Assessment of GPS Transmitters for Use on Northern Bobwhite Quail

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Abstract: Technological advances allow researchers to increase the quality and quantity of spatial information gathered for movement ecology and range estimation. We conducted a field experiment to assess accuracy of PinPoint GPS transmitters for use on small avian species using northern bobwhite quail (*Colinus virginianus*) as our test species. We conducted a series of static tests to evaluate relative impacts of canopy cover across a suite of data collection schedules. We also evaluated GPS units on 6 wild northern bobwhite quail trapped in north-central Texas. Radial error estimates from static tests indicated an overall mean spatial error of 39.7 m (191.7 SD; range 0–4389) between known and estimated locations. The median radial error was 2.68 m with an 85th probability quantile of 6.57 m. Less than 0.08% of locations had radial error >100 m; however, those locations significantly impacted error estimates. GPS units used for 4-day field tests of quail measured an estimated movement velocity ranging from 1.9 to 5 m min^{-1} with total daily movements ranging from 1200 to 2500 m. Our results suggest that accuracy of PinPoint GPS units were unbiased and similar to assessments of larger units. Additionally, we identified a combination of satellite and dilution of precision estimates which can be used to identify inaccurate locations. The units we evaluated were battery limited and likely of less use for longevity studies (multi-season tracking) which could hinder usefulness, but we see significant opportunity for evaluating short duration habitat selection and use, thermal ecology, or animal response to experimental manipulations.

Key words: Colinus virginianus, habitat selection, movements, northern bobwhite quail, PinPoint GPS

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The selection of habitats within a landscape is a hierarchical process wherein the selection or avoidance of particular habitat types varies depending on the spatial scale at which evaluations are conducted and the demographic contributions of a particular habitat (Morrison 2001). Animals select habitats at both spatial and temporal scales (Byrne et al. 2014); therefore, accurate evaluation of habitat selection decisions requires methods that address space use over time (Börger et al. 2006). VHF telemetry has been the standard for evaluating animal movements and behavior (White and Garrott 1990); however, satellite-based systems have provided a wide variety of data collection options for various wildlife species (Hebblewhite and Haydon 2010). For species with extensive ranges or migratory pathways, satellite telemetry (platform terminal transmitters; PTT) has been the primary approach used to monitor movements of medium to large birds and mammals (Cadahía et al. 2005). Satellite-based telemetric methods have commonly been used on small to medium sized birds; however, PTTs typically are required for identifying fine scale habitat use (Keating et al. 1991, Hays et al. 2001). As such, furthering our understanding of GPS unit accuracy under a variety of circumstances can better support adequate study designs for smaller species (Moen et al. 1997, Hebblewhite and Haydon 2010). However, we note that increased data acquisition options may induce trade-offs regarding study design and implementation which should be fully evaluated as part of any study design (Hebblewhite and Haydon 2010, Collier and Chamberlain 2011).

One of the primary limitations to use of global positioning system (GPS) on all fauna is related to package size. The amount of data acquired is driven by battery size, which has been shown to be extremely cost effective for moderately sized units (c. 80g; Guthrie et al. 2011). However, for smaller GPS units (<5 g), longevity (battery life) is determined by collection intensity, meaning there is a tradeoff between the number of locations per unit time and the number of days a unit can collect data (Hansen and Riggs 2008, Brown et al. 2012).

As technology has increased, our ability to potentially gather significantly greater quantities of data at either higher spatial or temporal resolution has occurred. However, even as technology advancements enable smaller transmitter size, we need to evaluate whether there are impacts on data accuracy which may affect management decisions. GPS data will become more important for habitat and conservation management decisions (Millspaugh and Marzluff

2001), and this methodology likely will be employed in research with increasingly smaller avian species and focused on habitat conservation and restoration in imperiled systems (Brennan 1991).

We evaluated spatial accuracy of backpack and necklace style PinPoint GPS transmitters. We used the northern bobwhite quail (*Colinus virginianus;* hereafter quail) as our test species as quail represent a locally abundant species of conservation interest in the southeastern United States (Brennan 1991, Hernández et al. 2012), methods for transmitter attachment and use are well documented (Hernández et al. 2003), and there is considerable previous research on movement ecology and habitat use providing a solid foundation for comparison. Our objectives were to conduct static tests of PinPoint GPS units (<3 g) to evaluate spatial accuracy in field conditions similar to those used by quail, and then to conduct on-bird field tests to determine whether accurate information on movements could be effectively collected using units of this size.

Study Sites

We conducted our field tests on two private properties (MT7 Ranch in Stephens County and Moncreif Ranch in Hood and Parker counties) in the Cross Timbers ecoregion in north-central Texas. Our sites consisted of rolling hills and prairies intermixed with occasional steep canyons and with elevations from 122 to 518 m above sea level (Gould 1962). The region was predominately rangeland with various species of bluestem (*Andropogon* spp.), grama (*Bouteloua* spp.), and panicum (*Panicum* spp.), with common overstory species including live oak (*Quercus virginiana*), Ashe juniper (*Juniperus ashei*), post oak (*Quercus stellata*), black jack oak (*Quercus marilandica*), and mesquite (*Prosopis glandulosa*). Cedar elm (*Ulmus crassifolia*), pecan (*Carya illinoinensis*), and cottonwood (*Populus deltoids*) were found along riparian areas. Study sites were managed for white-tailed deer (*Odocoileus virginianus*) and northern bobwhite (*Colinus virginianus*).

