



Tools and Technology

Home Range Estimator Method and GPS Sampling Schedule Affect Habitat Selection Inferences for Wild Turkeys

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ABSTRACT Understanding patterns in the spatial distribution of individuals in a population is a central question in ecology. Concurrent with advances in biotelemetry devices, development of home range estimator methods incorporating the temporal component of locational fixes are increasingly used to investigate these patterns at finer scales. However, these methods may necessitate sampling schedules that limit battery life and study period length. Practically, evaluating how home range estimator methods affect calculations of space use and habitat selection prior to deployment of biotelemetry devices could help researchers optimize data acquisition schedules. We quantified spatial overlap between a home range estimator using temporal information (dynamic Brownian bridge movement model [dBBMM]) and home range estimators not incorporating the temporal component of fixes (*ad hoc* and href kernel density estimator [KDE]) across differing sample schedules, and the resulting error in habitat selection ratios using data collected from wild turkeys (*Meleagris gallopavo*) equipped with Global Positioning Systems units in Texas, Georgia, South Carolina, and Louisiana, USA, during February–May 2015. When comparing ranges created from KDEs to dBBMM, commission errors were large (20–80%) and did not diminish with increased sampling rates. In contrast, omission error rate declined quicker and improvements were minimal when fix rates increased beyond 4/day. Compared with ranges estimated with dBBMM, KDEs poorly defined the spatial bearings of an individual's range, overestimated areas of use, underestimated areas avoided, and showed different patterns of habitat selection. Our results suggest home range estimator methods incorporating temporal information seem capable of estimating ranges encompassing nearly all area used by an individual and should be used even at relatively low-frequency collection schedules to assess home ranges of wild turkeys. If researchers are interested in describing habitat selection of wild turkeys, we recommend a sampling schedule of ≤ 1 location/hour during daytime and dBBMM for range estimation. © 2018 The Wildlife Society.

KEY WORDS dynamic Brownian Bridge movement models, Global Positioning Systems, home range estimators, isopleth, kernel density, *Meleagris gallopavo*, movement-based utilization distribution, wild turkey.

The recognition that animals maintain home ranges has provided the conceptual framework for development of empirical range estimators used to model spatial behaviors and movements (Burt 1943, Powell and Mitchell 2012). These estimators allow researchers to elucidate mechanisms and spatial relationships underlying habitat selection and species occurrences (Guisan et al. 2006). As biotelemetry devices decrease in size and price, ecological research has benefited from spatial data on a widening array of animals. Concurrently, range estimators are continuously refined to incorporate increasing accuracy and deployment lengths of

tracking data sets and, consequently, have provided unprecedented insight into animal behavior and ecology (Tracey et al. 2014, Walter et al. 2015, Fleming et al. 2016). As Global Positioning Systems (GPS) units have become miniaturized, use has increased such that they have been deployed on animals as large and cryptic as Amur tigers (*Panthera tigris altaica*; Hernandez-Blanco et al. 2015) to as small and common as European hedgehogs (*Erinaceus europaeus*; Recio et al. 2011). However, sampling intensity continues to be problematic for studies using this technology because researchers must optimize battery life relative to data needs to address hypotheses of interest (Hebblewhite and Haydon 2010, Cumming and Cornéllis 2012).

Optimally inferring unobserved behaviors from biotelemetry data is often conditioned on calculation of many quantities including areas occupied and habitats utilized.

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Accurate estimation of these variables relies on the temporal component of data to deduce an animal's movement (Fleming et al. 2016). Before GPS, locational data collected using very-high-frequency (VHF) technology resulted in data sets presumed not to be correlated in space and time, lessening the accuracy of previous approximations. New methods are continuously designed to benefit from the large numbers of temporally autocorrelated data GPS technology is capable of providing (Hebblewhite and Haydon 2010, Fleming et al. 2016). For example, home range calculations are in their "third-generation" of estimators (Walter et al. 2015). First- and second-generation methods such as kernel density estimators (KDE), can be used for large GPS data sets, but do not consider the temporal component of these data (Jones et al. 1996, Hemson et al. 2005, Walter et al. 2011). Third-generation methods utilize serial correlation in locations to provide a probabilistic estimation of an animal's movement between fixes. Probabilistic approaches to range estimation such as dynamic Brownian Bridge Movement Models (dBBMM) require rapid succession of locational fixes, but have been demonstrated to be more reliable than first- and second-generation methods (Benhamou and Cornélias 2010, Kranstauber et al. 2012, Walter et al. 2015). Although research has focused on what estimators are most accurate, none to our knowledge have examined the trade-off between sampling intensity, estimator method, and reliability of these estimations (Worton 1995, Seaman and Powell 1996, Cumming and Cornélias 2012, Walter et al. 2015).

