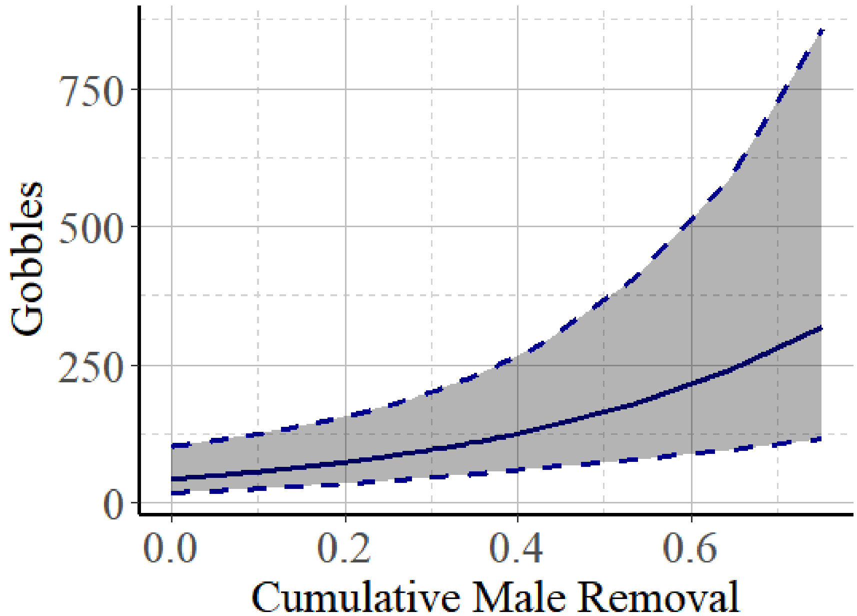

Figure 1.4. Comparison in the predicted number of gobbles through the spring hunting season with cumulative male removal, as well as 95% confidence intervals.

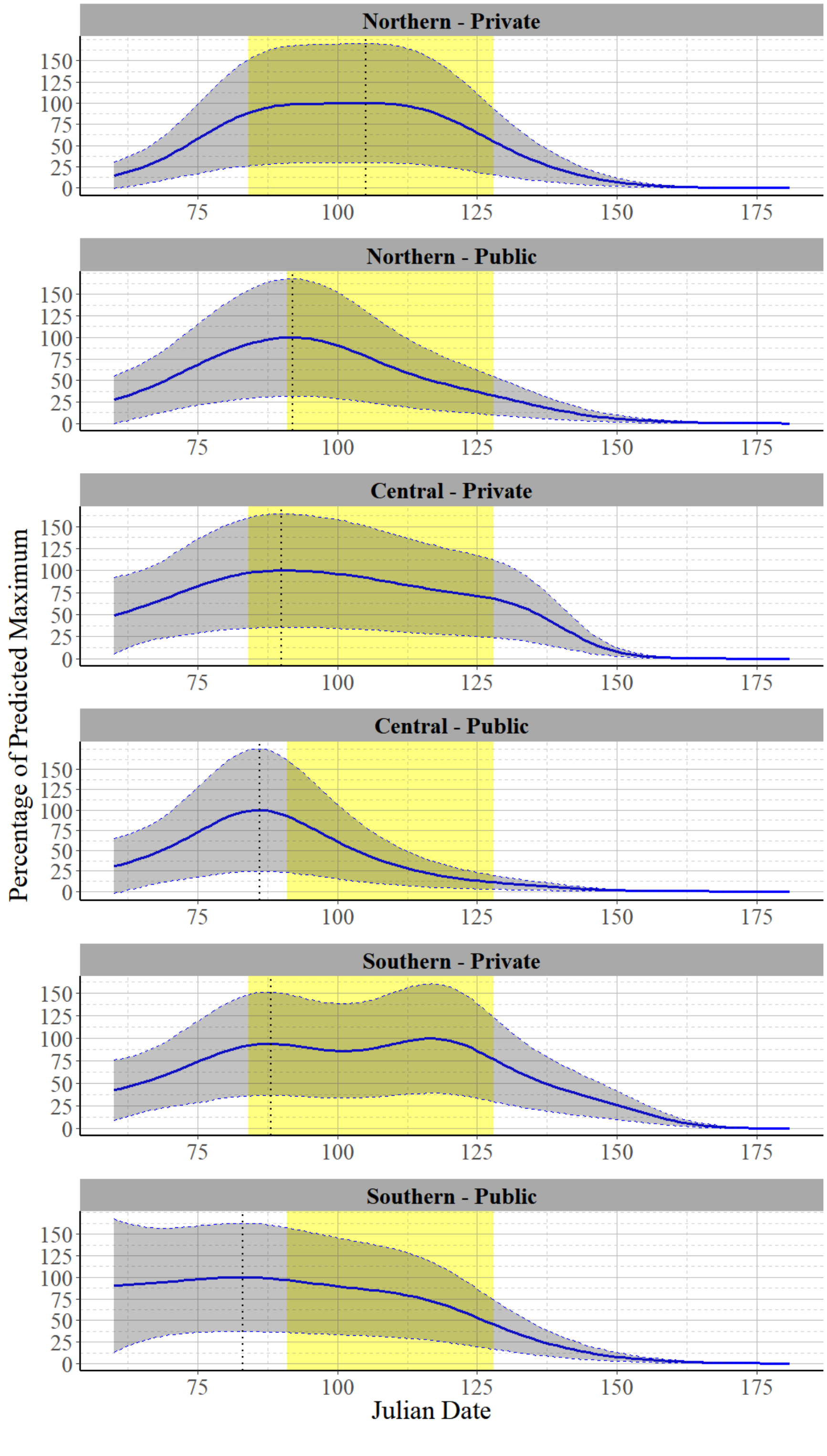

Figure 1.5. Distribution of predicted number of gobbles produced from latitude GAMM model from 1 March–30 June for both public and private lands in northern, central, and southern regions of Alabama for 2022 and 2023 with 95% confidence limits and a vertical dotted line to indicate time of peak gobbling activity. Includes spring turkey hunting seasons for both public and private land in yellow.