Methods

We tested rechargeable BioTrack PinPoint W 50 GPS transmitters (BioTrack Ltd., Wareham, Dorset, UK) that weighed 2.9 g to which we integrated VHF PIP AG376 transmitter beacon weighing .7 g for our experiment for a total weight of 3.6 g, although there might have been some slight variation (< 0.2 g) due to potting material thickness. As overall unit size is primarily driven by weight of the battery pack, we chose this package, which is the smallest store-on-board GPS unit (g) available in both a necklace and backpack style applicable to quail. Similar to the approach of Guthrie et al. (2011) our experimental design for the static test portion of our evaluation consisted of two research locations (Moncreif Ranch and MT7 Ranch) and five treatment (canopy) levels for two different GPS acquisition rates (hereafter fix rates). We visually located potential treatment locations (non-randomly located) and determined canopy cover estimates using both a Daubenmire frame and a spherical densiometer to ensure treatment levels were accurate for the following categories: bare ground (0% cover at transmitter location); 25%, 50%, and 75% canopy cover; and nesting cover (as identified by Hernández et al. 2003). Following the general approach used by Guthrie et al. (2011), each GPS unit was attached to a small wooden stake that was driven into the ground within 10 cm of a known location at an approximate 45° angle approximately 5–7 cm off the ground to simulate height attachment on a small grassland bird (e.g., quail, see below). Additionally, we used what we called “unit controls” where at each site a single GPS unit was placed 1 m above ground level following the previously described methods. The unit control was above all canopy vegetation and was on the same data collection schedule as the ground level units. Our intention with the unit controls was to provide a non-canopy biased additional estimate of transmitter accuracy at each site above any potential vegetation to the sides that might impact the bare ground location. The expected number of locations for each GPS was 50 locations, but may vary by 1–3 locations depending on the amount of battery life used per individual fix when aggregated across all fixes. Static tests used 2 continuous fix rates: 1 location every 15 minutes or 1 location every hour, with data collected over the course of several days. We used 17 GPS units for testing under the above fix and canopy cover experimental combinations. We randomly assigned each unit to each treatment type for each experiment and we note that during 2 sampling events we experienced data collection failure of a single unit and therefore have different levels of replication among treatments. Exact spatial coordinates for known locations were estimated using a Trimble GPS unit to ensure sub-centimeter accuracy for our evaluations. For our accuracy assessment, we compared the estimated coordinates from the GPS units to the Trimble GPS coordinates. We estimated radial error using a Vincenty Ellipsoid Great Circle Distance using R package spatial (Venables and Ripley 2002) and evaluated associated summary metrics using R v. 3.2.5 (R Development Core Team 2016). We qualitatively evaluated the relationship between dilution of precision (DOP) and the estimated error from a known location to determine if identification of accurate data could be easily identified via DOP evaluation. Because of highly skewed distribution of the error, we provided the full data set and we examined the distribution of errors further after removing outliers driven by poor satellite acquisition, focusing on the distribution of errors ≤100 m (Guthrie et al. 2011). At the 100 m scale the use of descriptive graphics would be more meaningful and allow for us to qualitatively identify what potential metrics were the drivers of variation in the residual error that were not discernable given overall data range (0–4389.2 m).

After preliminary static testing, we implemented short duration on-bird evaluations to determine whether quail could carry the units without any acute impacts to demography and whether units would stay affixed and collect spatial data. During our field test, we used walk-in traps baited with milo to capture 6 quail (3 males, 3 females) in December 2014 on the Moncreif Ranch in Hood and Parker counties, Texas. We followed standard capture and marking procedures for quail as each individual was banded with an aluminum leg band, affixed with either a necklace or backpack style GPS unit, and released. We programmed units to collect data every 1 hour, 30 minutes, or 15 minutes (1 each for 3 backpack and 3 necklace style transmitters). We radio-tracked each individual daily and immediately after the expected data collection period ended (approximately 3 days at maximum) we approached at night and used a dip net to capture each individual while roosting. We then removed the GPS and released the individual at the capture location and estimated velocity and total daily distance moved for each individual (similar to Guthrie et al. 2011). All experimental handling protocols were approved by the Louisiana State University Agricultural Center Institutional Animal Care and Use Committee (AUP A2014-10).

Results

In the static test, the mean spatial error from known to estimated location was 39.7 m (SD 191.7; range 0–4389.2) (Table 1). Median error (50% quantile) was 2.68 m with an 85th probability quantile of 6.57 m. At both sites, the error distribution was skewed; the maximum residual error estimate also exceeded 3000 m, but the majority (~85%) of all locations had a residual error of ≤7 meters. We found a strong relationship between dilution of precision (DOP) and the estimated error from a known location (Figure 1). There also was a consistent relationship between GPS accuracy and the number of satellites that the GPS unit used to estimate its position. As expected, as the number of satellites increases spatial error declines (Figure 2). Median estimates of unit accuracy did not appreciably vary between MT7 Ranch and Moncreif Ranch and were 2.58 and 2.75 m, respectively. In general, summary metrics for each experimental date (4 mutually exclusive experimental tests on 2 sites) provided similar accuracy assessment across all sites, study dates, and canopy density levels (Table 2).