Radiotelemetry has been widely used to monitor and study various aspects of wild turkey (*Meleagris gallopavo*) behavior and ecology. Although VHF radiotelemetry has provided guidance on management of wild turkey populations for decades, data suffer biases associated with distance between observer and the transmitter, intersection angle of triangulated bearings, and animal movement between readings (Saltz 1994, Withey et al. 2001). The advent of GPS transmitters for wild turkeys has facilitated a myriad of research possibilities (Collier and Chamberlain 2011, Guthrie et al. 2011), which were previously difficult, if not impossible, such as effects of hunting on behavior (Gross et al. 2015), influences of fire disturbances on movements (Oetgen et al. 2015, Yeldell et al. 2017c), identification of precise nest initiation dates (Byrne et al. 2014, Yeldell et al. 2017a), space use of incubating females (Conley et al. 2015), and movements of translocated individuals (Cohen et al. 2015). Accurate range estimators are critical to assess landscape attributes animals select and avoid; therefore, they continue to be important aspects of research on many species, including wild turkeys (Porter et al. 2015).

Range estimation is critical to identify landscape features important for behavioral activities such as finding food, shelter, and mates (Kie et al. 2010), and where animals survive, reproduce, and maximize their fitness (Krebs and Davies 1997). Previous research has compared accuracy among different types of KDEs (Worton 1995, Seaman and Powell 1996, Börger et al. 2006) and how sampling regime may influence these estimators (Hansteen et al. 1997,

Seaman et al. 1999, Girard et al. 2002, Getz and Wilmers 2004). Given that range estimators that incorporate temporal information seem more reliable than KDEs at estimating space use (Walter et al. 2015), a re-evaluation of how data acquisition schedules and different range estimator methods affect calculations of space use and habitat selection estimates seems warranted. Many studies have used simulated data sets of animal locations (Worton 1995, Seaman and Powell 1996, Getz and Wilmers 2004, Fieberg and Kochanny 2005), but research addressing these issues must be verified with real animal location data from different landscapes (Seaman et al. 1999, Börger et al. 2006, Walter et al. 2015). Therefore, we assessed how different combinations of data acquisition schedules and home range estimators would affect estimates of space use and resource selection of the wild turkey. Specifically, our objectives were to quantify: 1) the amount of spatial overlap between different estimators of home range across differing sample schedules, and 2) the resulting inferences in habitat selection ratios across a range of individual turkeys equipped with GPS technology from a range of landscapes. We hypothesized that as sampling frequency increased, both third- and second-generation estimators would create range estimates that more accurately included area used by an individual. However, we also hypothesized that as sampling frequency increased, third-generation estimators would better exclude areas not used by individuals.

STUDY AREA

We conducted our research on 5 study sites within 4 states in the southeastern United States (Fig. 1). One study site was the Silver Lake Wildlife Management Area (Silver Lake WMA) in southwestern Georgia, USA. Silver Lake WMA was a 3,9000-ha state-owned property in Decatur County, Georgia, consisting mostly of longleaf pine (*Pinus palustris*)–wiregrass

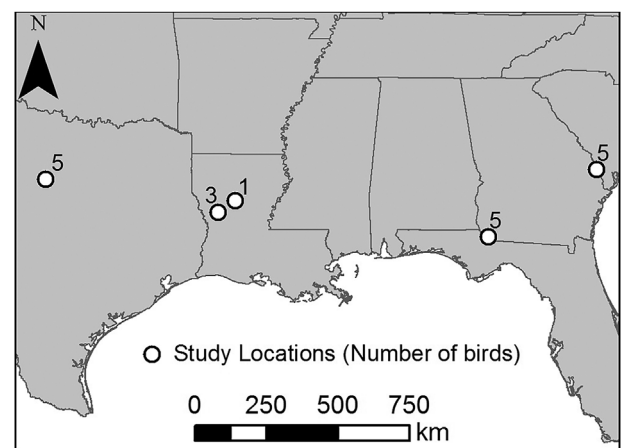


Figure 1. Distribution and number of female wild turkeys captured at 5 study sites within 4 states in the southeastern United States during 2015. We used Global Positioning System data associated with each wild turkey to investigate effects of different data acquisition schedules on rates of commission (area an animal did not use but was predicted to use) and omission (area an animal did use but was predicted not to use) from different home range estimators, and associated effects on habitat selection ratios.

