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# RELATIONSHIPS BETWEEN METEOROLOGICAL AND OTHER VARIABLES AND BOBWHITE SPRING CALL COUNTS

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## ABSTRACT

Accurate assessment of quail population trends is critical to the success of future conservation efforts. Financial considerations and time constraints often limit population trend estimates to indices, the most common of which are spring call counts and autumn covey counts. While all indices have limitations and caveats, spring call count data specifically possess variability that makes them ill-suited for detecting fine-scale trends. However, because spring call counts record calling males and are relatively easy to conduct, they are assumed to represent an index of breeding potential and produce the most data per unit cost. Here, we examine their variability, comparing the number of male northern bobwhites (*Colinus virginianus*; hereafter, bobwhite) calling and weather measurements recorded during >4,000 spring call counts conducted May–July 2014–2017. The number of male bobwhites recorded per call count decreased >2 hours after sunrise, as ambient temperatures increased, but increased with relative humidity. An increase in ambient noise was associated with recording fewer male bobwhites. There was no correlation with either wind speed <16 km/hour for 3 of 4 years, or with the Palmer Drought Severity Index. Comparing these results with other spring call counts in the literature highlights inconsistency in spring call count timing, and discrepancies between call count protocols and weather conditions that affect detection probability. We suggest incorporating these results into future call counts to more accurately assess bobwhite population trends.

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***Key words:*** abundance, climate, *Colinus virginianus*, drought, meteorology, northern bobwhite, quail, spring call counts, Texas, variability

Northern bobwhite (*Colinus virginianus*; hereafter, bobwhite) population numbers display high annual variability (Sauer et al. 2020), and are difficult to predict (Anderson 2001, 2003; Engeman 2003, 2005). As a result, wildlife managers, researchers, and conservationists need a practical, accurate, and reliable method to assess annual bobwhite population trends. Historically, indices of bobwhite population abundance such as spring call counts (Bennitt 1943) have been used to assess bobwhite population trends because they are more practical and require fewer resources than other methods (Engeman 2003). However, many underlying assumptions and variable factors affect the reliability of spring call counts (Anderson 2001, 2003). Standardizing location, timing, and conditions of spring call counts can produce data more suited for comparison (Engeman 2003, 2005). Weather conditions also influence the probability of detecting bobwhites during spring call counts (Anderson 2001), but this influence is poorly understood. To date, few published studies have critically examined these relationships. Thus, the goal of this study was to examine the relationships between spring call count results and meteorological, temporal, and other variables.

Northern bobwhite spring call counts have been used to assess bobwhite population trends to advise management, research, and conservation (Stoddard 1931, Bennitt 1951, Ellis et al. 1972, Burger et al. 2006, Reyna et al. 2012). The calls recorded are emitted by male bobwhites only, primarily during nesting, mating, and brooding season (Stoddard 1931, Bennitt 1951, Rosene 1957, Kabat and Thompson 1963, Ellis et al. 1972). Spring call counts are assumed to have a linear, positive relationship with bobwhite population density (Gibbs 2000). However, many factors influence the probability of detecting a calling bird (Nichols et al. 2000, Farnsworth et al. 2002, Royle and Nichols 2003, Mackenzie et al. 2005).

To reduce variation, some aspects of a spring call count are standardized (Robbins et al. 1986). These include time of day, time of year, duration of call counts, and limitations

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of weather conditions under which call counts may be conducted. Additionally, spring call counts are typically recorded at predetermined points or along a predetermined route. The observer records all male bobwhites heard calling for a set amount of time, often 2–8 minutes (Rosene 1957, Kabat and Thompson 1963, Ellis et al. 1972, Curtis et al. 1989), before moving to the next point. Spring call counts are timed to coincide with the local breeding season, with daily start times ranging from 45 minutes before sunrise (Hansen and Guthery 2001) to 25–30 minutes after sunrise (Robel et al. 1969), and listening period durations of 1.5–3 hours (Bennitt 1951, Rosene 1957, Kabat and Thompson 1963).

Hansen and Guthery (2001) recommended bobwhite spring call counts be performed at or near the peak of calling activity. The date of peak spring calls varies spatially and temporally, but generally occurs from the last week in May through the second week in July (Burger et al. 2006). For example, spring calling peaked 20 June–20 July in Missouri, USA (36.5°N–40.5°N; Bennitt 1951), 15 June–17 July in Kansas, USA (36.56°N–39.07°N; Robel et al. 1969), mid-late May with secondary, smaller peaks mid-June–late July in Georgia, USA and northern Florida, USA (30.5°N–32.7°N; Terhune et al. 2006), and 19 June in Oklahoma, USA (36.0°N–36.2°N; Hansen and Guthery 2001).