Table 1. Summary metrics (*n* = number of locations evaluated) for PinPoint GPS accuracy assessment classified by canopy treatment for all tests conducted in Texas during 2014.

Treatment	*n*	Mean	Median	Minimum	Maximum	SD
Bare ground	1175	35.2	2.5	0	2203	154.80
25% cover	1183	29.7	2.7	0	2596	142.30
50% cover	1183	27.0	2.5	0	3586	191.69
75% cover	1180	31.2	2.7	0	4389	207.02
Nest cover	808	89.1	3.4	0	3063	262.18

Table 2. Summary metrics (*n* = number of locations evaluated) for PinPoint GPS accuracy assessment classified by experiment replicate, and experimental treatment for static tests conducted on two sites in Texas during 2014.

Site	Experimental replicate	Treatment	*n*	Mean	Median	Min	Max	SD
MT7	1	Bare ground	96	4.7	1.7	0.2	184.5	20.83
MT7	1	25% cover	148	10.0	2.4	0.4	362.3	41.83
MT7	1	50% cover	148	44.3	1.9	0.2	3026.8	345.68
MT7	1	75% cover	146	8.1	2.3	0.0	413.8	37.32
MT7	1	Nest cover	21	157.3	77.7	1.1	839.8	232.62
MT7	1	25% cover-ctrl	98	4.0	2.1	0.2	97.3	11.39
MT7	2	Bare ground	179	70.3	2.3	0.0	2203.2	263.90
MT7	2	25% cover	135	31.9	3.0	0.2	1398.5	157.51
MT7	2	50% cover	135	29.6	2.2	0.2	1151.8	125.98
MT7	2	75% cover	134	45.9	2.1	0.2	2897.6	281.81
MT7	2	Nest cover	49	256.2	188.0	0.6	2175.1	373.95
MT7	2	Bare ground-ctrl	90	49.3	2.6	0.2	1030.6	172.29
MT7	3	Bare ground	200	32.9	2.3	0.2	437.2	84.17
MT7	3	25% cover	150	36.8	2.4	0.0	606.7	107.35
MT7	3	50% cover	150	59.0	2.4	0.0	3586.8	328.93
MT7	3	75% cover	150	16.5	2.5	0.0	411.0	57.24
MT7	3	Nest cover	49	200.1	109.0	0.2	1867.4	290.06
MT7	3	Nest cover-ctrl	39	261.6	159.1	0.3	1848.5	392.70
MT7	4	Bare ground	100	53.6	2.3	0.0	1788.5	234.87
MT7	4	25% cover	150	42.2	2.7	0.2	2596.6	247.43
MT7	4	50% cover	150	13.8	2.5	0.0	417.7	57.29
MT7	4	75% cover	150	58.7	3.3	0.3	4389.2	367.83
MT7	4	Nest cover	89	201.0	96.8	0.6	3063.3	416.05
MT7	4	75% cover-ctrl	100	13.2	2.5	0.0	422.6	57.17
Moncreif	5	Bare ground	150	10.4	2.5	0.2	467.8	44.60
Moncreif	5	25% cover	150	24.2	2.4	0.1	1773.7	151.88
Moncreif	5	50% cover	150	18.3	2.6	0.3	769.7	89.00
Moncreif	5	75% cover	150	17.9	2.9	0.1	811.9	85.76
Moncreif	5	Nest cover	150	39.8	2.9	0.2	2838.5	255.76
Moncreif	5	Bare ground-ctrl	100	52.4	2.5	0.3	968.5	168.04
Moncreif	6	Bare ground	150	14.6	2.5	0.0	291.1	46.37
Moncreif	6	25% gover	150	26.3	2.9	0.1	509.2	70.31
Moncreif	6	50% gover	150	22.0	2.6	0.2	2116.3	177.30
Moncreif	6	75% gover	150	65.4	3.0	0.2	2763.9	324.75
Moncreif	6	Nest cover	150	30.5	2.8	0.1	1021.1	108.55
Moncreif	6	25% cover-ctrl	100	7.6	2.6	0.0	225.3	27.64
Moncreif	7	Bare ground	150	43.1	2.9	0.3	1250.4	141.89
Moncreif	7	25% cover	150	26.2	2.6	0.0	1124.5	120.52
Moncreif	7	50% cover	150	12.2	2.6	0.0	484.0	54.64
Moncreif	7	75% cover	150	21.0	2.6	0.0	876.0	90.87
Moncreif	7	Nest cover	150	52.5	2.8	0.1	2193.5	212.17
Moncreif	7	75% cover-ctrl	50	21.4	3.5	0.6	320.5	60.22
Moncreif	7	Nest cover-ctrl	50	138.6	3.6	0.6	3273.8	478.54
Moncreif	8	Bare ground	150	41.1	2.8	0.2	1573.0	177.43
Moncreif	8	25% cover	150	39.7	2.7	0.0	990.7	143.40
Moncreif	8	50% cover	150	16.9	2.7	0.3	464.5	59.78
Moncreif	8	75% cover	150	16.5	3.1	0.0	544.8	61.98
Moncreif	8	Nest cover	150	66.6	2.6	0.4	1576.1	198.24
Moncreif	8	50% cover-ctrl	100	6.8	2.4	0.4	171.31	23.76