(*Aristida stricta*) among a mix of other forest types including pine (*Pinus* spp.), mixed pine and hardwood forests, hardwood forests, and lowland hardwood hammocks (Streich et al. 2015). In Louisiana, USA, we conducted our research on 2 study sites located within the Kisatchie National Forest in Winn and Natchitoches Parishes. Our first study site within the Kisatchie National Forest was located in the 41,453-ha Kisatchie Ranger District. The other study site was located in the 67,408-ha Winn Ranger District. The environmental conditions and forest management practices of these 2 study sites were similar. Vegetation was also similar and consisted of pine-dominated forests, interspersed with hardwood riparian zones, and forested wetlands. In South Carolina, USA, we conducted our research on the 2,374-ha James W. Webb Wildlife Center and Management Area (Webb Center) in Jasper County (see Byrne et al. 2015 for full description). The Webb Center consisted of approximately 60% upland vegetation typical of the Atlantic coast flatwoods, consisting of different species of pine intermixed with hardwood stands along drainages. The remaining 40% of the Webb Center was dominated by bottomland hardwoods typical of southeastern river floodplains. The primary management activity across these 4 study sites was the use of dormant and growing season prescribed fire to reduce fuel loads and inhibit growth of undesired hardwood species. In Texas, USA, we conducted our research on the Lyndon B. Johnson National Grasslands in Wise County. The Lyndon B. Johnson National Grasslands

area was predominately grassland with a variety of grass species including bluestem (*Andropogon* spp.), panicum (*Panicum* spp.), and blue grama (*Bouteloua gracilis*). Common tree species include cedar elm (*Ulmus crassifolia*), pecan (*Carya illinoensis*), and cottonwood (*Populus deltoides*) in riparian areas. Along with prescribed fire, rotational livestock grazing was allowed on the Lyndon B. Johnson National Grasslands (Conley et al. 2015).

METHODS

Animal Capture

We captured adult female wild turkeys using drop nets and rocket nets baited with wheat and cracked corn during January–March of 2015. We determined the sex of each bird and classified them as subadult or adult based on presence of barring on the ninth and tenth primaries (Pelham and Dickson 1992). We used only adult female turkeys for this study. We fitted turkeys with a numbered, butt-end style or riveted aluminum tarsal band. We also fitted each turkey with a remote downloadable backpack-style GPS radio-transmitter weighing approximately 88 g and equipped with a VHF beacon and mortality sensor (Lotek Minitrack Backpack L; Lotek Wireless Inc., Newmarket, ON, Canada). The backpack-style GPS radiotransmitters were attached to the turkeys following the methods of Guthrie et al. (2011). We released all turkeys at the capture site

Table 1. Percent of Global Positioning System (GPS) locations (in TX, GA, SC, and LA, USA) taken while a turkey was nesting, the number of successful nest attempts, failed nest attempts, successful brood attempts, and failed broods attempts for 19 adult female wild turkeys during 2015. We defined nesting locations by running a 3-day moving window over all GPS locations for each bird. We then identified the location that had the most surrounding locations within 30 m, and if the number of these locations was >30% of the total number of locations in the 3-day window, the collective group of locations was considered to be a nesting location and removed from further analyses. We confirmed if a female was nesting or if she had successfully hatched a brood following the methodology of Yeldell et al. (2017b).

Turkey ID	Subspecies	% nest locations ^a	Successful nest attempts (n)	Failed nest attempts (n)	Successful brood attempts (n)	Failed brood attempts (n)
60163	Eastern	5.3	1	1	0	1
60165	Eastern	7.8	1	1	0	1
60168	Eastern	28.2	1	1	1	0
60267	Eastern	26.2	1	0	0	1
60398	Eastern	26.9	0	2	0	0
60273	Eastern	34.8	1	0	1	0
60274	Eastern	0.0	0	0	0	0
60280	Eastern	10.7	0	3	0	0
60327	Eastern	30.7	2	0	0	2
60186	Eastern	9.8	0	2	0	0
60187	Eastern	24.5	1	0	1	0
60205	Eastern	25.0	1	0	1	0
60216	Eastern	23.2	1	0	1	0
60228	Eastern	4.2	0	1	0	0
60236	Rio Grande	38.5	0	1	0	0
60244	Rio Grande	7.4	0	2	0	0
60259	Rio Grande	16.4	0	3	0	0
5190	Rio Grande	21.9	0	1	0	0
5225	Rio Grande	47.4	0	1	0	0

^a Locations taken during the period a female was incubating a nest were removed from the data set used in our analysis to avoid collapsing utilization distributions around nesting locations.

immediately post-processing. We programmed GPS units to collect hourly locations from 0500 to 2000 and one location at midnight each day. We downloaded GPS location data from each turkey at regular intervals until transmitter batteries failed. We chose individuals captured from across the southeastern United States and of different subspecies because we were interested in expanding our findings across the biological and ecological variation encountered in the wild turkey's range. All turkey capture, handling, and marking procedures were approved by Institutional Animal Care and Use Committees at the University of Georgia (AUP# A2014 06-008-Y1-A0; A2013 12-002-Y1-A0) and Texas A&M University (AUP SPR-0608-078).

