ABSTRACT Wild turkeys (*Meleagris gallopavo* spp., hereafter turkey) are the second most pursued big game species in the United States. Turkey hunting occurs primarily during spring, and on publicly owned lands managers often monitor hunter numbers and harvest as components of managing hunter opportunity and satisfaction. Contemporary research has shown that hunting activity on public lands can influence male turkey behavior; hence, research detailing hunter behaviors is needed to better support informed management. We allocated 1,500 Global Positioning System units to hunters pursuing male turkeys during the spring hunting seasons of 2014–2018 on the Webb Wildlife Management Area Complex in South Carolina, USA. Mean number of unique hunting bouts per hunter per day was 2 (SE = 0.03, range = 1–8), whereas average time spent hunting was 230.1 minutes (SE = 4.6, range = 11.3–872.6)/hunter/day. Hunting effort was focused during the first half of hunting season, with 70.2% of the total time spent hunting occurring during the first 2 weeks of the season (~1–15 Apr). Mean distance a hunter traveled was 2,171 m (SE = 38.1, range = 10–20,685)/hunting bout. Almost 90% of hunting activity occurred between 0500 and 1200, 76% occurred before 1000. Access to roads appeared to be the primary driver of hunter movements, with 40.1% of all hunter locations <25 m from the nearest main or secondary road. On average, hunters were 480 m (SE = 0.5, range = 0–2,132) from main roads that allowed vehicle traffic, but only 123 m (SE = 0.3, range = 0–1,990) from secondary roads allowing only foot traffic. Hunters spent 54.3% of hunting bouts actively hunting and 45.7% stationary. The amount of time spent active decreased as the hunting season progressed. Hunter effort decreased significantly as the hunting season progressed, indicated by a decline in numbers of hunters and total time spent hunting. Understanding how and when turkey hunters move about the landscape is important for effectively managing hunting access and opportunity on public hunting lands. © 2020 The Wildlife Society.

Harvest is commonly the primary form of mortality for adult male turkeys (Godwin et al. 1991, Paisley et al. 1996, Wright and Vangilder 2001), and likely additive to natural mortality (Vangilder 1992, Healy and Powell 1999). Hunter–turkey interactions generally mimic predator–prey dynamics on the landscape (Ciuti et al. 2012, Bonnot et al. 2013, Gross et al. 2015a). However, turkey hunting is restricted in time (e.g., spring hunting season) and space (land ownership class), and during spring is primarily focused on a single sex of the population (males). Thus, on publicly owned areas that allow turkey hunting, managing hunter numbers and harvest intensity are often used to maintain adequate opportunity (Little et al. 2001, Nicholson et al. 2001). Hunting activities on public lands can influence male turkey movements (Godwin et al. 1991, Gross et al. 2015a, Collier et al. 2017), roosting behaviors (Wakefield et al. 2020a), and gobbling activity (Chamberlain et al. 2018, Wightman et al. 2019, Wakefield et al. 2020b). Thus, further information is warranted on hunter behaviors while turkey hunting to better focus turkey management activities.

Improved knowledge on movement ecology of hunters has been used to identify characteristics such as changes in search behavior, movement rates, time-activity budgets, and resource selection during hunting activities (Lyon and Burcham 1998, Brøseth and Pedersen 2000, McGrath et al. 2018). For turkey hunters, data on when and how they are distributed spatially on the landscape during hunting season has historically relied on hunter-reported surveys on hours spent hunting and general location of hunting activities (Hazel et al. 1990, Wynveen et al. 2005, U.S. Department of the Interior et al. 2016). Behavioral activities used during turkey hunting are a mixture of stationary and active behaviors (Hazel et al. 1990, Wynveen et al. 2005). Hunter survey reports provide little information on distribution and movements of active turkey hunters across the landscape. Currently, available information describing turkey hunter behaviors is limited to a study addressing effect of hunting activity on turkey behavior (Gross et al. 2015a). However, hunter behaviors can play a significant role in decisions for how to manage public lands for turkeys and turkey hunting, so additional information is warranted.