CHAPTER 2

THE EFFECTS OF LOCAL AND LANDSCAPE LEVEL HABITAT COMPOSITION ON GOBBLING ACTIVITY OF MALE WILD TURKEYS

ABSTRACT

Eastern wild turkeys (*Meleagris gallopavo silvestris*) are a socially and economically important game bird within the Southeastern United States, and gobbling by male wild turkeys is a key component of hunter satisfaction. Thus, we aimed to identify landcover and plant community attributes associated with greater gobbling detection rates that can be promoted by managers to improve hunter satisfaction. We deployed 68 and 91 autonomous recording units (ARUs) during 1 March–30 June 2022 and 2023, respectively, on 11 study sites across 3 ecoregions of Alabama. The units recorded from 1 h before sunrise to 5 h after. We used a convolutional neural network to flag potential gobbles and manually verified each selection. We used land cover, canopy cover, and LiDAR-derived forest height data to investigate the relationship between gobbling activity and vegetation characteristics at the property (i.e., landscape) scale. We also used within-stand vegetation measurements for a similar analysis at the scale of each recording unit. At the landscape scale, gobbling increased by 6.4% (95% CL = 1.8%–11.2%; P = 0.006) for each 1.0% increase in the proportion of the landscape comprised of mature bottomland forest. Gobbling increased by 10.5% (95% CL = 2.2%–19.5%; P = 0.012) for each 1.0% increase in the proportion of the landscape comprised of early successional plant communities. At the local (recording unit) scale, gobbling increased by 4.3% (95% CL = 1.6%–7.2%; $P = 0.002$) for each 1.0% increase in median forb coverage. In contrast, gobbling decreased by 2.7% (95% CL = 1.0%–4.4%; $P = 0.003$) for each 1.0% increase in median woody ground cover. Although we cannot say whether the gobbling/vegetation associations we observed were related to increased survival and reproduction or simple behavioral selection, areas providing a matrix of mature

forest and early successional cover types would likely support wild turkey populations that provide satisfactory hunting experiences. In addition, several recent studies have indicated positive associations between various facets of wild turkey ecology and availability of early successional cover. Therefore, this vegetation community may be limiting for wild turkeys across the landscape.

INTRODUCTION

Eastern wild turkeys (*Meleagris gallopavo silvestris*, hereafter; turkey) have both an immense economic and social influence (Dickson 2001, Isabelle et al. 2018). Millions of hunters pursue turkeys every year, making them one of the most pursued game species in North America (Dickson 2001, Aiken 2016, Isabelle et al. 2018). This generates millions of dollars in economic revenue across the US and numerous jobs (Grado et al. 1997, Chapagain et al. 2020). However, turkey populations have been experiencing declines for the past two decades (Tapley et al. 2011, Ericksen et al. 2015), and multiple state agencies across the Southeast reported declines in both estimated harvest and poult-per-hen ratios (Danks 2021, Chamberlain et al. 2022). A cause for the decline is still largely unknown; thus, there remains a need for additional research given the significant value of turkey hunting to Southeastern states, where reported harvest and productivity declines are most prevalent.

A key component of turkey hunter satisfaction is the vocalization, known as gobbling, that males produce during the spring hunting season. In fact, turkeys are primarily hunted during the breeding season within the contiguous United States because it overlaps with peaks in gobbling activity (Isabelle et al. 2018). Several have reported that opportunity to hear gobbles or view turkeys is one of the most important components of hunter satisfaction (Little 2001, Wynveen et al. 2005). Conversely, others have reported dissatisfaction among hunters when gobbling is unsatisfactory (Schroeder et al. 2018).

Spatial trends in gobbling activity can inform male turkey resource selection, which likely follows patterns in vegetation conditions at local and landscape scales (Miller et al. 1997). In fact, researchers recently used spatial trends in gobbling to identify land cover types that were important to (i.e., selected by) turkeys, but limited in availability across the study area (Pollentier et al. 2021, Grehan 2022). For example, Grehan (2022) found that within the heavily forested upstate of South Carolina, male occupancy probability increased with increasing coverage of pasture. Numerous other studies have indicated the important role that habitat plays across the range of wild turkeys, including improved recruitment (Hillestad and Speake 1970, Chamberlain and Leopold 2000, Chance et al. 2020, Pollentier et al. 2021), but few have assessed how this translates into the ultimate predictor of hunter satisfaction, which is the opportunity to hear and see male turkeys.

Turkeys are mobile habitat generalists that occupy a variety of plant communities across the continental United States, and resource selection is influenced by seasonal behaviors and temporal availability of food resources (Healy 1992, Chamberlain et al. 2000, Miller et al. 2000, Ogawa 2017). In general, a landscape comprising well interspersed open and closed-canopy cover types is best for turkeys throughout the year (Schroeder 1985). Although mature forests, typically hardwoods, are important throughout the year as roost sites (Dickson 2001), turkeys shift to regularly burned woodlands (Miller et al. 1999) and openings (Porter 1992, Dickson 2001, Grehan 2022) in spring. However, information on the relationship between various land cover types or plant communities, their representation across the landscape, and wild turkey vital rates, abundance, or gobbling activity is limited.