Location Data

We limited location data used in this study to the period from 15 February to 30 May 2015, because most birds had location data during this period and we sought to limit extraneous variability due to length of study. On average, this resulted in 88 days (range = 48–106 days) of observations per animal. Wild turkeys are a diurnal species; because we were primarily interested in space use when turkeys were active, we removed locations collected >30 min prior to sunrise or >30 min after sunset. This resulted in removing all locations taken while turkeys were roosting, which was 6% of our data set. We also removed nesting locations, which accounted for 20.4% of GPS fixes on average (range = 0.00–47.4%; Table 1). Although previous research using VHF technology has included nesting locations in calculating range estimates (e.g., Holbrook et al. 1987, Thogmartin 2001, Niedzielski and Bowman 2016) because of relatively low sampling frequency, the high frequency of GPS locations around a single nest location would collapse range estimates around the nesting area and affect selection inferences (Benhamou and Corn elis 2010, Kranstauber et al. 2012, Byrne et al. 2014). To avoid this collapse in range estimates, researchers would need to decrease GPS fix frequency, which eliminates a benefit of using GPS technology, or remove GPS locations taken during nesting as we have done. We defined nesting locations by running a 3-day moving window over all

locations for each bird. We then identified the location that had the most surrounding locations within 30 m, and if the number of these locations was >30% of the total number of locations in the 3-day window, we considered the collective group of locations to be a nesting location and removed it from further analyses. We confirmed if a female was nesting or if she had successfully hatched a brood following the methodology of Yeldell et al. (2017b). Briefly, we monitored females we suspected to be incubating for up to 30 days. After nest termination, we located nest sites and confirmed nest attempts based on presence of eggs, egg shell remains, or a shallow ground depression with turkey feathers present (Williams et al. 1971). If a nest was incubated for ≥ 25 days, we located the female after nest termination via VHF signal homing and performed a flush count to determine the presence of poults. We considered a brood to be present if ≥ 1 poult was seen or heard with the female. We performed these brood surveys 2 times/week up to 56 days posthatch or until we failed to detect poults during 2 consecutive brood surveys. Broods were considered successfully raised if ≥ 1 poult was present 56 days posthatch (Yeldell et al. 2017b).

We considered relocations remaining after removing roost and nesting locations for each individual to be our full data set. To investigate effects of GPS sampling frequency on estimates of space use and movement, we created a series of GPS fix schedules, subsampled from the full hourly data set, stratified every 2, 3, 4, 5, or 6 hr, with the schedule being collected every 1, 2, or 3 days. We also considered additional schedules with fix rates >2 hr by randomly choosing additional hours to make schedules with 9, 11, and 13 fixes/day (Table 2).

Calculation of Space Use and Movement

To investigate effects of sampling frequency on estimates of space use and movements, we calculated several commonly used measures of both variables for each wild turkey with the full location data set and each modified GPS fix schedule (Table 2). To estimate space use of individual animals, we calculated 50% and 95% utilization distributions (UD) estimated using different generation range estimators. We first estimated UD's using first-generation kernel density estimators that do not incorporate the

Table 2. Example of a subsampled Global Positioning System (GPS) fix schedule for our study, showing 8 alternative GPS daily fix schedules that were evaluated for wild turkeys (in TX, GA, SC, and LA, USA) during 2015. Each row represents a single schedule where "x" indicates an hour that a GPS location was used. Fixes refers to total number of fixes per day, stratification refers to number of hours between successive fixes, <2 (random) indicates the situation where additional locations were randomly chosen to sample more frequently than every 2 hr. Random samples and the starting hour for stratification varied among individuals.

Fixes per day	Stratification	Sampling hour (local hour of day)															
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
3	6		x						x							x	
3	5		x					x					x				
4	4		x				x				x					x	
5	3		x			x			x			x				x	
7	2		x		x		x		x		x		x		x	x	
9	<2 (random)		x		x	x	x		x		x		x		x	x	
11	<2 (random)		x		x	x	x	x	x	x	x	x	x		x	x	
13	<2 (random)	x	x	x	x	x	x	x	x	x	x	x	x		x	x	

temporal component of each location. To calculate estimates for kernel density estimates, we used 2 approaches to calculate the bandwidth parameter: 1) the *ad hoc* approach (Berger and Gese 2007, Jacques et al. 2009), which resulted in a single contiguous UD, and 2) by setting the bandwidth equal to 30% of the reference bandwidth, which created a kernel (hereafter, 30% href) with less smoothing than the *ad hoc* approach.