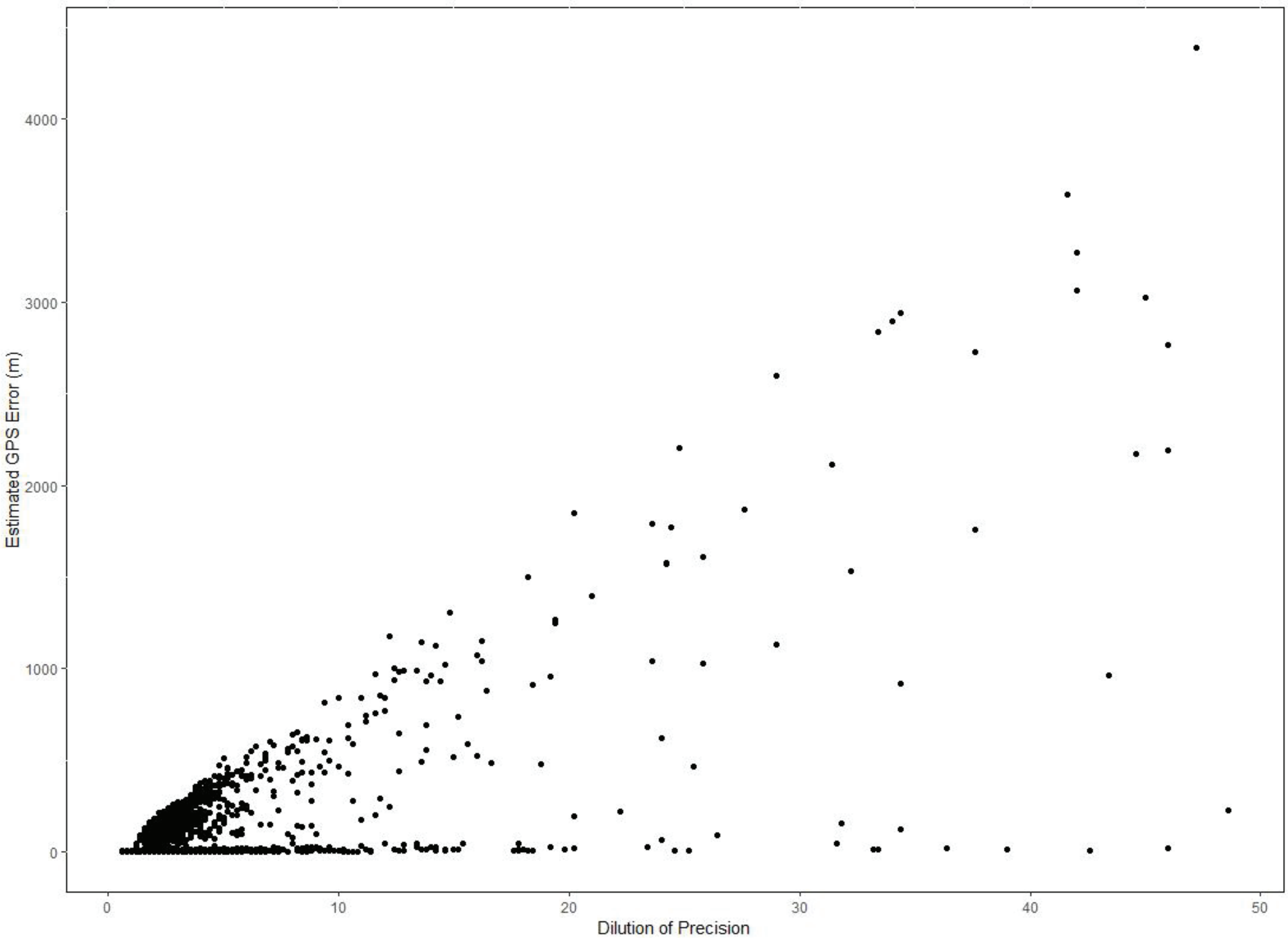

Figure 1. Estimated residual error relative to dilution of precision measurements for all PinPoint GPS transmitters evaluated in north-central Texas during 2014.

We chose a 100-m threshold as it was the 0.992 percentile of the overall distribution, so truncating at this distance removed 58 locations. Using the edited data (Table 3), the vast majority of spatial error estimates are clustered in the region <25 m having a DOP of less than 10 (Figure 3). The primary driver of error was due to having 3 satellites when estimating locations (Figure 4; far left boxplot for each cover class). As satellite coverage increased, accuracy increased substantially across all canopy cover classes (Figure 4).