While more difficult to control for, weather conditions can influence call detection probability (Anderson 2001). However, these influences are not always consistent (Table 1). Although temperature varies spatially and temporally (Tomecek et al. 2017), it is consistently negatively correlated with the number of cock calls recorded in all but one year of one study (Elder 1956; Table 1). Similarly, wind speed was negatively correlated with the number of male bobwhites recorded (Elder 1956, Robel et al. 1969, Hansen and Guthery 2001) except when the observer alternated between "upwind" and "downwind" to determine mean audibility distances (Bennitt 1951). Additionally, drought conditions may reduce nesting and brood rearing in bobwhites (Stanford 1972). As a result, the Palmer Drought Severity Index (PDSI; Palmer 1965) has been correlated with a decrease in male calling (Bridges et al. 2001, Reyna et al. 2012). Though there are valid criticisms of the PDSI (Alley 1984, Dai et al. 2004), it remains one of the most prominent drought indices used, particularly for the central United States (Dai et al. 2004).

Protocol from Burger et al. (2006) proscribes data collection when cloud cover exceeds 75%, presumably due to decreased calling activity. However, separate from light intensity (Robel et al. 1969, Hansen and Guthery 2001), the relationship between cloud cover and bobwhite calling activity is either not significant (Bennitt 1951, Elder 1956) or equivocal at best, with trends inconsistent from year to year (Hansen and Guthery 2001). In South Texas, USA, calling activity increased following summer rains, but conducting call counts during rain is not recommended, presumably due to noise considerations (Lehmann 1984).

Although spring call counts are the most common index of bobwhite relative abundance, few studies have analyzed the relationship between meteorological, temporal, and other variables and spring call counts. Of 4 previous studies (Table 1), only Robel et al. (1969) collected weather data at each call count location. Other studies recorded weather data hourly or at the start and end of each call count route, which may be the reason for some of the inconsistencies in determining

Table 1. Correlations between meteorological conditions and number of male bobwhite (*Colinus virginianus*) calls recorded during spring call counts by previous studies. + = positive correlation; - = negative correlation; 0 = no correlation.

| Factor | Measured | Correlation(s) | Reference |
|---|---|---|---|
| Temperature | Hourly | - | (Bennitt 1951) |
| | Start and end | +/-[a] | (Elder 1956) |
| | Each stop | - | (Robel et al. 1969) |
| | Hourly | - | (Hansen and Guthery 2001) |
| Wind speed | Hourly | 0 | (Bennitt 1951) |
| | Start and end | - | (Elder 1956) |
| | Each stop | - | (Robel et al. 1969) |
| | Hourly | - | (Hansen and Guthery 2001) |
| Humidity (%) | Hourly | 0 | (Bennitt 1951) |
| | Start and end | -/+ | (Elder 1956) |
| | Each stop | -[b] | (Robel et al. 1969) |
| | Hourly | + | (Hansen and Guthery 2001) |
| Barometer | Hourly | 0 | (Bennitt 1951) |
| Cloud cover | Hourly | 0 | (Bennitt 1951) |
| | Hourly | -/0[c] | (Hansen and Guthery 2001) |
| Light intensity | Each stop | 0 | (Robel et al. 1969) |
| | Hourly | - | (Hansen and Guthery 2001) |

[a] 1954–1955
[b] Correlation recorded only outside of peak calling time
[c] 1998–1999

the relationship between the number of male bobwhites recorded and weather (Table 1). Thus, the objectives of this study were to 1) record the number of bobwhites calling along with meteorological, temporal, and other variables during >4,000 spring call counts to determine how the number of bobwhite calls recorded varies with the weather, time of day, and ambient noise; and 2) improve protocols for future spring call counts.

## STUDY AREA

Northern bobwhite spring call counts were conducted in Clay and Montague counties (Figure 1) in the Central Great Plains Ecoregion of North Texas (Griffith et al. 2004). Vegetation was primarily mesquite-lotebush (*Prosopis* spp.-*Ziziphus obtusifolia*) to the west, and post oak (*Quercus stellata*) woods, forest, and grassland mosaic to the east with portions of post oak parks, mesquite brushland, cropland, and cottonwood-hackberry (*Populus deltoides-Celtis* spp.) forest (McMahan et al. 1984). In 2016, land use in the 2 counties was approximately 72.2% rangeland, 11.6% forest, 10.6% cropland, hay, and pasture, and 3.5% urban or otherwise developed (Jin et al. 2019). In addition to access granted from private ranches, the 2 counties also had approximately 3,700 km of publicly accessible roads (Texas Department of Transportation 2015) from which to collect data.