We also estimated UDs using a third-generation estimator, the dynamic Brownian Bridge Movement Model (dBBMM; Kranstauber et al. 2012). The dBBMM requires several parameters to estimate a Brownian-Bridge UD: a time index series of animal locations, an estimate of mean telemetry error for each location, and an estimate of Brownian motion variance (σ^2_m), which is a measure of irregularity of an animal's movement path between 2 locations and a function of the animal's behavior. The dBBMM accounts for changes in animal behaviors (i.e., foraging, resting, etc.) over time by estimating a unique σ^2_m value for each time step between GPS locations (Gurarie et al. 2009). For the dBBMM parameters, we chose to use a constant window and margin size equal to 7 and 3 respectively and a location error of 20 m (Kranstauber et al. 2012, Byrne et al. 2014). We kept values for the window and margin size constant rather than varying them to account for changes in GPS sampling frequency because we failed to see any measurable effects of altering these values when we began our analyses. Because we removed roost and nest locations, we also modified the integration of dBBMM UD so as to not create movement paths between the nonroost or nonnest locations temporally adjacent to removed locations. We calculated all UDs on a raster with a 30-m resolution in Program R (R version 3.2.5, www.r-project.org, accessed 1 May 2016) and packages *adehabitatHR* (version 0.4.14, <https://cran.r-project.org/package=adehabitatHR>, accessed 1 May 2016) for KDE (Calenge 2006) and *move* (version 1.5.514, <https://cran.r-project.org/package=move>, accessed 1 May 2016) for dBBMM.

Range estimators are critical for estimates of habitat selection (Benhamou and Cornélis 2010); therefore, we compared measures of habitat selection assessed with each UD estimate and GPS fix schedule using landcover data from the 2011 National Land Cover Database (Homer et al. 2015). To account for the variability in land cover across our study sites and substantive number of combinations in fix schedules we compared, we calculated which land cover class was most common in the 50% dBBMM UD and then calculated the selection ratio for this class. We calculated the selection ratio as the ratio of the proportional area of the most common cover class in the 50% UD divided by the proportion in the 95% UD for all GPS fix schedules and UD estimates (Manly et al. 2007).

Comparative Analyses

All of our comparative analyses were done within each individual by comparing how GPS fix schedules and range estimator affected range estimates and resource selection inferences for each individual turkey. This comparison

allowed us to remove any extraneous variation that may have been introduced as our sample shifted through reproductive phases at different calendar dates.

Researchers have noted third-generation estimators are more reliable at estimating space use than first- or second-generation methods because third-generation estimators incorporate temporal information (Walter et al. 2015). Hence, we assumed that the dBBMM UD calculated with the full location data set of each individual was the most accurate and complete estimate of space use, and used this as our reference estimate. By treating the full-data-set dBBMM as a reference, we were able to compare how GPS fix schedules affected the dBBMM UD estimates and also how KDE estimates lacking temporal information compared with the reference dBBMM UD for each individual. To quantify differences in the predicted UDs (from each GPS fix frequency and estimator combination) and the reference dBBMM, we calculated omission and commission error rates. We defined the omission error rate as the percentage of the reference UD that the sample UD failed to capture (i.e., did not overlap with the sample UD). Likewise, we defined the commission error rate as the percentage of the predicted UD that fell beyond the area captured by the reference UD (i.e., did not overlap the reference UD). We also calculated error in selection ratios by taking the absolute value of the predicted selection ratio (for each combination of GPS fix schedule and UD estimate) subtracted from the reference dBBMM selection ratio for each individual. We then calculated mean absolute error (MAE) by averaging error in selection ratios of individuals within each combination of GPS fix schedules and UD estimates.

RESULTS

We used data from 14 adult female eastern wild turkeys (*M. g. silvestris*) from 3 states and 5 adult female Rio Grande wild turkeys (*M. g. intermedia*) from 1 state (Fig. 1). One turkey did not initiate a nest, leaving 18 turkeys in our sample initiating ≥ 1 nest. Of the 18 turkeys that initiated ≥ 1 nest, 9 hatched a clutch and began brooding. Of 9 brooding turkeys, 5 successfully raised their brood (Table 1).

After the removal of locations collected >30 min prior to sunrise or >30 min after sunset, our full hourly data set consisted of 15 relocations for each day of data collection. The type of home range estimator used and GPS fix rates had considerable influence on range estimation errors. When comparing 50% and 95% range estimates from KDE to the dBBMM, we observed large commission errors (~ 20 – 80% ; Fig. 2). For both the *ad hoc* and 30% href KDEs, commission error rates were essentially constant with respect to GPS fix rate. The lowest commission rate between KDE and dBBMM was the 30% href kernel when estimating the 95% home range, which had a commission rate of 20% (Fig. 2). We also observed large commission errors ($\sim 60\%$) when using dBBMMs with low fix rates compared with the reference full-data-set dBBMM. However, in contrast to the KDE methods, which had large commission error even with high GPS fix rates, the