Our objectives were to describe metrics of turkey hunter movement behaviors on public lands over the course of the spring hunting season. Specifically, we evaluated how much time turkey hunters spent hunting (both in stationary and active phases), distances traveled and movement velocity of hunters, and how hunters were distributed relative to road access while turkey hunting.

**STUDY AREA**

We conducted our research on the Webb Wildlife Management Area Complex (WMA: Wightman et al. 2019) from 2014 to 2018 (Fig. 1). The Webb Wildlife Management Area Complex was a conglomerate of 3 contiguous WMAs (Webb, Palachacola, and Hamilton Ridge) owned and managed by the South Carolina Department of

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**Figure 1.** Webb Wildlife Management Area (WMA) Complex, South Carolina, USA, including all boundaries, buffered primary roads (yellow) and secondary-tertiary roads (red).
Natural Resources (SCDNR), USA. The 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 approximately 4,673 ha. Planted and managed upland pines, primarily loblolly (Pinus taeda) and longleaf pine (P. palustris), comprised approximately 3,346 ha. The remaining 2,464 ha consisted of mixed-pine hardwoods, wildlife openings, and wetlands. Mean annual temperatures ranged from 3–34° C and received approximately 50 cm of precipitation each year. During our study period the long-term average temperature was 18° C with 4.5 cm of precipitation. Management activities included prescribed fire, timber management, fallow field management, and maintaining agricultural food plots for wildlife species such as white-tailed deer (Odocoileus virginianus), turkey, red-cockaded woodpeckers (Picoides borealis), and northern bobwhite (Colinus virginianus). During 2014–2015, the regular turkey season opened on 1 April and closed 1 May. In 2016–2018 the regular season opened 1 April and closed 5 May. Dates of youth hunts varied by year, but generally occurred the Saturday before the regular season opened (Table 1). Hunting was permitted all day, with legal hunting hours being 30 minutes prior to sunrise until 30 minutes post sunset. Hunting was not permitted on the Webb WMA Complex on Sundays.

The Webb WMA Complex contained 3 distinct road types, which we define here as main, secondary, and tertiary roads. Vehicle access was permitted on main roads (maintained gravel roads) and prohibited on secondary and tertiary roads. Secondary roads were maintained by SCDNR staff with annual mowing and herbicide applications to maintain ease of access. Tertiary roads consisted of firebreaks maintained sporadically on a multiple-year rotation, with maintenance often being restricted to discing before prescribed fire activities. Secondary and tertiary roads prohibited vehicle access, but were the primary entry for hunters accessing the Webb WMA Complex; therefore, we grouped secondary and tertiary roads into one category labeled secondary roads (Fig. 1).

**METHODS**

To evaluate how wild turkey hunters distributed themselves within a public hunting landscape, we monitored movement behaviors of turkey hunters during spring hunting seasons 2014–2018. On the Webb WMA Complex, hunters were required to complete a self-clearing hunter data card upon entering the WMA and return the card upon exiting. The self-clearing card was equivalent to a 1-day permit for WMA access and there were no restrictions on hunter numbers each day. If a hunter left and returned to the WMA on the same day, (s)he was not required to fill out an additional hunter data card. Information collected on hunter cards included date, hunter name, total hours hunted, and number of turkeys seen or heard. Thus, each hunter must complete a self-clearing permit, so we stationed personnel at road access points near self-clearing stations approximately 2 hours before until 30 minutes after sunrise to meet with hunters and allocate Global Positioning System (GPS) units (j-gotU GT-120 GPS; Mobile Action, New Taipei City, Taiwan) to those individuals who volunteered to carry them. We scheduled GPS units to record a location every 30 seconds. If hunters planned to group hunt (e.g., parent and child), we only allocated 1 unit/group. Hunters were asked to carry the GPS units in a front pocket or in the top of a backpack to ensure data acquisition, and hunters were asked to deposit GPS units at self-clearing permit stations at the end of the hunt. We collected returned GPS units twice daily, and, after downloading hunter locations, erased and recharged the battery for redeployment the following day.

