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SPATIAL AND TEMPORAL ANALYSES OF NORTHERN BOBWHITE HUNTING DYNAMICS

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ABSTRACT

A variety of factors influence the harvest of northern bobwhites (*Colinus virginianus*) and where that harvest occurs on a landscape. Many of these factors can be quantified and manipulated to distribute harvest pressure across time and space to meet desired spring densities. We collected spatial hunting metrics using global positioning system units on trucks and hunting dogs, along with detailed hunting logs from 211 quail hunts during the 2018–2019, 2019–2020, and 2020–2021 statewide hunting seasons in Jim Hogg County, Texas, USA. We found that hunting parties effectively covered 23.8 ± 0.3 hectares per hour, with hunts lasting 3.5 ± 0.1 hours in the morning and 1.7 ± 0.1 hours in the evening. Hunts were less productive during the early season (November–mid-December), with 13% fewer encounters per hour and 31% lower harvest per encounter. We expected daily harvest to increase with hunt velocities, but found no significant relationship with the velocity of either pointing dogs or vehicles. However, as we predicted, total hunting pressure (hunts per 50-meter × 50-meter area) decreased by 12% (range = 7–17) for every 5% increase in brush density and every 10-meter increase in the distance to the nearest access road. Our findings can assist landowners and managers in the distribution of harvest and hunting pressure across properties and hunting seasons.

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Key words: bobwhite hunting, *Colinus virginianus*, hunting variables, northern bobwhite, quail hunting

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A modern realization in northern bobwhite (*Colinus virginianus*; hereafter, bobwhite(s)) conservation is that harvest must be managed at the individual property or pasture scale (Williams et al. 2004, Sands et al. 2012, Tomećek et al. 2015). At these scales, scientists recommend using a sustained yield harvest strategy (SYH; Roseberry 1982, Peterson 1999, Guthery et al. 2004, Brennan and Guthery 2007:412), where annual harvest prescriptions are constructed and assumed to leave sustainable spring densities (DeMaso 1999, Guthery 2002) that ensure maximum yield over time (Sands et al. 2013).

Incorporating a SYH prescription also involves managing the spatial and temporal distribution of the harvest. The spatial distribution of hunting pressure can affect seasonal hunting success (Radomski and Guthery 2000, Palmer et al. 2002, Brooke et al. 2017), daily movements patterns (McGrath et al. 2018), and local population persistence of bobwhites (Sands 2010). Guthery (2002:121) suggested that coveys learn avoidance responses after repeated exposure to hunting. McGrath et al. (2018) recorded instances where coveys altogether avoided heavily hunted areas after repeated encounters.

Researchers have suggested that bobwhite harvest adds to natural mortality when it occurs closer to breeding season (Roseberry 1979, Robinette and Doerr 1993, Williams et al. 2004, Hernández et al. 2007). This is especially concerning in South Texas, USA, where the hunting season concludes at the onset of the breeding season (i.e., late Feb–early Mar), and hunting pressure is geared toward the latter half of the hunting season (Hernández and Guthery 2012, Brennan et al. 2014).

However, a common goal for bobwhite managers is to control harvest without reducing the overall numbers of hunts and hunters (Howard 2007). This goal is particularly challenging in South Texas, where harvest objectives (e.g., meeting spring density goals) can fluctuate drastically with annual precipitation and reproductive success (i.e., fall density; Guthery 2002). Many quail hunting operations place self-imposed regulations to limit harvest, including limiting the number of bobwhites harvested per covey and hours spent hunting, and reduced bag or truck limits (Guthery et al. 2004, Howard 2007, Schnupp and Delaney 2012, Brennan et al. 2014, Brooke et al. 2017). Hardin et al. (2005) found that daily harvest increased linearly with increases in the hunt velocity and area hunted. Regulating hunting parameters such as hunting method (e.g., walking vs. vehicle), the area available to hunt, hunt velocity (Guthery 2002, Brennan 2012), and the number of pursuits per covey (i.e., relocating flushed coveys and re-engaging with a firearm) can assist the distribution of harvest across long seasons.

The aim of this study was to analyze the spatial and temporal aspects of quail hunts to provide insight for landowners and managers regarding the implementation of a sustainable harvest. Specifically, we estimated bobwhite hunting variables associated with South Texas quail hunts that can be used to strategically plan hunts across properties and hunting seasons to meet desired harvest prescriptions and spring density objectives. We assumed that hunters would frequently select areas within a pasture that are easiest to access and where brush densities provide the least obstruction for shooting. According to Hernández and Guthery (2012), quail hunters become dissatisfied with hunting leases that have brush densities exceeding 30%. Therefore, we hypothesized that hunters would select areas within a pasture nearest access roads (e.g., quail lanes, ranch roads) containing <25% brush canopy cover. Second, we hypothesized that daily harvest would increase as the velocity of the hunt (i.e., dogs and truck) increases, similar to the models from Hardin et al. (2005).

STUDY AREA

This study took place on the Buena Vista Ranch (6,118 ha) in Jim Hogg County, Texas. The ranch is located approximately 35 km south of Hebbronville, Texas, within the South Texas Plains Ecoregion (Gould 1975). The property is owned and operated by the East Foundation, established in 2007 from the estate of Robert C. East. The primary land use is cattle production, and until the start of this project, quail hunting was prohibited on the property. For the last 30 years, the average annual rainfall for the study site was 55.6 cm, with a mean daily temperature of 22.9° C (PRISM Climate Group 2020). Predominant soils ranged from deep fine sands to sandy loams (Sanders et al. 1974, Gould 1975). Dominant woody vegetation consisted of honey mesquite (*Prosopis glandulosa*), brasil (*Candalia hookeri*), granjeno (*Celtis pallida*), and catclaw acacia (*Acacia greggi*). The herbaceous plant community was dominated by seacoast bluestem (*Schuzachyrium scoparium*), Lehman love grass (*Eragrostis lehmanniana*), purple threeawn (*Aristida purpurea*), Texas broomweed (*Gutierrezia texana*), and croton (*Croton* spp.).