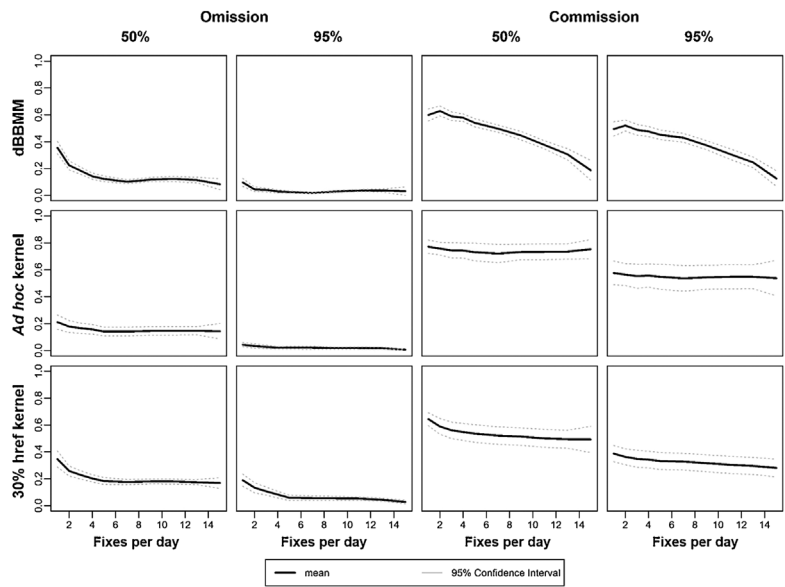


Figure 2. Rates of commission (area an animal did not use but was predicted to use) and omission (area an animal did use but was predicted not to use) for dynamic Brownian bridge movement model (dBBMM), *ad hoc* kernel density, and 30% href kernel density range estimators. Each plot shows the omission and commission error rates for the 50% core area and 95% home range at different daily Global Positioning System sampling intervals for 19 female wild turkeys (in TX, GA, SC, and LA, USA) during 2015. We calculated error rates relative to 50% and 95% ranges estimated using dBBMM with hourly fixes taken daily during daylight hours.

commission error for dBBMM declined linearly as GPS fix rate increased (Fig. 2).

In general, we observed relatively low omission errors (range = 5–35%) when comparing KDE methods to the dBBMM; these error rates decreased slightly with increasing GPS fix rate, but levelled off at rates >4 fixes/day. Similarly, omission error with the 50% dBBMM range declined slightly from 35% to 8% with increasing

GPS fix rate, and the error rate remained relatively stable at rates >4 fixes/day. When comparing GPS schedules collected daily to those collected every 2 or 3 days, we observed increased commission errors only in dBBMMs at reduced fix rates compared with the reference full-data-set dBBMM, whereas in all other comparisons the 2- or 3-day scheduling did not appear to have a strong influence (Fig. 3).

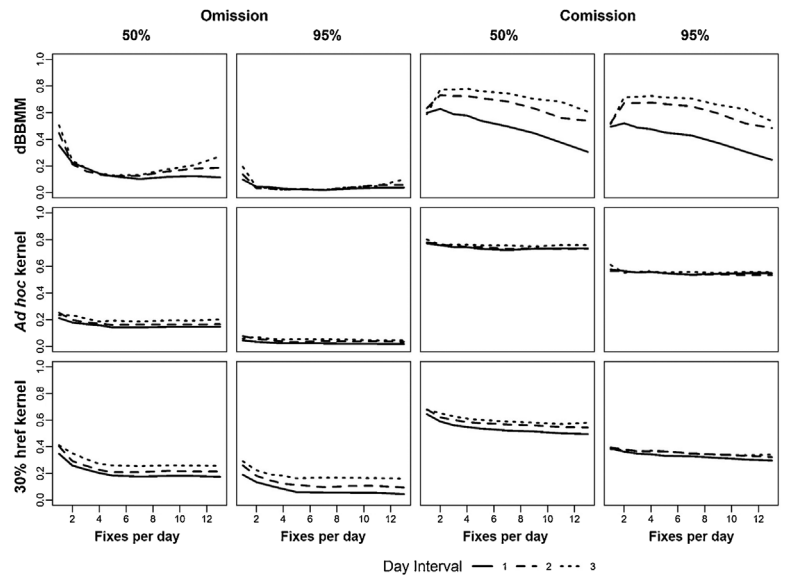


Figure 3. Rates of commission (area an animal did not use but was predicted to use) and omission (area an animal did use but was predicted not to use) for dynamic Brownian bridge movement model (dBBMM), *ad hoc* kernel density, and 30% href kernel density range estimators across different sampling intervals per every 1, 2, or 3 days. We calculated error rates relative to 50% and 95% ranges estimated using dBBMM with hourly fixes taken daily during daylight hours. Each line shows the mean error rate for data from 19 female wild turkeys (in TX, GA, SC, and LA, USA) during 2015.