Hunting season on the Webb WMA Complex varied by year. We deployed GPS units during all spring hunting season days during 2014–2018 except during the 2014 youth hunt (Table 1). We manned check-stations each morning that hunting was occurring, and to ensure our data were representative of hunting activity on the Webb WMA Complex, graphically compared how many GPS units we distributed daily with the number of self-clearing hunter permits collected each day to evaluate whether we were tagging a consistent proportion of the hunters with GPS units.

For spatial analysis of hunter locations, we buffered main roads by 100 m (50 m/side) using ArcMap 10.3.1 (ESRI, Redlands, CA, USA) and considered any GPS locations falling within these buffers as nonhunting points because main roads at the Webb WMA Complex are not typically used for hunting (J. R. Cantrell, personal communication). Additionally, we buffered any infrastructure such as hunter check-stations or campgrounds by 150 m and classified all locations within the buffers, or locations that occurred outside the boundaries of the Webb WMA Complex, as nonhunting points. Turkey hunters have specific search behaviors when hunting that include periods of stationary hunting activity interspersed with active periods when a hunter is moving (Hazel et al. 1990). Thus, one hunter could have multiple, independent periods of hunting activity.
that are both temporally and spatially separated, which we hereafter define as hunting bouts. Hunters typically drove between areas they hunted, so we excluded points collected on main roads from analysis, which created a time lapse in hunter GPS data that we used to identify initiation of potential hunting bouts. Based on GPS time-lapse data from road travel, we estimated on average it took hunters approximately 7 minutes to relocate to a new area when starting a new bout. Thus, we used any time lapse >7 minutes to assist with separating unique turkey hunting bouts. We also incorporated a minimum distance filter of 300 m between GPS locations, given our 30-second GPS intervals, to assist with separating hunting bouts because foot travel is limited to approximately 83 m/minute in optimal conditions (Barton et al. 2003). Finally, to be defined as a hunting bout, we required ≥10 minutes of continuous activity outside of any nonhunting buffer (e.g., main road).

To separate stationary from active hunting periods during each hunting bout, we used dynamic Brownian Bridge movement models in Program R package move (Kranstauber et al. 2019, R Core Team 2020) to create utilization distributions (UDs) for each hunting bout. We set the locational error at 20 m (twice the mean error found by Morris and Conner 2017), with a window size of 7 and margin size of 3 (Byrne et al. 2014, Cohen et al. 2018). We tested various sizes of UD from 25% to 99%, and via trial and error, selected 45% UD as most appropriate for identifying stationary activity centers. We then used package raster and intersected GPS locations during each bout with the 45% UD (Hijmans et al. 2019). We classified each location within the UD as stationary and locations outside the UD as either 1) active locations because hunters moved through the landscape, or 2) abandoned points (i.e., points with no preceding or subsequent locations), which were primarily errant locations tied to stationary points not captured within the 45% UD. We used the 45% UD and classified the location closest to the UD center via package centroid as the stationary hunter centroid (Brundson and Chen 2014). We calculated the distance of each hunter centroid from main and secondary roads to evaluate how hunters were distributed from roads during hunting activities (Fig. 2).

To differentiate between walking points and missed GPS fixes, we used a time filter to separate walking segments from missed fixes. Walking segments consisted of consecutive active points, occurring <54 seconds apart, grouped together forming strings of spatio-temporally connected points. We excluded any segment classified as walking that was ≤2 points when calculating spatial movement distances. To further improve our ability to estimate hunter movements, we added a distance filter because we reasoned that