To provide managers and researchers with a better understanding of how vegetation composition and structure at the local and landscape scales influence male turkey detectability and, thus, hunter satisfaction, we conducted a study that compared landscape and vegetation characteristics across public and private sites within Alabama to the detection of gobbles during the breeding season. We hypothesized that gobble detectability at the local scale would increase with coverage of herbaceous vegetation due to the role of this vegetation type in courtship, nesting, and brooding. At the landscape scale we hypothesized that gobble detectability would be greatest on sites that balanced availability of cover types that provide abundant herbaceous vegetation with availability of mature forest that provides roosting, loafing, and winter foraging cover.

STUDY AREA

Data were collected on 8 study areas during March–June 2022 and 11 study areas during March-June 2023. Study areas were distributed across three major ecoregions of Alabama (Figure 2.1). Alabama's climate was subtropical, with long, hot, humid summers and mild, cool winters (Runkle et al. 2022). Most of the state received all its precipitation in the form of rain, and the total annual rainfall averaged 141 cm (Runkle et al. 2022). Of our study sites, eight fell within the Coastal Plain, one was within the Ridge and Valley, and the remaining two were within the southwest Appalachia ecoregion. The Coastal Plain sites were predominantly comprised of loblolly pine (*Pinus taeda*) forests and plantations and bottomland hardwoods dominated by oaks (*Quercus* spp.), as well as various open cover types (e.g., food plots, shrubland, grasslands). The Ridge and Valley study site was largely dominated by loblolly pine forests and oak-hickory (*Carya* spp.) hardwood forests, along with open cover types (e.g., food plots, shrubland, grasslands). Finally, the Appalachia study areas were predominantly comprised oak-hickory forests, loblolly and shortleaf pine (*P. echinata*), and small openings (e.g., food plots).

METHODS

Data Collection

We used Song Meter SM4 acoustic recorders with 10-m SM4 microphone cables and external A2 acoustic microphones (Wildlife Acoustics, Inc., Concord, MA) to collect gobbling data. Each ARU was placed in a tree via a climbing tree stand and screwed into place an estimated 3-m above the ground. Each external A2 microphone rested on top of a 15x15 cm corner bracket that we screwed into the tree an estimated 9-m above the ground and attached to the corner bracket using two zip ties.

A total of 68 ARUs were deployed during the 2022 field season across 9 study areas. A total of 95 ARUs were deployed across 11 study areas during the 2023 field season. Each ARU recorded daily from 1-hr before sunrise to 5-hrs after starting March 1st and ending on June 30th for a total of 122 days of data collection annually. Every ARU had a 64 GB SD card to store data during recordings. Each unit was checked monthly, and batteries and SD cards were replaced for the next month's recording period. We deployed ARUs on each study area based on its size and the number of available ARUs. Within each site, 4–10 units were spaced >600 m apart to avoid overlap in area sampled (Chamberlain et al. 2018).

We recorded vegetation measurements near each ARU to identify local vegetation structure and composition variables that affected gobbling detectability. First, we divided a circle with a 200-m radius around each unit into 15 even segments of 0.8 ha each using the subdivide polygon tool in ArcGIS Pro. We chose to use a 200-m radius because Colbert et al. (2015) reported 207 m was the greatest distance an ARU could reliably record gobbling. We then placed a point in the center of each 0.8 ha segment to establish a vegetation sampling point. Starting at each point, we collected data using the point intercept method along a randomly generated azimuth for 10 m. We used a 0.3-cm diameter metal rod at 1-m intervals along the transect (10 total), and recorded each plant that touched the rod to functional group (i.e., grass, forb, woody, etc.). We recorded basal area at each transect using a 10-factor wedge prism, visual obstruction using a vegetation profile board with four 50-cm strata at a distance of 15 m and height of 1 m in all four cardinal directions (Nudds 1977), and canopy cover using a spherical densiometer at the starting point of each transect (Lemmon 1956).

To assess and account for the influence of daily weather conditions on gobbling activity, we used the Spatial Synoptic Classification (SSC) system (Sheridan 2002). This categorical system uses surface-based data to create air-mass types for a nearby area. The SSC humidity categories include dry (D), moist (M), and transitional (TR). We used the measure tool in ArcGIS Pro to locate the nearest SSC station to each study site and used the corresponding data from these stations for analysis. The average distance was 41 km. If any daily data was missing from the nearest SSC station, the next closest station with available data was used.

To identify any potentially important landscape-level vegetation structure and composition variables for turkeys, we used a land cover dataset from the National Land Cover Database (NLCD) managed by U.S. Geological Survey (USGS), in association with the Multi-Resolution Land Characteristics (MRLC) Consortium (Dewitz 2023). This Landsat-based dataset was generated for the year 2021 and provides land cover information using a modified Anderson Level II classification system at a 30 m resolution (Homer et al. 2012). Additionally, to include structural characteristics of each land cover type, we used a tree canopy cover (TCC) dataset produced from the 2021 NLCD (Ruefenacht et al. 2015), as well as airborne light detection and ranging (lidar) data to produce canopy height estimates (USGS 2024).