Errors in estimates of habitat selection ratios for the most abundant land cover class in the 50% UD were affected by both the range estimator used and sampling schedule. We found that MAE values were similar and near 0.1 for

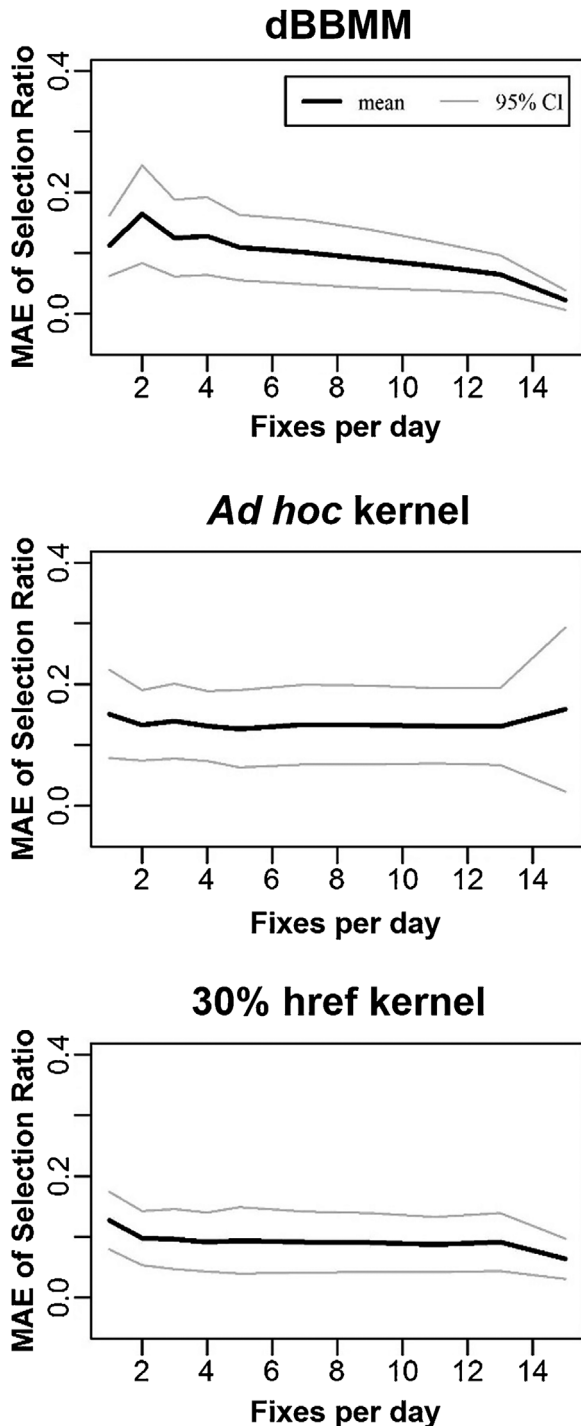


Figure 4. Mean of the absolute error (MAE) in selection ratios for dynamic Brownian bridge movement model (dBBMM), *ad hoc* kernel density, and 30% href kernel density range estimators at different daily Global Positioning System sampling intervals for 19 female wild turkeys (in TX, GA, SC, and LA, USA) during 2015. We calculated MAE for the most used land cover by comparing selection ratios from dBBMM range estimates with hourly locations to the selection ratio calculated using reduced sampling rates and kernel density estimates. Bold lines show the mean for all individuals, grey lines show ± 1 standard deviation.

dBBMM and the 30% href kernel at sampling frequencies < 7 fixes/day; however, the MAE continued to decline to near 0.0 for dBBMM at greater GPS fix rates (Fig. 4). Values of MAE for the *ad hoc* kernel were greater (~ 0.13) and did not vary with increasing fix rate.

DISCUSSION

The home range concept is important for understanding dynamics of animal movements and spatial patterns. The use of GPS in conjunction with range estimators that incorporate temporal information has led to improved estimates of animal space use and movements (Benhamou and Corn elis 2010, Walter et al. 2015). However, current technology is limited by battery life and research projects must make tradeoffs between temporal resolution (GPS fix rate) and temporal extent (length of study). Our results indicate that the primary advantage of increased frequency of spatial fixes for wild turkeys appears to be to reduce commission errors in range estimators. Specifically, the UD becomes relatively more refined with increasing data, is relatively less likely to overestimate space use, and better able to differentiate used from unused areas. For the dBBMM 50% and 95% UDs, we found that commission errors decreased linearly with increasing fix rates, and the decrease did not asymptote near our maximum sampling rate of 15 locations/day. We interpret this as evidence that commission errors could continue to decrease if sampling frequencies were increased even more. Conversely, when comparing 50% and 95% ranges created from KDE (*ad hoc* and 30% href) to dBBMM ranges, we found that commission errors were relatively large and did not diminish with increased sampling rates. This finding highlights relevant differences between dBBMM and kernel methods. Unlike dBBMM, kernel methods do not incorporate the temporal component of telemetry fixes, and assume a lack of correlation in space and time among locations, which can result in considerably different estimates of range size even with high sampling frequency (Walter et al. 2015).