For on-bird field testing, mean estimated velocity (m min^{-1}) for quail (test individual 1 or 2) for 15-, 30-, and 60-minute schedules was 5.2 (SD = 9.6) and 4.4 (SD = 7.1), 3.0 (SD = 4.5) and 3.8 (SD = 3.8), and 2.3 (SD = 2.6) and 1.9 (SD = 1.7), respectively. However, in all cases the median m min^{-1} was <1 m. For the 2 birds tagged with 30 minutes schedules between locations, total daily movements (complete days, $n = 2$ for each bird) ranged from 1,206 to 2998 m. For quail with 60-minute schedules (complete days, $n = 3$ for each bird), total daily movements ranged from 1,250 to 2,546 m.

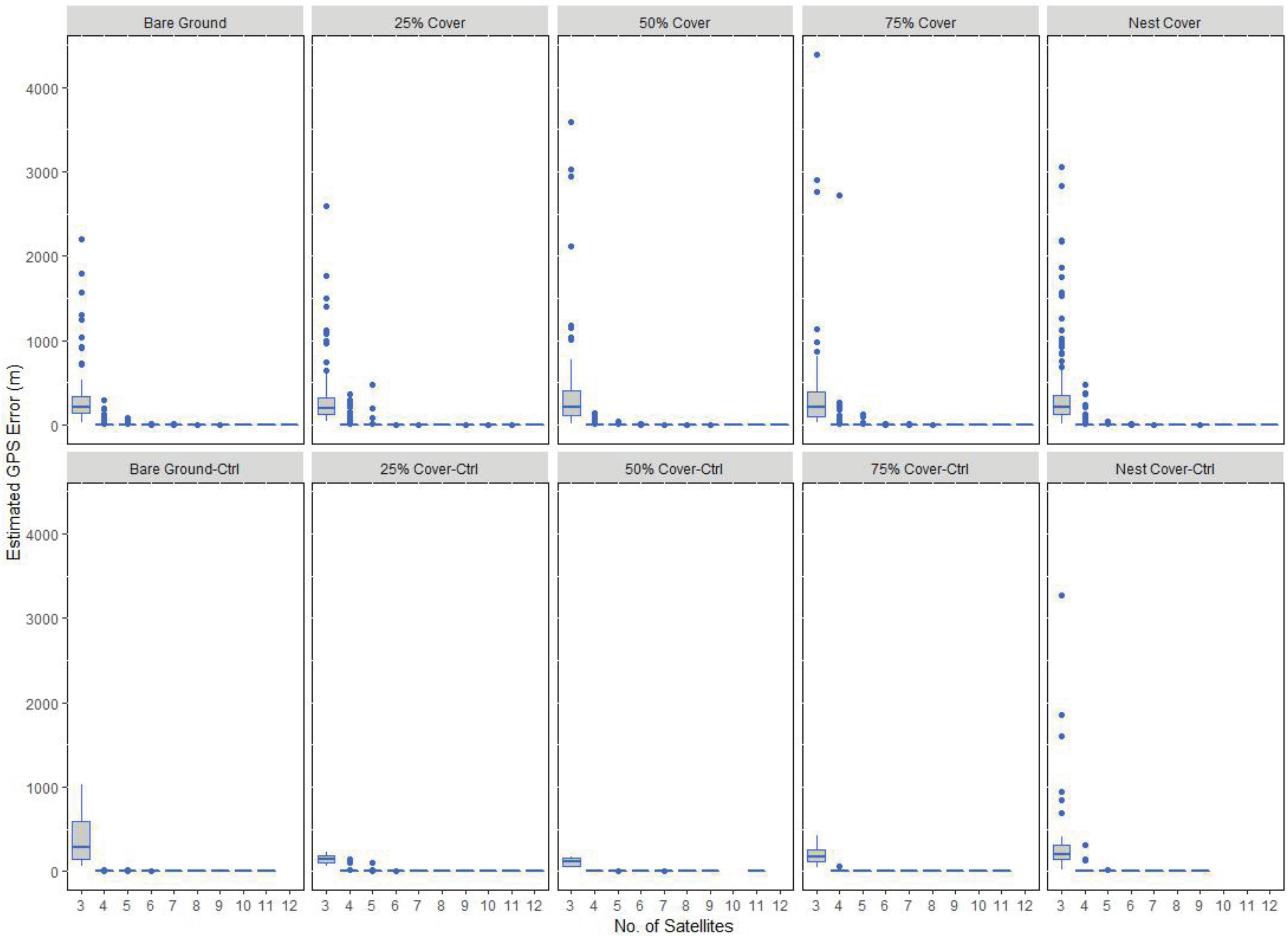

Figure 2. Estimated residual error relative to number of satellites acquired for all PinPoint GPS transmitters evaluated in north-central Texas during 2014.