![Figure 2](image-url). Example of a 113.5-minute turkey-hunting bout (ID: 233), conducted in Webb Wildlife Management Area Complex, South Carolina, USA, during 2018, where the hunter traveled 2.9 km. Yellow points indicate stationary hunter behavior, whereas green points indicate active behavior. Yellow points falling outside of 45% dynamic Brownian bridge movement model utilization distribution (light gray polygons) indicate errant Global Positioning System fixes. Main roads (thick black line with gray shaded buffer) allowing vehicle traffic plus the 50-m buffer on either side is indicated in dark gray. Secondary roads allowing foot traffic only represented by thin black lines. Red lines connecting all points temporally regardless of distance or time elapsed from last point (pre-analysis); gray lines connecting points indicate walking segments separated from stationary points and excluding telemetry drift eliminated by time and distance filters (>54 sec and or >150 m apart from last fix).
no active hunter could move >150 m in a 54-second interval (Barton et al. 2003); thus, we eliminated any locations exceeding this rate of movement as inaccurate GPS locations. For each bout, we estimated hunter speed (velocity), distance traveled, time spent per bout, and time spent per hunter by day. Additionally, we calculated distance from each hunter point and centroid to the nearest main and secondary road. We used package dplyr for data manipulation and analysis (Wickham et al. 2019). We used linear regression to test whether hunter behaviors varied temporally (by day) relative to opening dates of hunting season. We calculated a correlation coefficient to evaluate how well our GPS hunter activity related to the total hunting effort on the Webb WMA Complex.

RESULTS

We allocated 1,500 GPS units to hunters across 144 hunting days during 2014–2018 (Table 1). Based on self-cleaning permit counts, we estimated that 38% of turkey hunters on the Webb WMA Complex carried a GPS during our study (Fig. 3). Minutes spent hunting by GPS-tagged hunters was positively correlated to the total number of hunters using the Webb WMA Complex (0.83, 0.90, 0.90, and 0.78) for 2014, 2015, 2016, and 2018, respectively. We collected 1,048,529 hunter locations and after removing locations within buffers around main roads and infrastructure, any hunting bouts <10 minutes, and locations that were filtered based on impossible rates of distance or speed, we used 321,419 locations from 2,558 unique hunting bouts to quantify turkey hunter behaviors.

Most hunting activity (89%) occurred before 1200, and 76% occurred prior to 1000 (Fig. 4). Mean number of hunting bouts per hunter per day was 2 (SD = 0.5, range = 1–8). Mean time per day spent hunting was 230 minutes (SD = 22.9, range = 11–872), with a mean time per bout of 115 minutes (SD = 1.6, range = 11–604). Approximately 70% of hunting activity occurred before 15 April. The number of bouts per hunter decreased with increasing number of days since the hunting season opened ($\beta = -0.01$, SE = 0.004, $P < 0.01$; Fig. 5). However, mean

Figure 3. Total number of turkey hunters who checked into a hunter check-station (black), number of turkey hunters who opted to carry Global Positioning System (GPS) units (red) and total time (min) spent hunting (blue) each day by GPS-tagged hunters for the 2014 (a), 2015 (b), 2016 (c), and 2018 (d) spring turkey hunting seasons on the Webb Wildlife Management Area Complex, South Carolina, USA (comparable hunter check data were unavailable for 2017).
Figure 4. Hunter Global Positioning System (GPS) locations collected per hour for spring turkey hunting seasons (2014–2018) on the Webb Wildlife Management Area Complex, South Carolina, USA.

Figure 5. Number of turkey hunting bouts per hunter by number of days since hunting season opened on Webb Wildlife Management Area Complex, South Carolina, USA, for spring turkey hunting seasons 2014–2018.
time spent per hunting bout did not fluctuate as the hunting season progressed ($\beta = -0.28$, SE = 0.22, $P = 0.22$). On average, hunters spent 54.3% of hunting bouts active and 45.7% stationary. The amount of time spent actively hunting (e.g., not in a stationary phase) decreased as the hunting season progressed ($\beta = -0.123$, SE = 0.05, $P = 0.023$). Average hunter velocity was 60.0 m/minute (SD = 12.6, range = 0–130). Mean distance traveled per hunting bout was 2,171 m (SD = 1,882, range = 0–20,685; Fig. 6), with 74% of hunters travelling <3,000 m during a hunting bout (Fig. 6). On average, hunters traveled 4,304 m (SD = 1,209, range = 14.8–28,682.0)/day across all hunting bouts. Mean daily distance traveled by hunters decreased as the season progressed ($\beta = -50.96$, SE = 11.24, $P < 0.01$; Fig. 7). Both total number of hunters ($\beta = -0.37$, SE = 0.04, $P < 0.01$) and total time spent hunting ($\beta = -107.66$, SE = 11.49, $P < 0.01$) also decreased as the season progressed.