METHODS

Harvest Methods and Structure

We prescribed annual bobwhite harvest quotas for the hunting cooperators, with hunts ongoing until quotas were reached. The annual harvest quotas represented 20% of the prehunting abundance estimate as recommended by Brennan et al. (2014). Prehunting surveys were conducted in early November using line-transect distance sampling from a helicopter platform and following protocols described in Rusk et al. (2007), DeMaso et al. (2010), and Schnupp et al. (2013). We analyzed surveys and calculated density estimates using Conventional Distance Sampling (Buckland et al. 2001, Rusk et al. 2007, Schnupp et al. 2013) within Program Distance version 7.2, release 1 (Thomas et al. 2010).

The harvest quota was calculated for each pasture within the study area to distribute harvest based on local density (Guthery et al. 2000, Brennan et al. 2014, see Woodard et al. this volume). The total harvest quota was 422 northern

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bobwhites for the 2018–2019 hunting season, 852 in 2019–2020, and 1,005 in 2020–2021. These figures included both bobwhites bagged (i.e., harvested and retrieved) and an estimate of bobwhites crippled and not recovered. The estimated crippling loss was according to Haines et al. (2006), who estimated losses to be on average 20% of the birds brought to bag. Therefore, the 20% harvest recommendation was represented by 16% birds retrieved to bag and 4% crippling loss. Additionally, researchers recorded all crippled bobwhites detected by hunting parties (i.e., including researcher) in the field. When the number of detected cripples surpassed the 4% designation, the detected cripples were tallied towards harvest quota to maintain a maximum annual harvest of 20%.

Hunting cooperators used standard hunting methods for South Texas (Howard 2007), where hunters followed pointing dogs in vehicles cross-country (i.e., off-road) throughout pastures until a covey is pointed, and then hunters approached the pointed covey on foot (Hernández and Guthery 2012). The only restriction to the hunting method was that hunting cooperators could not provide supplemental feed or bait roadsides within the study area. We placed no limit on the number of birds harvested per covey or pursuit of coveys following the initial covey rise. Hunters were also free to hunt anywhere within the study area throughout the hunting season and were limited only by the annual estimated harvest quota (i.e., total harvest prescription distributed by pasture).

We divided the statewide hunting season into 3 periods to examine the potential for within-season variation of harvest and hunting variables. The 3 periods were:

1. Early (Nov–mid-Dec).
2. Middle (mid-Dec–late Jan).
3. Late (late Jan–late Feb).

We gave a harvest "target" per period to the hunting cooperators to distribute hunting pressure throughout the hunting season. However, hunting cooperators were not penalized for falling short of monthly harvest targets, and annual harvest quotas were cumulative across periods.

We recorded detailed hunting logs from each hunt, excluding 10 hunts during the 2018–2019 hunting season (i.e., only Global Positioning System [GPS] spatial data recorded). Hunts were half-day excursions that took place in either the morning or the afternoon. Each hunt's start and end times were manually recorded and stored within the Garmin (Garmin Ltd., Olathe, KS, USA) tracklogs. We also documented the start and end time for each brace (i.e., 1 or 2 dogs hunting simultaneously), covey found, travel (e.g., hunting without dogs by driving roads), and nonhunting activity (e.g., snack breaks, nonhunting travel). We estimated covey size, pursuits, shots fired, bobwhites retrieved, and bobwhites crippled during each covey interaction. Like Mecozzi and Guthery (2008), we recorded the breeds, ages, and sexes of all individual dogs used during each hunt.

SPATIAL HUNTING EFFORT AND ANALYSIS

We collected hunting location data using Garmin Dog Tracking Systems (Garmin Ltd., Olathe, KS, USA). Tracking systems consisted of a GPS hand-held unit for the dog handler and GPS collars to be attached to the dogs. We used a combination of Garmin Astro 430 hand-held units, Garmin Alpha 100 hand-held units, T5 GPS dog collar, and TT 15 dog collars. Tracklogs were stored within the hand-held devices with track location intervals on default setting for hand-held units (i.e., 5 seconds) and GPS dog collars (i.e., 2.5 seconds). Prior to each hunt, tracking systems were turned on and left in the open area for 15 minutes to allow for proper satellite connection and accuracy. Garmin currently reports the tracking systems' accuracy to be within 3.65 meters (personal communication, Garmin Ltd., 8 Jun 2021). Hunting tracklogs were downloaded as text files upon completion of each hunt and analyzed for nonhunting related activity (e.g., nonhunting travel; Brooke et al. 2017).

Waypoints for each covey interaction and associated data (i.e., shots fired, harvested bobwhites, crippled bobwhites) were collected manually from stored tracklogs using corresponding event times documented within hunting logs. These waypoints represented the location of the individual dog credited with each specific covey found; if coveys were jumped by the truck and not pointed by dogs, the GPS hand-held unit location was used. Each waypoint was designated as a covey encounter location, evaluated for accuracy and covey interaction behavior (e.g., multiple waypoints with exact locations resembling dogs pointed).