We used ArcGIS Pro (Esri, v 3.3) to create a 1-km buffer around each ARU and merged the resulting polygons to delineate each study area. This buffer distance was selected based on the average home range of a male wild turkey within Alabama (Barwick and Speake 1973, Speake et al. 1975, Everett et al. 1979). We then clipped both the NLCD and TCC layer to the resulting boundaries using the clip tool in ArcGIS Pro. Next, we created a digital elevation model (DEM) and a digital surface model (DSM) at a specified 30-m spatial resolution to match our other data sources. Specifically, we used the LAS Dataset To Raster tool within ArcGIS Pro to convert classified point clouds to gridded surfaces with a cell size of 30 m. For the DEM, we filtered LAS points to those only classified as ground and used a cell assignment of minimum. Further, for the DSM, we excluded points greater than 30 m in height and used a cell assignment of maximum. These model products were then subtracted from one another to produce a canopy height model (CHM) that was then used for further data development. We then clipped this CHM product to the same spatial extent as the NLCD and TCC datasets. To ensure that our 30-m pixels aligned across all 3 datasets, we used the snap raster function within the clipping tool. Once all 3 datasets were created for each study site, we constructed a decision tree using ENVI (v 5.5, Exelis Visual Information Solutions, Boulder, Colorado) to further classify land cover types within the NLCD dataset using structural characteristics from the TCC and CHM datasets (Table 2.3). This process produced cover types based on the structural characteristics within each dataset.

Analysis

We used logistic regression in R (v 4.3.1, R Development Core Team 2023) for both our local- and landscape-level analyses. More specifically, we used generalized linear mixed effect models within the glmmTMB package (Brooks et al. 2017) to assess the relationship between gobbling activity and vegetation conditions at each scale. We developed 2 models that assessed the relationship between our binary dependent variable (GOBBLE) and independent variables. Within the local model, we assessed the detectability of male turkeys at each ARU/day; thus, we included a random effect of UNIT nested within SITE (Table 2.1). For the landscape level model, we assessed the detectability of male turkeys at each SITE/day; thus, we only included a random effect of SITE. We adjusted all independent variables to be on a 0 to 1 scale. A recapture variable was also included within the model to account for the likelihood of recording a gobble the day after a positive detection. We then checked correlation amongst our variables using a correlation matrix. Variables with strong correlation (>0.7) were removed from further analysis. The remaining variables were selected based on biological importance and improvement of the model when included via Akaike's information criterion adjusted for small sample sizes (AICc). Once both the local and landscape level models included all potentially biological important variables, we conducted goodness-of-fit tests through checking collinearity, as well as simulating residuals and testing outliers within the DHARMa package (Hartig 2022). Our final local model included independent variables RECAP, WOODY, GRASS, FORB, BARE, and SDGRS (Table 2.1). The final landscape model included independent variables RECAP, YEAR, MBOTF, and ERSUC (Table 2.1). Both models also included a smoothing term for JULIAN to account for the non-linear pattern in gobbling activity throughout the breeding season. Further, since humidity has been found to suppress gobbling activity (Chapter 1), we included SSC humidity data (HUMID) within the underlying structure of both models.

RESULTS

We recorded and verified a total of 186,548 gobbles across approximately 111,840 hours of ambient sound recordings in both 2022 and 2023. Of those gobbles, 85,482 (46%) were in 2022 and 101,066 (54%) in 2023. During the 2022 breeding season, a total of 48,960 (44%) hours of ambient sound recordings were collected across 68 ARUs. A total of 62,880 (56%) hours across 91 ARUs were collected during the 2023 breeding season. ARU malfunctions resulted in the loss of 4,548 hours (4%) of ambient sound recordings across years.

At the landscape scale, we recorded ≥1 gobble/day an average of 86 days out of our 122 day study period (70%). The number of days with ≥1 gobble at the landscape (i.e., site) scale ranged from 53–103 (43%–84%) across both years. The percentage of the landscape in mature bottomland forest ranged from 0–29% and averaged 11%. The percentage of the landscape comprised of early successional cover across our study sites ranged from 1–25% and averaged 12%. Both landscape characteristics were positively correlated with the detection rate of gobbles (Table 2.2). For each 1.0% increase in the proportion of the landscape comprised of mature bottomland forest, we observed a 6.4% (95% CL = 1.8%–11.2%; $P = 0.006$) increase in the detection rate of gobbles across study sites (Figure 2.2). Also, for each 1.0% increase in the proportion of the landscape comprised of early successional cover, we observed a 10.5% (95% CL = 2.2%–19.5%; $P = 0.012$) increase in the detection rate of gobbles across study sites (Figure 2.2). There were 1.5 (95% CL = 1.1–2.1; $P = 0.011$) times as many gobble detections in 2023 as in 2022. Further, gobble detections were 2.3 (95% CL = 1.6–3.2; $P = 1.37 \times 10^{-6}$) times as likely to occur following a positive detection the previous day.

There was significant variation in gobbling activity at the local scale. Across both years, 3 units detected no gobbles, one unit recorded ≥1 gobble/day on 86 days, and the average unit recorded ≥1 gobble on 34 days. Median grass coverage ranged from 0–90% and averaged 22%. Median forb coverage ranged from 0–30% and averaged 5%. Median woody coverage ranged from 0–50% and averaged 15%. Median bare ground coverage ranged from 0–100% and averaged 20%.