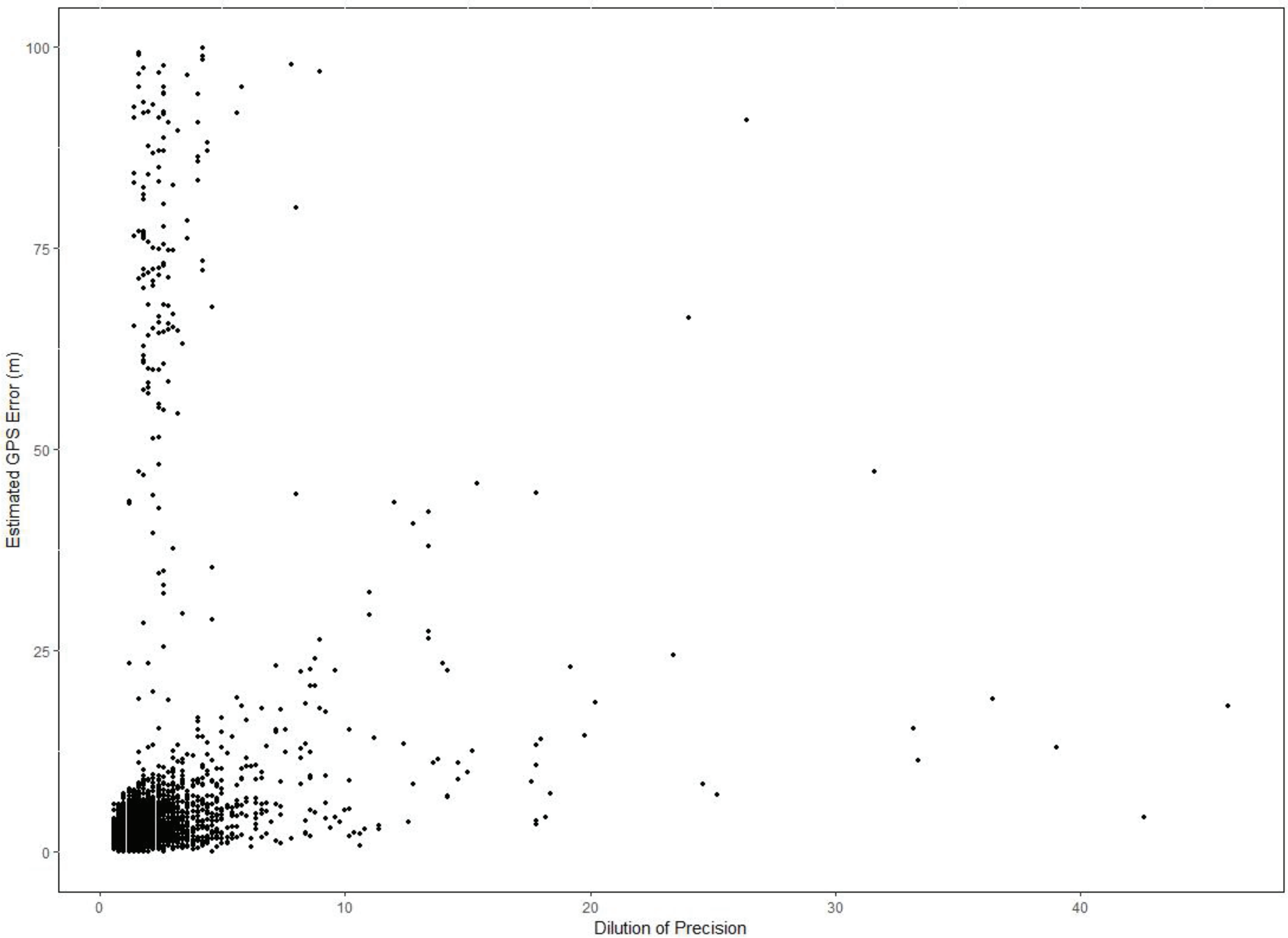

Figure 3. Estimated residual error relative to dilution of precision measurements for all PinPoint GPS transmitters evaluated in north-central Texas during 2014 using edited dataset of all residual error locations <100 m.