We processed and analyzed all tracklogs using ArcMap 10.8.0 (Esri Inc., Redlands, CA, USA). To start, we converted interval locations to Universal Transverse Mercator (UTM) coordinates before transforming each tracklog from individual points to a line, thus calculating total distance traveled and velocity (i.e., length divided by time). The track lines from GPS hand-held units were buffered by 7.2 meters, representing the effective search width without dogs, derived from Rusk et al. (2007). Each track line from GPS dog collars was buffered by 13.2 meters (Guthery and Mecozzi 2008), representing the standardized width of the hunting zone for each dog track. This figure was the average effective search area as determined from point to flush estimates by Guthery and Mecozzi (2008). We combined tracklogs of dogs and hunting vehicles per hunt into a classified raster (i.e., hunted or nonhunted; McGrath et al. 2018). We combined each hunt raster using the Raster Calculator function in ArcMap 10.8.0, creating a cumulative raster with 50-meter resolution (Brøseth and Pedersen 2000), with values representing the total hunting pressure. We consider this resolution the observed scale (Hernández 2020) of bobwhite hunters, representing the maximum range of firearms used during quail hunts and the resolution at which quail hunters analyze habitats (e.g., perceive landscape features to yield covey contact and feasible

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shooting opportunities). We defined landscape following the definition of Turner et al. (2002) as an area that is spatially heterogeneous in at least one factor of interest.

The covariates used for our analysis were the distance of hunters from roads and the percentage of brush canopy cover on hunted and nonhunted areas of the landscape. Due to the style of quail hunting in South Texas, managers strategically design access roads (i.e., quail lanes, mowed paths) for fire prevention in the semiarid landscape and to increase covey contacts in optimal locations (e.g., where visibility allows viable shooting). Although no baiting was permitted in this study, quail lanes were hunted and utilized to access various locations within the study area. Therefore, we calculated the nearest distance to a quail lane for the cell center of each 50-meter × 50-meter pixel of our hunting raster, using the near function in ArcMap 10.8.0.

We assessed the influence of brush canopy coverage using imagery from the U.S. National Agriculture Imagery Program (NAIP; 0.6-meter resolution). The 2020 imagery for Jim Hogg County was downloaded from Texas Natural Resources Information System (2020) and processed within Program ERDAS IMAGINE (Hexagon Geospatial, Madison, AL, USA). Pixels were classified into 200 clusters, then subcategorized into 2 categories: brush and non-brush. We analyzed the accuracy of our classifications according to methods outlined in Mata et al. (2018) by generating 200 random points within our boundary and comparing land cover classifications to visual observations in Google Earth 7.1 (Google, Menlo Park, CA, USA). In addition, a field assessment was conducted in March 2021. We calculated the brush canopy coverage of the observed scale for bobwhite hunters by resampling the classified raster to 1-meter resolution and aggregating the resampled raster to 50-meter resolution using the Resample and Aggregate tools in ArcMap 10.8.0.

We used Program R (R package version 4.1.0, www.r-project.org, accessed 15 Jun 2021) for data analysis. We determined the influence of brush canopy coverage and distance from a road using negative binomial regression, accounting for overdispersion and zero inflation, and compared the performance of models using Akaike's Information Criterion (Burnham and Anderson 2002). We used Spearman's Rank Correlation to analyze the correlation between brush canopy coverage and distance from the road and the correlation between daily harvest and hunting velocities (i.e., dog velocity and truck velocity) due to non-normality (Shapiro and Wilk 1965).

RESULTS

We documented 59 half-day quail hunts during the 2018–2019 Texas quail hunting season (27 Oct–24 Feb), 74 hunts during the 2019–2020 season (26 Oct–23 Feb), and 78 hunts during the 2020–2021 season (31 Oct–28 Feb; Table 1). In total, we recorded 668 hours of quail hunting activity, consisting of 595 hours in the morning (i.e., between 0700 and 1400 CST, start time = 07:46 ± 0:25 standard deviation [SD]) and 73 hours in the afternoon (i.e., between 1400 and 1900 CST, start time = 16:00 ± 0:39 SD). On average, morning hunts lasted 3.5 ± 0.1 hours and evening hunts lasted 1.7 ± 0.1 hours.

Total hunting pressure was greatest during the middle period (i.e., mid-December–late January), accounting for 50% of the total hunts, 53% of total covey encounters, and 55% of the total harvest (Table 2). We found harvest rate per covey encounter during the early period was significantly lower than the middle and late periods (>30% lower), as was the encounter rate per hour (>13% lower).

We recorded details from braces, dogs, and overall running times for 201 of the 211 hunts. We recorded tracklogs and hunting parameters from 153 individual dogs (n females = 67; n males = 86) belonging to 9 different professional dog handlers. Forty dogs were recorded in two different hunting seasons, and 32 dogs were recorded in all three hunting seasons. The mean age of dogs across all years was 4.6 ± 0.04 years, and the majority of these were the English pointer breed (n = 143), with 10 English setters participating in the hunts. We recorded the details of 836 separate braces. Overall, dog handlers ran 4.2 ± 0.1 braces per hunt, lasting 40.7 ± 0.7 minutes per brace and covering 17.8 ± 0.3 hectares.

Table 1. Annual summary of hunting effort and harvest for morning (0700–1400 CST) and afternoon (1400–2000 CST) hunts for northern bobwhites (*Colinus virginianus*) recorded during the 2018–2019, 2019–2020, and 2020–2021 hunting seasons in Jim Hogg County, Texas, USA.

Year	Time	Hunts	Hours	Encounters	Harvest	Crippled
2018–2019	AM	41	131.3	375	271	64
	PM	18	31.9	81	67	21
	Totals	59	163.2	456	338	85
2019–2020	AM	61	232.8	672	611	181
	PM	13	21.6	50	47	13
	Totals	74	254.4	722	658	194
2020–2021	AM	67	231.1	589	719	247
	PM	11	19.4	38	23	10
	Totals	78	250.5	627	742	257

Morning braces lasted 42.9 ± 0.8 minutes per brace (n = 707 braces) and covered 18.7 ± 4.6 hectares, with evening braces averaging 28.8 ± 1.2 minutes (n = 129 braces) and covering 12.4 ± 0.6 hectares. We found that individual dogs had 32.8 ± 0.3% redundancy of search area, and the redundancy between dogs (i.e., brace) was 39.5 ± 0.3%. The average vehicle velocity across all recorded hunting activities was 3.8 ± 0.1 kilometers per hour, and the average velocity of dogs was 10.6 ± 0.1 kilometers per hour (Table 3). We found no relationship between daily harvest and the velocity of dogs or trucks (Figure 1).