We observed that omission error rates declined much more rapidly and improvements were minimal when GPS fix rates increased beyond 4 times/day. Furthermore, we did not observe an increase in omission error even when sampling was reduced to every 2 or 3 days for this species. Similar omission patterns likely hold for most species with established home ranges and in such situations, a lower fix rate can be used to estimate a home range that will likely omit few areas actually used by the animal, although it may contain considerable amounts of unused area (Seaman and Powell 1996, Benhamou and Corn elis 2010).

Walter et al. (2015) concluded range estimators incorporating both spatio-temporal components were most biologically reliable, but did not discern how these differences in estimates affected inferences of habitat selection. We observed that use of different range estimators can induce error in selection estimates of wild turkeys. Additionally, because we only considered the most abundant land cover class when computing selection ratios, we expect that a more thorough selection analysis including all land cover classes

would likely reveal even stronger differences among estimators. Because KDE and dBBMM estimate different ranges of space use, inferences about habitat selection of wild turkeys can be greatly influenced simply by the estimator used. Assuming that estimates from the full location data set dBBMM were closest to truth (Walter et al. 2015), we found errors in selection estimates decreased more rapidly with increasing fix rates for dBBMM than the 30% href KDE and, especially, the *ad hoc* KDE. It is important to note here that we assumed our full location data set dBBMM was the most accurate range measure (Kranstauber et al. 2012, Walter et al. 2015), and the degree to which this range accurately estimated an individual's true range affects our estimates of commission and omission. Therefore, it is possible that the commission and omission we identify might not be in error to the magnitude we record. Nonetheless, researchers using less intensive fix rates should recognize potential biases associated with relying on KDE for range estimates and subsequent estimates of habitat selection or avoidance by wild turkeys. Furthermore, avoidance of areas is particularly difficult to estimate with KDE because of large commission errors, and researchers should recognize spatio-temporal estimators like dBBMM, which better capture the underlying movement process of the animal, are more likely to detect avoidance behavior of wild turkeys.

Previous research on habitat selection of wild turkeys has relied mostly on VHF technology and minimum convex polygons or KDE (e.g., Bidwell et al. 1989, Palmer et al. 1996, Miller et al. 1999, Miller and Conner 2007, Little et al. 2016). When compared with ranges estimated with dBBMM, KDEs seem to induce significant error in defining home ranges and corresponding selection estimates of wild turkeys. This error is induced because KDEs overestimate the amount of area an animal is using, making it difficult to detect avoidance behaviors (Benhamou and Corn elis 2010). With dBBMM, omission errors require fewer locations to minimize because uncertainty in movement paths are explicitly accounted for by estimating the animal's mobility (e.g., Brownian motion variance) and location error when constructing UD (Horne et al. 2007, Kranstauber et al. 2012). Commission errors are more difficult to reduce because this requires minimizing the uncertainty between locations, which is influenced by time between locations and an animal's mobility (Horne et al. 2007).

In general terms, when fixes are infrequent such that there is high uncertainty in a turkey's position between locations, dBBMMs are likely still capable of estimating 50% or 95% ranges that encompass nearly all of the area used by an individual, whereas a fix rate that is sufficiently large to minimize uncertainty between locations would aid in discerning used from unused areas within these ranges. Home ranges estimated using KDEs and reduced fix rates likely give reasonable estimates of home range size and do not omit areas used by individual turkeys. However, we should not be surprised when contemporary studies using increased fix rates and improved estimators similar to dBBMM, which reduce commission error, show patterns of habitat selection and avoidance different from older studies

examining wild turkey habitat selection (Yeldell et al. 2017b). Technology will continue to improve our ability to monitor wild turkeys and estimate habitat selection. As such, researchers should examine data collection and analysis methodology before deployment of GPS units on wild turkeys to take advantage of the increasing data and ultimately improve management recommendations.

Having clearly defined research objectives is essential when designing a study of wildlife space use, and should guide choice of a particular sampling schedule. Our findings, coupled with previous works noting biases associated with estimating space use and resource selection using KDEs, suggest necessary improvements for studies desiring to assess habitat selection of wild turkeys. For wild turkeys, we found that on average 15 GPS fixes/day were needed to reduce commission errors in the 50% UD to <20%, whereas 4 GPS fixes collected every 3 days would suffice to reduce omission error in the 50% UD to <20% using dBBMM (compared with a full-data-set dBBMM). Specifically, use of KDEs results in overestimating areas of use and errors in estimating areas avoided. If researchers are interested in describing habitat selection of wild turkeys, we recommend a sampling schedule of <1 location/hour coupled with use of UD estimators that take movements into account, such as dBBMM for range estimation.

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