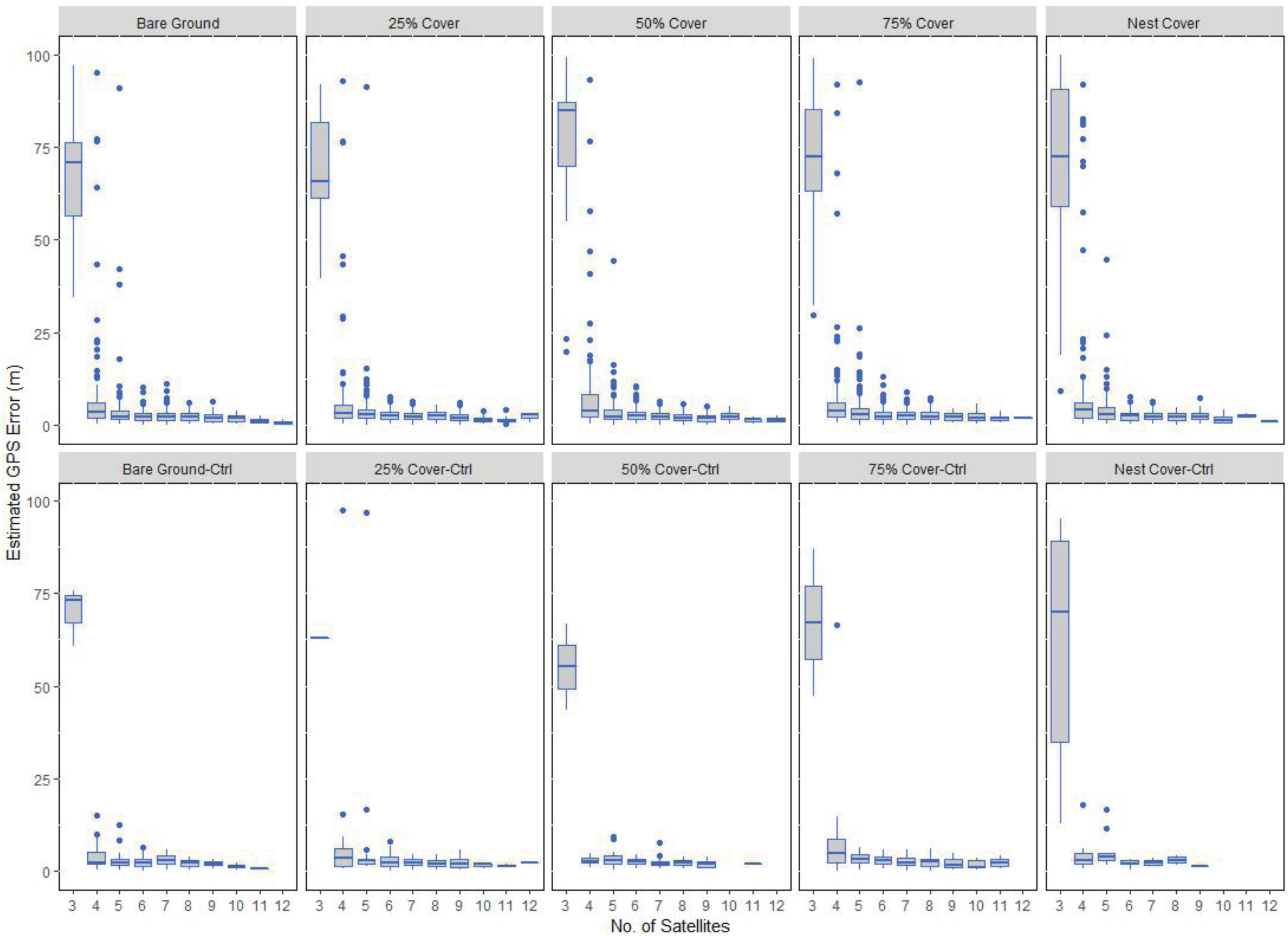

Figure 4. Estimated residual error relative to number of satellites acquired for all PinPoint GPS transmitters evaluated in north-central Texas during 2014 using edited dataset of all residual error locations <100 m.

Table 3. Summary metrics (n = number of locations evaluated) for an edited dataset (estimates of radial distance >100 m removed, 0.08% of total sample) for PinPoint GPS accuracy assessment classified by experiment replicate, and experimental treatment for static tests conducted on two sites in Texas during 2014.

Site	Experimental replicate	Treatment	*n*	Mean	Median	Min	Max	SD
MT7	1	Bare ground	95	2.8	1.7	0.2	94.3	9.54
MT7	1	25% cover	143	3.1	2.4	0.4	88.7	7.30
MT7	1	50% cover	144	2.1	1.9	0.2	8.0	1.24
MT7	1	75% cover	143	3.8	2.3	0.0	83.1	8.70
MT7	1	Nest cover	11	14.2	2.8	1.1	77.7	23.52
MT7	1	25% cover-ctrl	98	4.0	2.1	0.2	97.3	11.39
MT7	2	Bare ground	155	5.5	1.8	0.0	76.3	14.30
MT7	2	25% cover	128	5.2	2.9	0.2	91.2	12.47
MT7	2	50% cover	127	5.0	2.1	0.2	96.4	11.39
MT7	2	75% cover	128	3.4	2.1	0.2	72.3	6.92
MT7	2	Nest cover	17	15.8	3.0	0.6	82.8	29.12
MT7	2	Bare ground-ctrl	82	4.4	2.3	0.2	75.7	11.32
MT7	3	Bare ground	177	4.1	2.0	0.2	95.0	11.85
MT7	3	25% cover	134	3.7	2.1	0.0	92.8	10.19
MT7	3	50% cover	139	5.4	2.3	0.0	87.0	13.68
MT7	3	75% cover	143	5.1	2.4	0.0	94.1	13.07
MT7	3	Nest cover	23	46.5	58.4	0.2	99.8	39.75
MT7	3	Nest cover-ctrl	13	27.4	6.2	0.3	94.1	36.38
MT7	4	Bare ground	92	4.5	2.2	0.0	97.0	12.69
MT7	4	25% cover	140	4.3	2.6	0.2	91.8	10.27
MT7	4	50% cover	145	4.1	2.5	0.0	93.0	10.42
MT7	4	75% cover	137	5.5	2.9	0.3	95.0	12.23
MT7	4	Nest cover	47	24.9	4.9	0.63	98.4	33.74
MT7	4	75% cover-ctrl	96	3.8	2.5	0.00	66.3	8.07
Moncreif	5	Bare ground	146	4.2	2.4	0.20	75.4	7.96
Moncreif	5	25% cover	143	3.5	2.3	0.16	83.3	7.81
Moncreif	5	50% cover	145	3.8	2.6	0.31	78.4	8.56
Moncreif	5	75% cover	145	4.1	2.9	0.14	84.2	8.88
Moncreif	5	Nest cover	143	3.4	2.8	0.28	47.1	4.46
Moncreif	5	Bare ground-ctrl	88	3.4	2.4	0.34	60.7	6.52
Moncreif	6	Bare ground	142	4.3	2.4	0.00	89.6	10.90
Moncreif	6	25% cover	132	3.8	2.5	0.19	76.6	8.57
Moncreif	6	50% cover	146	2.9	2.6	0.22	17.6	2.12
Moncreif	6	75% cover	135	4.9	2.8	0.22	84.0	11.16
Moncreif	6	Nest cover	137	4.5	2.6	0.1	74.8	9.88
Moncreif	6	25% cover-ctrl	98	4.0	2.5	0.0	96.6	9.77
Moncreif	7	Bare ground	131	3.7	2.7	0.3	58.1	5.91
Moncreif	7	25% cover	143	5.0	2.5	0.0	74.7	11.67
Moncreif	7	50% cover	146	3.9	2.2	0.0	99.3	11.16
Moncreif	7	75% cover	142	3.6	2.4	0.0	88.1	7.98
Moncreif	7	Nest cover	133	4.4	2.5	0.1	64.9	9.17
Moncreif	7	75% cover-ctrl	46	5.4	3.3	0.6	86.8	12.51
Moncreif	7	Nest cover-ctrl	39	10.2	3.0	0.6	95.0	21.09
Moncreif	8	Bare ground	137	4.3	2.6	0.2	71.3	9.39
Moncreif	8	25% cover	137	4.0	2.6	0.0	61.7	8.24
Moncreif	8	50% cover	143	5.0	2.6	0.3	87.1	12.76
Moncreif	8	75% cover	145	6.4	2.9	0.0	98.9	15.48
Moncreif	8	Nest cover	129	4.6	2.3	0.4	97.8	12.27
Moncreif	8	50% cover-ctrl	98	3.6	2.3	0.4	66.8	7.80