The hunters had a total of 1,805 quail encounters (= 9.3 ± 0.1 bobwhites per covey), including all points by bird dogs (n = 1,653 coveys) and coveys jumped by vehicle (n =155 coveys) undetected by the dogs. Hunting parties averaged 9.7 ± 0.3 encounters per morning at a rate of 2.8 ± 0.1 per hour and 4.0 ± 0.3 encounters per afternoon at a rate of 2.4 ± 0.2 per hour. Hunters pursued 90.1% of total quail encounters with a firearm (i.e., attempted harvest by discharged firearm), presenting a total of 15,394 targets (i.e., individual quail). Unpursued encounters (n = 179 coveys) were due to the nature of flush (e.g., flushed by a dog, beyond gun range), size of covey (e.g., singles and pairs), hunter experience, and brush densities around encounter locations. On average, 1.0 ± 0.04 quail were retrieved per encounter (i.e., averaged by hunt), with an additional 0.3 ± 0.02 quail wounded per encounter. The number of shots per encounter was recorded for 199 hunts, resulting in 1,685 encounters with gunfire documented and 8,220 gunshots recorded. The average number of shots per encounter (i.e., rates derived from individual hunts) was 4.87 shots. Hunters retrieved a bird for every 5.1 shots and crippled one quail for every 15.3 shots (i.e., detected cripples).

Table 2. Summary of annual bobwhite hunting parameters according to designated periods: early (Nov–mid-Dec), middle (mid-Dec–late-Jan), and late (late Jan–late Feb). The hunting parameters were collected during the 2018–2019, 2019–2020, and 2020–2021 hunting seasons in Jim Hogg County, Texas, USA. Encounters per hour were significantly lower during the early period (t = -2.78, $P < 0.01$), as was harvest per covey encounter (t = -3.45, $P < 0.01$).

		Hunts	Hours	Encounters		Harvest		Crippled	
Period	Year	(n)	(n)	rate[a]	SE	rate[b]	SE	rate[c]	SE
Early	2018–2019	10	24.9	2.3	0.14	0.4	0.13	0.2	0.08
	2019–2020	23	70.8	2.7	0.13	0.8	0.13	0.3	0.04
	2020–2021	24	73.7	2.2	0.20	0.8	0.10	0.3	0.05
	pooled	57	169.4	2.4	0.10	0.7	0.07	0.3	0.03
Middle	2018–2019	33	91.6	2.9	0.19	0.8	0.08	0.2	0.04
	2019–2020	35	124.8	2.9	0.14	0.9	0.09	0.3	0.03
	2020–2021	37	118.4	2.7	0.13	1.4	0.11	0.4	0.05
	pooled	105	334.8	2.8	0.09	1.04	0.06	0.3	0.02
Late	2018–2019	16	46.7	2.9	0.29	0.7	0.08	0.2	0.06
	2019–2020	16	58.9	2.8	0.18	1.1	0.13	0.4	0.06
	2020–2021	17	58.4	2.3	0.22	1.3	0.19	0.7	0.08
	pooled	49	164.0	2.7	0.14	1.0	0.09	0.4	0.05

[a] Mean covey encounters per hour.
[b] Mean bobwhites harvested and retrieved per covey encounter.
[c] Mean crippled bobwhites detected and not recovered per covey encounter.

Table 3. Velocities and area covered by northern bobwhite hunting parties recorded during the 2018–2019, 2019–2020, and 2020–2021 hunting seasons in Jim Hogg County, Texas, USA.

			Truck velocity (km/hr)		Dog velocity (km/hr)		Coverage rate[a] (ha/hr)	
Year	Time	n	$\bar{x}$	95% CI	$\bar{x}$	95% CI	$\bar{x}$	95% CI
2018–2019	AM	41	4.4	3.9–4.9	11.7	11.2–12.2	27.7	26.2–29.1
	PM	18	4.1	3.3–4.9	11.1	10.1–12.0	24.0	20.2–27.8
2019–2020	AM	61	3.6	3.4–3.8	10.6	10.2–10.9	24.6	23.7–25.5
	PM	13	3.8	2.7–4.9	9.8	9.2–10.5	22.6	19.4–25.9
2020–2021	AM	67	3.8	3.5–4.1	9.6	9.2–9.9	21.2	20.2–22.1
	PM	11	3.1	2.3–3.8	9.3	8.1–10.6	21.4	18.8–24.0

[a] Area effectively hunted by pointing dogs and hunting vehicle in hectares per hour.

Hunting occurred on 77% of the total study area. Bobwhite hunting parties effectively hunted 23.8 ± 0.3 hectares per hour (e.g., area effectively hunted with dogs and truck) on average across 3 hunting seasons. Morning hunts covered 83.8 ± 1.6 hectares on average at a rate of 24.0 ± 0.4 hectares per hour. The evening hunts covered less area, averaging 39.9 ± 2.3 hectares per hunt at 22.9 ± 1.0 hectares per hour.