We did not detect a relationship between the detection rate of gobbles and median grass ($P = 0.099$) or bare ground coverage ($P = 0.051$) at the local scale; however, there was a negative relationship between gobble detections, median woody coverage, and the standard deviation of grass coverage (Table 2.2). Specifically, for each 1.0% increase in median woody ground cover, we observed a 2.7% (95% CL = 1.0%–4.4%; $P = 0.003$) decrease in the detection rate of gobbles (Figure 2.3). Also, for each 1.0% increase in the standard deviation of grass coverage, we observed a 2.4% (95% CL = 0.02%–4.7%; $P = 0.048$) decrease in the detection rate of gobbles. We found a positive relationship between the detection rate of gobbles and forb ground cover (Table 2.2). For each 1.0% increase in median forb coverage, we observed a 4.3% (95% CL = 1.6%–7.2%; $P = 0.002$) increase in the detection rate of gobbles (Figure 2.3). Further, gobble detections were 3.0 (95% CL = 12.8–3.3; $P = < 2 \times 10^{-16}$) times as likely to occur following a positive detection the previous day.

DISCUSSION

Our landscape-level results support our initial prediction that detection rates of gobbles would increase with coverage of open, early successional plant communities. Adult male turkeys select for open areas during the breeding season to attract females (Porter 1992, Wunz and Pack 1992). Similar to our results, Pollentier et al. (2021) found that male turkey occupancy was greater in areas with a moderate availability of open cover types within forested dominated northern Wisconsin. Specifically, they found that male occupancy peaked when the landscape was comprised of 25% open areas and declined beyond that point. On our study areas across Alabama, which represented both public and private ownership, no site had greater than 25% coverage of early successional plant communities, and the average coverage was 12%. Thus, it is likely that male wild turkey occupancy probability in Alabama could benefit from the creation of additional early successional cover. Grehan’s (2022) work even suggests open cover types may be limiting for turkeys elsewhere, as they found that pasture coverage was the strongest predictor of site use by male wild turkeys, even though it only represented 7% of their South Carolina study area.

Our findings at the local, unit-level, scale lend further credibility to the hypothesis that early successional vegetation is limiting for wild turkeys. Specifically, we found that gobble detection rates were positively associated with forb ground cover and negatively associated with woody ground cover. Forbs represent a notable portion of an adult turkeys’ diet (Dalke et al. 1942, Hurst 1992). Early successional plant communities are also known to be associated with greater productivity and recruitment (Hillestad and Speake 1970, Chamberlain and Leopold 2000, Bryne and Chamberlain 2013, Pollentier et a. 2014, Wann et al. 2020), and nest success is often greater there (Badyaev et al. 1996, Streich et al. 2015). However, we also acknowledge that our results relative to gobbling/vegetation associations may also have been due to simple selection for those areas by adult males, as opposed to increased survival and recruitment resulting from improved habitat.

The results from our landscape-level analysis also suggested that detection rates of gobbles were positively associated with coverage of mature bottomland forest, which peaked at 29% across our study areas. These forests are a preferred cover type for roosting by male turkeys (Dickson 2001, Juhan 2003, Grisham et al. 2008, Ruttinger 2013), and are often spatially aggregated with open cover types (Everett et al. 1985, Hurst et al. 1991, Pollentier et al. 2021). Moreover, previous research has suggested that gobbling activity increases closer to water (Colbert 2011), a key component of bottomland forests, and male wild turkey occupancy was positively associated with hardwood forest aggregation (Pollentier et al. 2021). Given the propensity of male wild turkeys to roost in bottomland hardwood forests, combined with the fact that gobbling activity peaks just before and after sunrise when males are on the roost (Colbert et al. 2015, Wightman et al. 2019, Pollentier et al. 2021), it is logical that gobbling activity would be greater in that cover type. However, Everett et al. (1985) and Hurst et al. (1991) also reported preferential use of bottomland hardwoods and pasture/fields by male turkeys using telemetry, and other research has determined that optimal habitat for turkeys should include interspersion of open and closed cover types to meet daily and seasonal habitat requirements (Porter 1992, Dickson 2001, Schroeder 1985). Collectively, this provides additional lines of evidence for selection of the cover types we found to be important predictors of gobbling.

Many previous studies have reported positive relationships between wild turkeys, mature bottomland forest, and open cover types. However, our data also provide insight that adequate coverage and interspersion of these cover types is likely to benefit hunter satisfaction since gobbling plays a key role in turkey hunter satisfaction (Healy 1992, Quehl et al. 2024). Unfortunately, early successional areas dominated by native, shade-intolerant, herbaceous plants have been declining across landscapes in recent decades, and woody encroachment is often a problem within those that remain (Brennan 1991, King and Schlossberg 2014, Archer et al. 2017). Thus, deliberate management of the landscape to increase coverage of early successional areas is likely necessary to improve habitat conditions and male turkey detection rates.

Our results highlight spatial trends in male wild turkey gobbling detection during the breeding-season and can be used to inform management at the local and landscape scales to increase turkey hunter satisfaction. Specifically, we found that gobble detection rates increased with increasing coverage of early successional vegetation up to 25% of the landscape; gobbling also increased with mature bottomland forest up to 29% of the landscape. We are uncertain whether gobble detection rates would have increased further with greater coverage of either cover type because none of our study areas contained those conditions. At the local scale, our data suggest managers implement practices to increase coverage of forbs and decrease coverage of woody plants in the understory. An increase in forb coverage likely increases food availability (Hurst 1992, Harper 2007, McCord et al. 2014), nest success (Badyaev et al. 1996, Streich et al. 2015), and perhaps even productivity and recruitment through an increase in nesting and brooding habitat quality (Johnson 2019, Johnson et al. 2022). At the landscape scale, timber harvest is a cost-effective means of increasing early successional vegetation where it is limiting (Harrington and Edwards 1999, McCord et al. 2014, Keene et al. 2021, Stewart 2022), and prescribed burning can be used to maintain it once established (Harper 2019, Turner et al. 2020, Stewart 2022). Harvest of mature bottomland forest should generally be avoided in areas where wild turkeys are a management priority unless early succession is more limiting. Future research should focus on determining whether the gobbling/habitat associations we observed are driven by adult male selection, demographic responses at the population level, or both.