Discussion

Assessing how wildlife move and select habitats has long been of significant interest to ecologists. As technology advances and miniaturization of GPS-based tracking equipment continues, options for movement data acquisition have increased while costs have continued to decline (Guthrie et al. 2011). As such, we are able to garner more detailed information on animal movements for a wide variety of species than was previously collected using more traditional VHF methods. Our results indicate that spatial accuracy using a PinPoint GPS provide fairly high resolution (median radial error <3 m), similar or smaller to what we would expect during triangulation using VHF telemetry on radio-tagged quail (Liu et al. 2002, Palmer et al. 2012). Location estimates for quail and other species that are moderately sedentary are likely to be accurate based on radio-telemetry (White and Garrott 1990). However, the potential impact that observer disturbance may have on daily movements, combined with the rate of data collection needed to identify fine scale locations may benefit from application of GPS to certain questions (Hebblewhite and Haydon 2010). As expected, canopy cover density can have a significant impact on data accuracy (Guthrie et al. 2011), as the units tested that had the greatest number of outlier (>100 m) points were located in what would be considered heavy cover typical of nesting habitats such as the middle of a prickly pear (*Opuntia spp.*) a commonly used substrate for quail (Hernández et al. 2003). We note, however, that the primary driver of accuracy was satellite contact, and locational accuracy across all canopy cover types showed a significant increase in accuracy when 4 satellites were used relative to 3 (see Figure 4). Thus, we suggest that appropriate project planning should include area evaluations for appropriate vegetative conditions before GPS units are selected.

We can see several avenues for the application of GPS units on smaller avian species. As an example, for the suite of grassland birds the potential to evaluate why species tend to cluster on the landscape, as opposed to being uniformly distributed in available habitats may lead to identification of alternative/unidentified environmental characteristics that are being selected upon. Significant opportunity exists for evaluation of the response of management activities and/or disturbance such as prescribed fire at both the individual and group level (Little et al. 2014). Additionally, perhaps increased resolution of spatial data will allow ecologists and managers to identify areas of low and high risk to mortality (Collier and Chamberlain 2011) and what individual or group decision processes lend to the selection or avoidance of locations where mortality is increased.

We note there are several negative aspects of the GPS we evaluated, which include short duration of rechargeable battery life, potential issues with recovery of the unit and hence data acquisition and reduced VHF reception range. The units we tested had an approximate lifespan of 50 locations, whether taken 50 points in 1 hour, or 1 point per day over 50 days, before the battery pack would need to be recovered and recharged. For tracking time frames over a long period (e.g., several months, focused on survival) GPS units such as we tested would likely not be cost effective relative to VHF telemetry (Guthrie et al. 2011) due to recapture and retagging costs. However, for short duration, high intensity periods of tracking, when frequent, accurate locations are necessary (in response to habitat treatments), GPS may prove more useful than VHF. Based on a qualitative evaluation, we found that reception of the integrated VHF on the GPS we tested was <500m in an open grassland, and was significantly lessened (<200 m) as vegetative conditions became denser. However some of this may be applicable to the size of the PIP unit we used on the GPS and there are likely other options available. The GPS units we tested require recovery for data download; however, units are available for remote download which may mitigate some of the issues associated with the need to recapture individuals for data recovery (Guthrie et al. 2011). Given our results, the use of GPS on small avian species may provide researchers additional avenues for linking movement ecology with habitat selection and demographic drivers.

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