According to the spatial hunting distributions at the observed scale (i.e., 50-meter resolution, Figure 2), 10% of grid cells were not hunted through 3 hunting seasons, 11% only hunted once, and 79% hunted more than once (range = 2–24), with only 9% of grid cells hunted on more than 10 occasions (Figure 3). The nonhunted cells had a mean brush canopy coverage of 44.7 ± 0.6%, and the mean distance to a quail lane was 163.9 ± 1.9 meters, while brush canopy coverage of hunted cells was 21.71 ± 0.12% (see Appendix A) and mean distance to a quail lane was 84.2 ± 0.5 meters (see Appendix B). We found that mean brush canopy cover and mean distance to road decreased as total hunting pressure increased (Figure 4). Our top model, according to Akaike's Information Criterion with a correction for sample size, was our full model with an interaction term (Table 4), which we included due to a correlation between our brush canopy coverage and distance to roads. Therefore, we found that total hunting pressure had a negative relationship with percent brush coverage, distance to a road, and their interaction (Table 5), suggesting hunters are selecting areas to hunt based on lower brush densities and proximity to access roads.

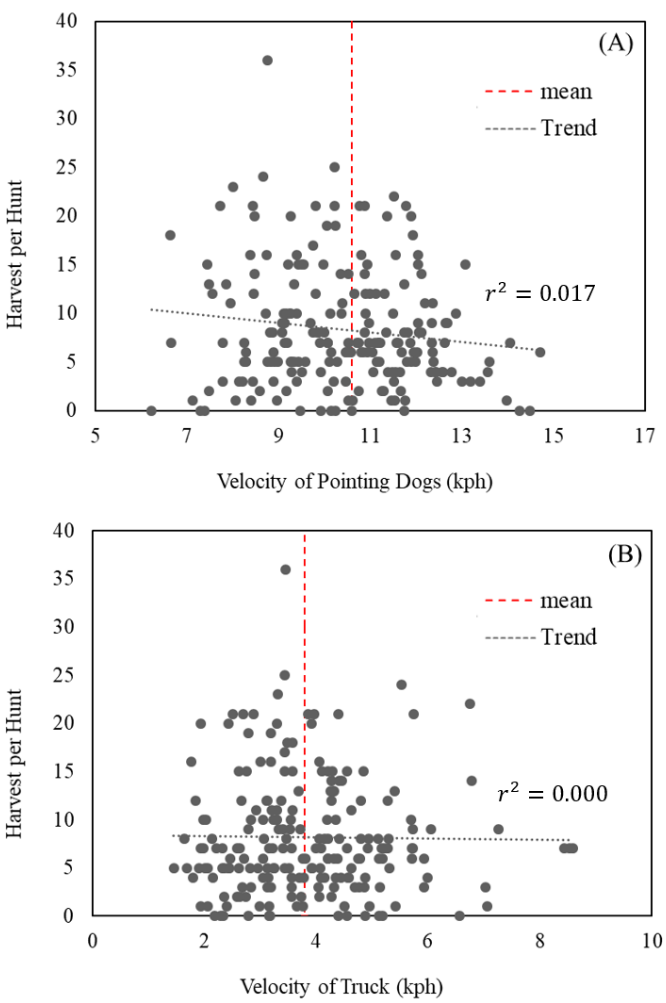

Fig. 1. Relationship between northern bobwhite (*Colinus virginianus*) harvest per hunt and hunting velocity (km/hr), categorized by mean velocity of pointing dogs (A; x̄ = 10.6 ± 0.1 km/hr ; rs = -0.09, P = 0.1786) and mean velocity of hunting vehicles (B; x̄ = 3.8 ± 0.1 km/hr; rs = -0.01, P = 0.9194) from 211 quail hunts in Jim Hogg County, Texas, USA.

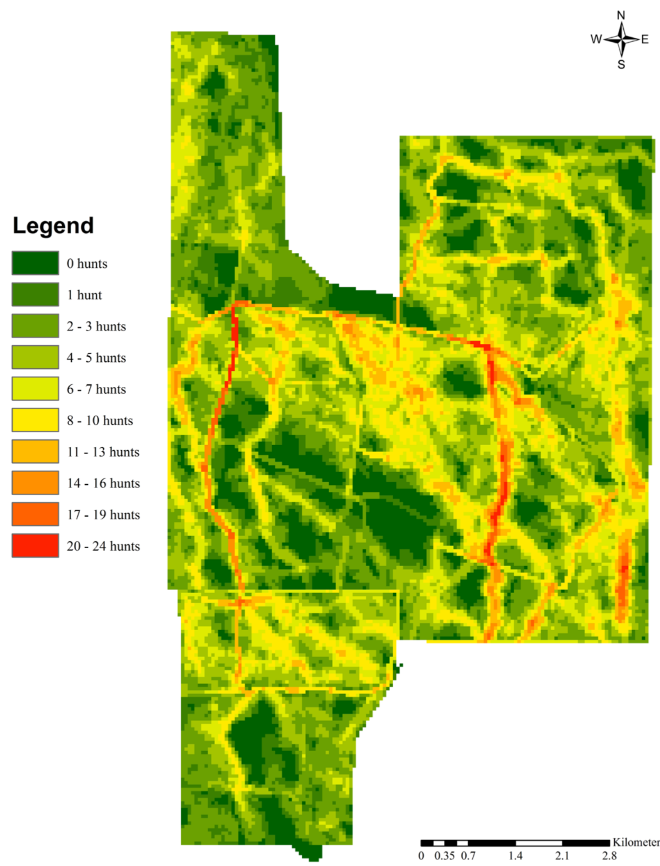

Fig. 2. Spatial distribution of 211 quail hunts at 50-meter resolution, recorded during the 2018–2019, 2019–2020, and 2020–2021 hunting seasons in Jim Hogg County, Texas, USA.