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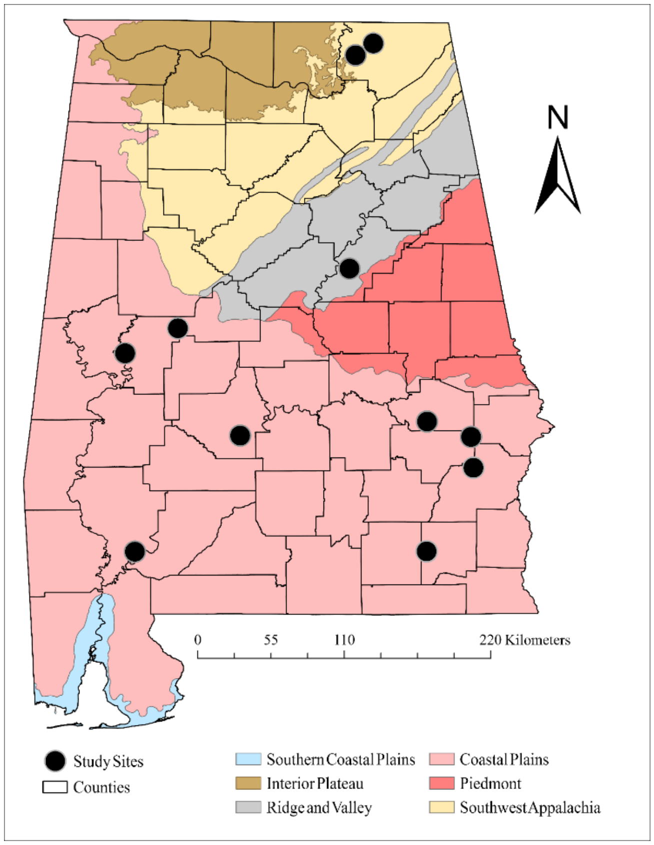

Figure 2.1. Location of study sites across the state of Alabama where we deployed ARUs to examine the relationship between habitat structure and composition on gobble detection rates of male wild turkeys (*Meleagris gallopavo*) during 2022 and 2023.