Across every location designated as hunting (either active or passive), 40.1% of all hunting locations were <25 m from the nearest road (main or secondary; Fig. 8). On average, hunters were 480 m (SD = 290, range = 0–2,132) from main roads that allowed vehicle traffic, but only 123 m (SD = 183, range = 0–1,990) from secondary roads allowing only foot traffic. Hunter centroids were on average 84 m (SD = 139.2, range = 0–1,701) from the nearest road. Mean distance of hunter centroids to the nearest main road was 489 m (SD = 286, range = 0.2–2,078.0) and to the nearest secondary road was 103 m (SD = 174.3, range = 0–1,701).

**DISCUSSION**

Agencies responsible for ensuring sustainable populations of turkeys must maintain wild turkey population trajectories while ensuring hunter satisfaction and opportunity on public lands. We offer that agencies would benefit from a working knowledge of how turkey hunters behave, so that

![Figure 6](source-image-url). Mean distances (m) traveled by hunter by day, weekend days indicated in light gray and weekdays indicated in dark gray, for the spring turkey hunting seasons of 2014–2018 on the Webb Wildlife Management Area Complex, South Carolina, USA.
management strategies focused on enhancing areas for turkeys could also incorporate metrics of hunter behavior and adjust management as necessary (Stedman et al. 2004). We found that turkey hunter locations and hunter centroids (stationary locations where hunters remained) were regularly close to the nearest main or secondary road. Collectively, road availability seemed to be the primary driver of hunter distribution and access in our study, which agrees with Gross et al. (2015b), who found that 50% of turkey hunter locations fell within 18 m of an access road or trail (similar to our secondary roads) on a public hunting area in Louisiana, USA. Likewise, previous studies on other taxa have noted significant use of roads by hunters, including by hunters pursuing elk (Cervus elaphus; Lyon and Burcham 1998) and white-tailed deer (Diefenbach et al. 2005, Karns et al. 2012). Specifically, Diefenbach et al. (2005) found that approximately 87% of white-tailed deer hunters stayed within 500 m of a trail, whereas Lebel et al. (2012) found that approximately 80% of white-tailed deer hunters stayed within 100 m of a road.

Our results indicated that turkey hunters on the Webb WMA Complex traveled considerably greater distances per day (4.3 km) than turkey hunters in Louisiana (1.5 km; Gross et al. 2015b). Turkey hunter movements obviously vary based on accessibility, terrain, turkey abundance, and hunter density (Gross et al. 2015b); however, the Webb WMA Complex

Figure 7. Mean distance traveled per hunter by number of days since hunting season opened on the Webb Wildlife Management Area Complex, South Carolina, USA, for spring turkey hunting seasons 2014–2018.
had no limitations on public access, whereas Gross et al. (2015b) was on an area managed with a quota hunt and hence limited access. Thus, it is plausible that hunter density on the Webb WMA Complex was greater and may have affected movement distances of turkey hunters. We postulate, as did Gross et al. (2015b), that spatial variation in hunter behaviors across hunted lands logically influences hunting pressure experienced by individual male turkeys within a population. Wild turkeys (Gross et al. 2015a) and other species (Naugle et al. 1997, VerCauteren and Hygnstrom 1998) exhibit highly individualistic responses to increased hunting pressure as well as broader population-level effects (Wakefield et al. 2020a, b); thus, differential hunting pressure across public hunting areas should be recognized and considered by agencies charged with managing for sustainable populations, while considering that the primary drivers of hunter satisfaction are opportunity and frequency of gobbling activity (Cartwright and Smith 1990, Wightman et al. 2019).