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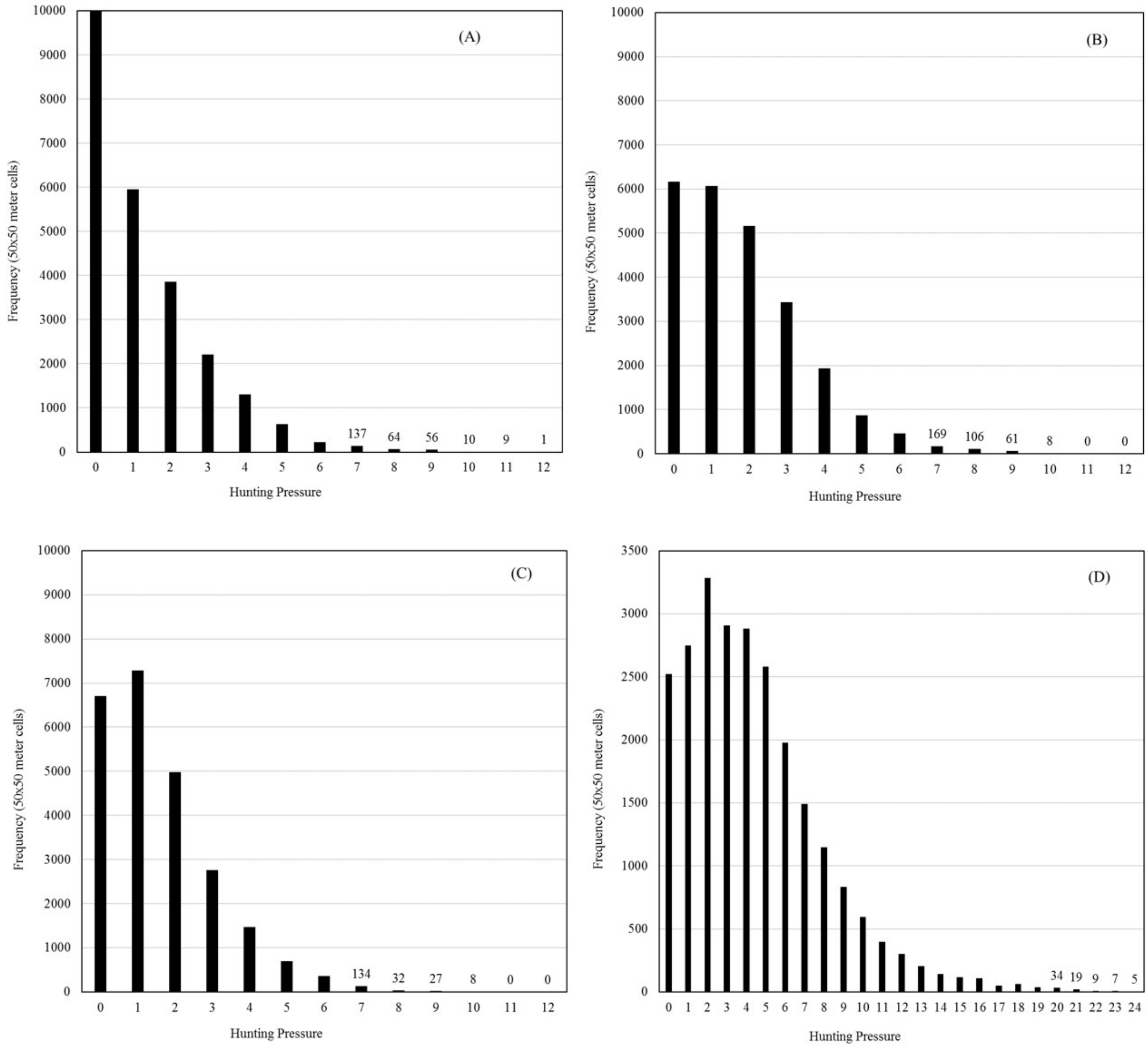

Fig. 3. Frequency of 50-meter grid cells categorized by total hunting pressure for the A) 2018–2019, B) 2019–2020, and C) 2020–2021 seasons, and D) cumulative across the 3 seasons from quail hunts in Jim Hogg County, Texas, USA.

Table 4. Model selection results for total hunting pressure over the 2018–2019, 2019–2020, and 2020–2021 hunting seasons in Jim Hogg County, Texas, USA. Negative binomial regression used percent brush canopy coverage (Brush) and distance to access road (Road) per 50-meter × 50-meter grid cell.

Model	*K*	log(L)	AIC_c[a]	ΔAIC_c	W_i
Brush + Road + Interaction	5	-57,815.3	115,640.6	0.00	1.0
Brush + Road	4	-57,960.1	115,928.3	287.69	0.0
Road	3	-59,137.8	118,281.6	2,641.05	0.0
Brush	3	-60,327.5	120,661.0	5,020.4	0.0

[a] Akaike's Information Criterion with a correction for sample size.

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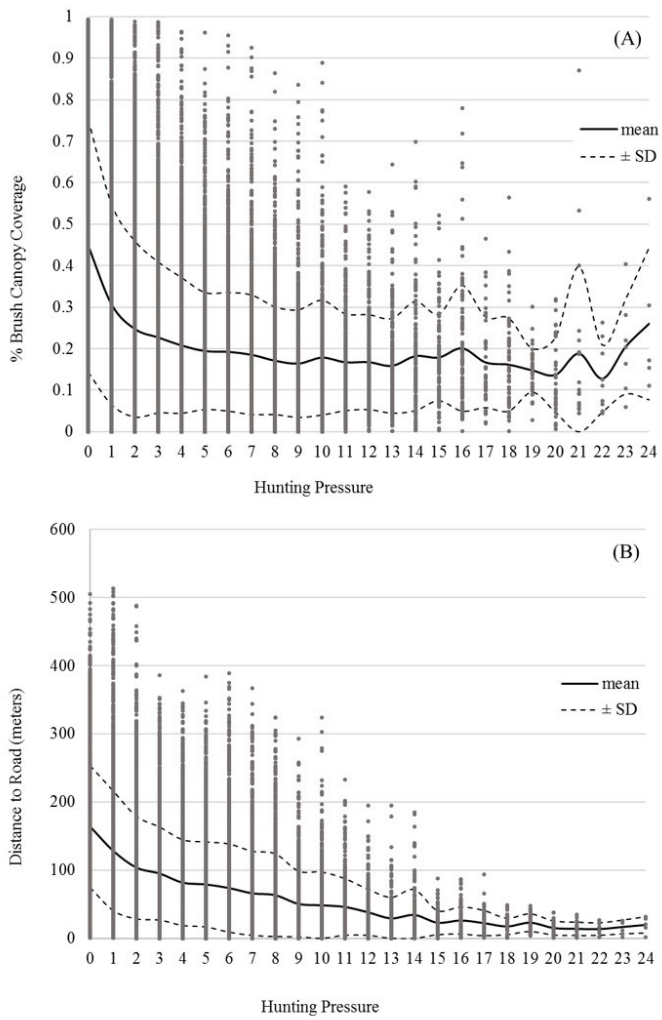