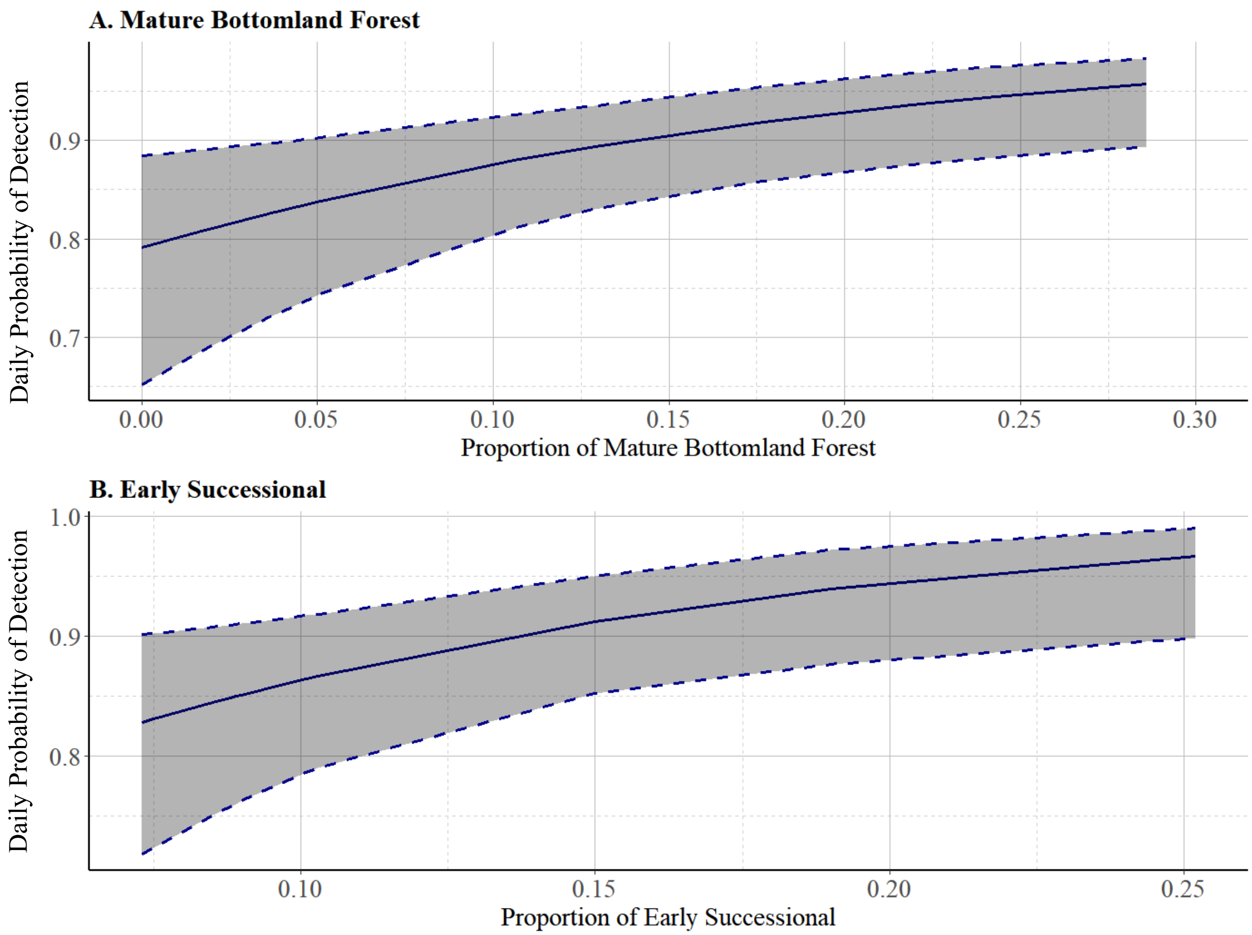

Figure 2.2. Model-fitted relationships for male wild turkey (*Meleagris gallopavo*) gobble detection rates across Alabama, USA compared to proportion of mature bottomland forest (A) and proportion of early successional (B) with changing y-axis scales.

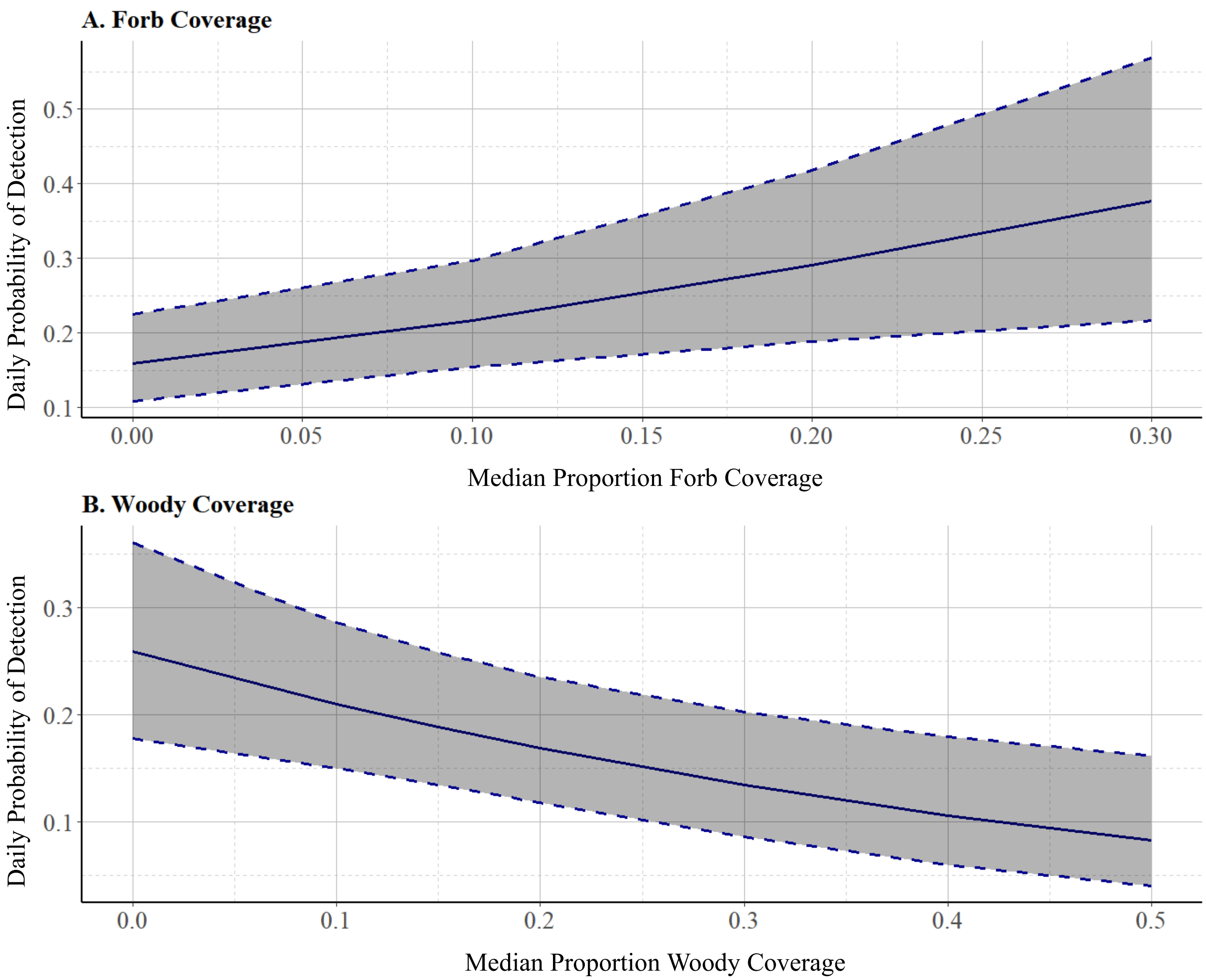

Figure 2.3. Model-fitted relationships from the local scale model for gobble detection rates across Alabama, USA compared to median forb ground cover (A) and median woody ground cover (B) with changing y-axis scales.