We observed that turkey hunters averaged 2 separate hunting bouts/day, with each bout averaging approximately 115 minutes. However, we also note that the proportion of time spent actively hunting decreased considerably as the season progressed. We estimated hunters hunted turkeys approximately 4 hours/day. Gross et al. (2015b) reported that turkey hunters in Louisiana spent approximately 6 hours hunting each day. Gross et al. (2015b) reported that turkey hunters spent approximately 10% of the time hunting stationary, and Lyon and Burcham (1998) reported that elk hunters averaged 4.7 hours/hunt. Brøseth and Pedersen (2000) found that willow ptarmigan (Lagopus lagopus) hunters moved more (16.2 km), whereas Mezzozi and Guthery (2008) found that northern bobwhite hunters spent approximately 60% of the time actively moving and averaged between 50 and 82 minutes/hunt. Thus, based on our work, we suggest that further opportunity exists in evaluating potential drivers of hunter behavioral ecology to better assist with public-land management activities.

We observed that most hunting activity (70%) occurred during the first 2 weeks of the season, and nearly all hunting activity occurred during the morning hours. Gobbling activity primarily occurred within an hour of sunrise on our study site (Wightman et al. 2019); hence, it is plausible that hunters did not continue hunting later into the morning and afternoon because of a reduced gobbling activity. We acknowledge that based on our sampling protocols for distributing GPS units to hunters, our results would omit any hunters arriving midmorning or later. However, turkey hunting has conventionally been a morning activity based on male auditory activities (Wightman et al. 2019); therefore, we suggest that our data are likely representative of the average turkey hunter as the correlation between the time hunting by our GPS-tagged hunters and total hunters on

Figure 8. Number of Global Positioning System (GPS) locations taken relative to distance from nearest road, including secondary and main roads, for the spring turkey hunting seasons of 2014–2018 on the Webb Wildlife Management Area Complex, South Carolina, USA.
the Webb WMA Complex was high. Our results clearly show that both hunter effort and participation declined as the season progressed on the Webb WMA Complex. Contemporary studies detailing gobbling chronology have noted that gobbling activity is negatively affected by hunting activity (Chamberlain et al. 2018, Wightman et al. 2019, Wakefield et al. 2020a), presumably through removal of males coupled with reductions in gobbling activity from surviving males and natural decrease in gobbling activity as the breeding season wanes (Wakefield et al. 2020b). In our study, hunting activity was nonuniformly distributed both spatially and temporally. We note that some states have adopted spring turkey seasons in attempts to distribute harvest and effort more uniformly through time, while also seeking to maintain consistent hunter harvest success rates (Dhuey and Witecha 2017). With increased understanding of how hunters behave on the landscape, managers tasked with public land management for wild turkeys may consider manipulating hunter effort temporally during the season, especially during the greatest periods of hunting intensity. Specifically, alternative season frameworks, such as quota access hunts during periods nearing the peak of reproductive timing, would more uniformly distribute hunter effort, and perhaps reduce the relative impacts of hunting activities on gobbling activity and male behavior (Wightman et al. 2019, Wakefield et al. 2020a, b).

MANAGEMENT IMPLICATIONS

Managers wanting to manipulate hunting pressure or hunter access to portions of public lands may consider relaxing or restricting road access, or developing a road access gradient as a method to distribute hunting pressure and increase hunter satisfaction. Additionally, managers may consider manipulating hunter effort temporally during the season, especially during periods that overlap with primary breeding periods. Secondary roads (e.g., walking trails) were used extensively by hunters, and hunters often remained stationary close to these access routes, suggesting that managers should monitor use of such routes and consider ways of manipulating traffic on them to more equally distribute hunting activity. Hunters regularly utilized areas near secondary roads for hunting, so there are potential hunter safety concerns likely necessitating continued education about hunter safety and target identification. However, our work also suggests that if managers seek to limit hunter access in certain areas reducing or closing access roads may be a viable management alternative (vis à vis Ranglack et al. 2017).

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LITERATURE CITED


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