Fig. 4. A) Percent brush canopy cover and B) distance to road per 50-meter × 50-meter grid cell, categorized by total hunting effort from quail hunts recorded during the 2018–2019, 2019–2020, and 2020–2021 hunting seasons in Jim Hogg County, Texas, USA.

Table 5. Parameter estimates of top-ranking model for total hunting pressure over the 2018–2019, 2019–2020, and 2020–2021 hunting seasons in Jim Hogg County, Texas, USA.

Variable	β-estimate	SE	Z-value
(Intercept)	2.0168	0.0106	189.92
Brush	-0.6887	0.0417	-16.50
Road	-0.0035	0.0001	-34.79
Interaction[a] (Brush × Road)	-0.0063	0.0003	-16.82

[a] $r_s = 0.13$, $P < 0.01$

DISCUSSION

According to daily harvest predictions from Hunter Covey Interface models by Hardin et al. (2005) and similarities between our velocity rates, we expected to find a relationship between daily harvest and hunting velocity. We found no such relationship; however, Hardin et al. (2005) predicted daily harvest using constant parameters for harvest rate (i.e., 2.0 per encounter) that was 50% higher than our results. In fact, our mean harvest rate per covey encounter was lower than those reported by Bennitt (1951; $\bar{x}$ = 1.9 ± 0.02), Guthery (2002; $\bar{x}$ = 1.7 ± 0.07), Hardin et al. (2005; $\bar{x}$ = 1.8 ± 0.04), and Mecozzi and Guthery (2007; $\bar{x}$ = 1.4 ± 0.16). The 5.1 shots per bobwhite retrieved were 2 shots higher than reported from Doster et al. (1982; $\bar{x}$ = 3.1) and 3 shots higher than Mecozzi and Guthery (2007; $\bar{x}$ = 2). Therefore, our hunting participants were significantly less efficient when presented with harvest opportunities. However, we feel this harvest rate and shooting efficiency are an honest representation of the current trends in bobwhite hunting participants (Rollins 2002, Johnson et al. 2012) and diversity of hunters in South Texas. Quail hunters in South Texas are composed of a variety of ages and experiences. Some hunting parties are composed of seasoned veterans, while others focus on the entertainment of families and corporate customers, ranging from novice to expert. Second, the model by Hardin et al. (2005) did not account for the time constraints when hunters find and engage with a covey and as the daily number of covey encounters increases more time will be spent with dogs on point (i.e., 0 kilometers per hour; Mecozzi and Guthery 2007). Our results support the findings of Mecozzi and Guthery (2007), who found a weak negative relationship between dog velocity and encounter per kilometer during walk-hunts in Oklahoma, USA, northern Texas, and eastern Missouri, USA.

Several studies have examined how access or road systems influence hunting distributions. For instance, when analyzing willow ptarmigan (*Lagopus lagopus*) hunters in central Norway, Brøseth and Pedersen (2000) found that the access point (i.e., hunter's cabin) strongly influenced spatial hunting distributions. Richardson (2006) found that the distance from a road system significantly influenced walk-only quail hunts in Oklahoma and recommended designing road systems within average walking distance to maintain huntable area. However, Tanner et al. (2016) found that the risk of mortality for northern bobwhites in Oklahoma decreased as the distance from roads increased, regardless of hunting pressure. The relationship we found between percent brush canopy cover and access roads is straightforward. Hunters focus on areas with the highest rate of return (i.e., shooting efficiently and harvest per covey), or one could say the path of least resistance, which is heavily influenced by brush configurations and access roads throughout landscapes in South Texas. Hernández and Guthery (2012) indicated the landowners will "lose the goodwill" of hunters when brush exceeds 30%. If hunters cannot walk or drive through particular areas due to brush densities, they are less likely to hunt there. Likewise, if hunters find quail in dense brush but have no viable shooting opportunities, they are more likely to avoid such areas in the future.

Our results differ from those of Kellogg et al. (1982) in Florida, USA, as well as Wellendorf et al. (2012), who reported a 17% higher covey encounter rate during evening

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hunts in Georgia, USA. We attribute this discrepancy to 2 possible explanations: first, the temperature typically increases throughout the day, limiting bobwhite activity (Carroll et al. 2015) and reducing overall variability in scenting conditions for pointing dogs (Gutzwiller 1990, Wellendorf et al. 2012). Second, our hunters consistently started at legal shooting light to take advantage of scenting conditions in the early morning and to maximize the time spent in the field. This is unlike most quail hunters, and on average 2 hours earlier then starting times reported by Wellendorf et al. (2012), who rarely begin morning hunts at daybreak.