Table 2.1. Independent and random variables (and acronyms) of GLMM models to predict wild turkey (*Meleagris gallopavo*) gobble detection rates at local and landscape scales in Alabama, USA for 2022 and 2023.

Variable	Acronym
Study Site/Location	SITE
Individual ARU Identifier	UNIT
Year[2]	YEAR
Recapture Effect	RECAP
Julian Day of Year	JULIAN
Humidity[1]	HUMID
% Median Woody Coverage[2]	WOODY
% Median Grass Coverage[2]	GRASS
% Median Forb Coverage[2]	FORB
% Median Bare Ground Coverage[2]	BARE
Standard Deviation of Grass Coverage[2]	SDGRS
% Mature Bottomland Forest[3]	MBOTF
% Early Successional[3]	ERSUC

1. Categorical humidity values included Dry (D), Transitional (TR), and Moist (M), and were obtained from the Spatial Synoptic Classification (SSC) system.
2. Variables only used within the local scale analysis
3. Variables only used within the landscape scale analysis

Table 2.2. Parameter estimates (β), standard errors (SE), 95% confidence limits (LCL and UCL), and P-values predicting the effect of independent variables on wild turkey (*Meleagris gallopavo*) gobbling at both the local and landscape scale.

	β	SE	LCL	UCL	*P*
Local					
Intercept	-0.8	0.3	-1.5	-0.2	**0.016**
HUMID - TR	-0.8	0.1	-0.9	-0.7	**<0.001**
HUMID - M	-0.7	0.0	-0.7	-0.6	**<0.001**
RECAP	1.1	0.0	1.0	1.2	**<0.001**
JULIAN	1.5	0.5	0.6	2.5	**0.002**
WOODY	-2.7	0.9	-4.5	-1.0	**0.003**
FORB	4.2	1.4	1.6	6.9	**0.002**
GRASS	1.0	0.6	-0.2	2.2	0.099
BARE	-0.9	0.5	-1.9	0.0	0.051
SDGRS	-2.4	1.2	-4.9	0.0	**0.048**
Landscape					
Intercept	-0.7	0.6	-1.8	0.4	0.225
HUMID - TR	-1.2	0.3	-1.8	-0.7	**<0.001**
HUMID - M	-0.8	0.2	-1.1	-0.5	**<0.001**
RECAP	0.8	0.2	0.5	1.2	**<0.001**
JULIAN	0.3	0.7	-1.6	2.2	0.767
YEAR - 2023	0.4	0.2	0.1	0.7	**0.011**
MBOTF	6.2	2.3	1.8	10.6	**0.006**
ERSUC	10.0	4.0	2.2	17.9	**0.012**

Table 2.3. Thresholds used to create decision tree and the final land cover layer with corresponding cover types to investigate the relationship between structural habitat characteristics at a landscape scale and the detection of wild turkey (*Meleagris gallopavo*) gobbling.

Cover Type	Threshold
Water	Same as NLCD[1] source
Developed - Open	Same as NLCD source
Developed	NLCD: Low + Mid + High Intensity Developed
Barren	Same as NLCD source
Mature Deciduous Forest	NLCD: Deciduous + TCC[2]: >80% + LiDAR[3]: >10 m
Mature Deciduous Woodland	NLCD: Deciduous + TCC: 10–30% + LiDAR: >10 m
Mature Deciduous Savanna	NLCD: Deciduous + TCC: 30–80% + LiDAR: >10 m
Mature Evergreen Forest	NLCD: Evergreen + TCC: >80% + LiDAR: >10 m
Mature Evergreen Woodland	NLCD: Evergreen + TCC: 10–30% + LiDAR: >10 m
Mature Evergreen Savanna	NLCD: Evergreen + TCC: 30–80% + LiDAR: >10 m
Mature Mixed Forest	NLCD: Mixed + TCC: >80% + LiDAR: >10 m
Mature Mixed Woodland	NLCD: Mixed + TCC: 10–30% + LiDAR: >10 m
Mature Mixed Savanna	NLCD: Mixed + TCC: 30–80% + LiDAR: >10 m
Mature Bottomland Forest	NLCD: Woody Wetland + TCC: >80% + LiDAR: >10 m
Mature Bottomland Woodland	NLCD: Woody Wetland + TCC: 10–30% + LiDAR: >10 m
Mature Bottomland Savanna	NLCD: Woody Wetland + TCC: 30–80% + LiDAR: >10 m
Young Forest	NLCD: forest cover types[4] + TCC: >80% + LiDAR: <10 m
Young Woodland	NLCD: forest cover types + TCC: 30–80% + LiDAR: <10 m
Young Savanna	NLCD: forest cover types + TCC: 10–30% + LiDAR: <10 m
Young Bottomland	NLCD: Woody Wetland + LiDAR: <10 m
Crops	Same as NLCD source
Early Successional	NLCD: Shrub + Grassland + Pasture + Herbaceous Wetlands

1. National Land Cover Database threshold used.
2. Tree Canopy Cover layer threshold used.
3. LiDAR dataset threshold used via CHM layer.
4. Forest cover types include deciduous, evergreen, and mixed.

APPENDIX

Table A.1. Full model sets for both the latitude model and hunting pressure model.

Model	Variables Included
Latitude model	COUNT ~ s(JULIAN, by = REGION) + HUMIDITY + offset(log(ARU))
Hunting pressure model	COUNT ~ s(JULIAN, by = REGION) + HUMIDITY + MALES Cumulative + HUNTERS + HUNTERS Cumulative + offset(log(ARU))