The differences we found during the early season (i.e., Nov–mid-Dec) regarding covey encounter rates (≥13% lower) and harvest per encounter (≥30% lower) are likely why quail hunting in South Texas is geared towards the later portions of season dates. Wellendorf et al. (2012) reported no differences in encounter rate between their early (Nov–Dec) and late (Jan–Feb) periods. Bobwhite populations should be highest at the start of the season and decrease throughout winter (Guthery 2002). With fewer bobwhite available for detection, we would naturally expect to see a declining trend in covey encounter rate as the season progresses. Radomski and Guthery (2000) predicted an increase in covey avoidance behavior throughout the season as naïve coveys learn from repeated contact with hunting parties, resulting in lower hunting success, a trend detected by Palmer et al. (2002) in Florida and Brooke et al. (2017) in Kentucky, USA. McGrath et al. (2018) also found evidence of avoidance behavior while analyzing forage and movement patterns of bobwhites after being exposed to hunting parties. However, we predict that our discrepancy is likely due to climatic factors, with typical weather patterns in early winter unfavorable for quail hunting and cooler weather with optimal scenting conditions more common throughout January and February in South Texas.

MANAGEMENT IMPLICATIONS

We suggest time of day, period of the bobwhite hunting season (i.e., early, middle, late), and length of time spent hunting influence the within-season variation of covey encounter rates and subsequent harvest in South Texas. Adjusting these parameters can increase or decrease harvest depending on management objectives. For instance, hours spent hunting are more influential to the total area covered and daily harvest than minor variations in hunting velocities. Our results also indicate that brush densities of areas selected by quail hunters are at the lower end of brush density thresholds utilized by bobwhites, according to various findings in the region. We strongly recommend that landowners and managers focus on strategic placement of road systems and combating brush encroachment to optimize the huntable area available and spatially distribute hunting pressure.

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APPENDIX A. Summary statistics for percent brush canopy cover per 50-meter × 50-meter grid cell, categorized by total quail hunting effort recorded during the 2018–2019, 2019–2020, and 2020–2021 hunting seasons in Jim Hogg County, Texas, USA.

		% Brush canopy coverage			
Hunted[a]	n[b]	$\bar{x}$	SD	SE	95% CI
0	2,520	0.45	0.30	0.01	0.44–0.46
1	2,747	0.31	0.24	0.00	0.30–0.32
2	3,283	0.25	0.21	0.00	0.24–0.25
3	2,907	0.23	0.18	0.00	0.22–0.23
4	2,884	0.21	0.16	0.00	0.20–0.21
5	2,579	0.19	0.14	0.00	0.19–0.20
6	1,978	0.19	0.14	0.00	0.19–0.20
7	1,492	0.19	0.14	0.00	0.18–0.19
8	1,149	0.17	0.13	0.00	0.16–0.18
9	834	0.16	0.13	0.00	0.16–0.17
10	596	0.18	0.14	0.01	0.17–0.19
11	399	0.17	0.12	0.01	0.16-0.18
12	301	0.17	0.11	0.01	0.15–0.18
13	204	0.16	0.11	0.01	0.14–0.17
14	142	0.18	0.13	0.01	0.16–0.20
15	115	0.18	0.10	0.01	0.16–0.20
16	109	0.20	0.15	0.01	0.17–0.23
17	48	0.17	0.11	0.02	0.14–0.20
18	63	0.16	0.11	0.01	0.13–0.19
19	37	0.15	0.05	0.01	0.13–0.17
20	34	0.14	0.09	0.02	0.11–0.17
21	19	0.19	0.21	0.05	0.09–0.29
22	9	0.13	0.08	0.03	0.07–0.19
23	7	0.21	0.11	0.04	0.10–0.31
24	5	0.26	0.18	0.08	0.03–0.49

[a] Hunted value represents the total hunting pressure per grid cell.
[b] Total number of grid cells per Hunted category.

APPENDIX B. Summary statistics for distance to roads per 50-meter × 50-meter grid cell, categorized by total quail hunting effort recorded during the 2018–2019, 2019–2020, and 2020–2021 hunting seasons in Jim Hogg County, Texas, USA.

		Distance from road			
Hunted[a]	n[b]	$\bar{x}$	SD	SE	95% CI
0	2,520	163.9	89.5	1.8	160.4–167.4
1	2,747	128.3	87.7	1.7	125.0–131.6
2	3,283	103.8	75.3	1.3	101.3–106.4
3	2,907	95.1	68.2	1.3	92.6–97.6
4	2,884	81.7	62.9	1.2	79.4–84.0
5	2,579	79.1	62.3	1.2	76.7–81.5
6	1,978	73.8	64.7	1.5	70.9–76.6
7	1,492	66.1	61.7	1.6	62.9–69.2
8	1,149	63.3	60.7	1.8	59.8–66.8
9	834	50.5	48.2	1.7	47.2–53.8
10	596	48.5	48.8	2.0	44.6–52.4
11	399	46.1	41.5	2.1	42.0–50.2
12	301	38.2	33.8	1.9	34.4–42.0
13	204	29.4	30.8	2.2	25.2–33.7
14	142	34.3	37.2	3.1	28.1–40.5
15	115	23.0	17.6	1.6	19.8–26.3
16	109	26.2	19.9	1.9	22.4–30.0
17	48	22.4	18.5	2.7	17.0–27.8
18	63	17.5	12.0	1.5	14.5–20.6
19	37	23.0	13.0	2.1	18.7–27.3
20	34	15.3	10.3	1.8	11.7–18.9
21	19	14.0	9.8	2.2	9.3–18.7
22	9	13.7	9.2	3.1	6.6–20.7
23	7	16.8	10.1	3.8	7.4–26.1
24	5	19.8	12.0	5.4	4.9–34.7

[a] Hunted value represents the total hunting pressure per grid cell.
[b] Total number of grid cells per Hunted category.