## METHODS

Bobwhite calls and meteorological, temporal, and other variables were recorded at preestablished data collection points (DCPs) set approximately 1.6 km apart (Figure 1; Whitt and Reyna 2017). All data collection points for this study were located 33.42°N–34.15°N. Since calling begins earlier in southern U.S. latitudes (Rosene 1957, Terhune et al. 2006), we began spring call counts in mid-May, a week earlier than recommended by Burger et al. (2006). Counts were generally performed Tuesday–Friday and continued until all DCPs were visited. Data were collected 16 May–24 June 2014 and 19 May–30 June 2015 in Clay County, and 16 May–1 July 2016 and 16 May–6 July 2017 in Clay and Montague counties. More data collection time was required 2015–2017 due to multiple rain delays and flooding. Calls were recorded within the first 3 hours after sunrise. It was not feasible to visit all points within the 8-week study period by recording only 1 hour/day as recommended by Kabat and Thompson (1963) and Burger et al. (2006). The latter recommendation was based on results from Hansen and Guthery (2001), who noted that peak time of calling occurred 30–75 minutes after sunrise. However, they also noted that while extending the listening period to 3 hours resulted in undercounts for high-density sites, it had no significant effect on presence and absence detection in low-density sites. Bennitt (1951) also measured the highest activity in the first hour after sunrise, but calling activity decreased significantly only after hour 3.

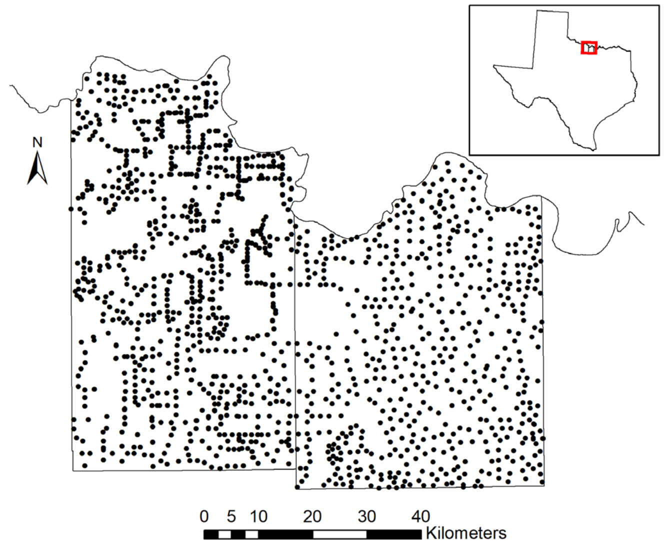


Fig. 1. Data collection points (black dots; 1,213 points) for spring call counts for northern bobwhite (*Colinus virginianus*) in (left) Clay County and (right) Montague County, Texas, USA, 2014–2017. Inset shows extent of main map.

Call counts were conducted by trained field technicians. Technicians lacking experience trained with experienced observers in the field for ≥1 day. Technicians were assigned a predetermined region each day and provided with a pen, clip board with data collection sheets, hand-held global positioning system (GPSMAP® 64st; Garmin Ltd., Olathe, KS, USA) with coordinates of each DCP preloaded, and pocket weather meter (Kestrel 3500, Nielsen-Kellerman, Boothwyn, PA, USA).

To reliably detect trends, point counts require an estimate of detection probability (Anderson 2003, Engeman 2003, Johnson 2008). Counts are often performed in conjunction with distance sampling theory to produce this estimate. However, assumptions of distance sampling are regularly violated. For example, not all occurrences at the point are detected (Alldredge et al. 2008, Applegate et al. 2011, Murray et al. 2011). During spring call counts, only males are recorded, so sex ratios remain unknown (Applegate et al. 2011). Even experienced observers have difficulty assigning a correct distance to observations (Alldredge et al. 2008, Murray et al. 2011), a violation that could be exacerbated with technicians unfamiliar with the study area (Wellendorf and Palmer 2005). Multiple observers can also be used to estimate detection probability (Rosenstock et al. 2002, Thomas et al. 2010). Data for unreconciled double observer counts (Riddle et al. 2010*a*) were collected either by technicians during their second day of training, or when the number of technicians exceeded the number of available vehicles.

Beginning at sunrise, technicians recorded approximate distance and direction of each male bobwhite heard during a 5-minute listening period before continuing to the next DCP. Technicians were instructed to avoid nearby obstructions and to move about 20 m from any vehicle before recording to reduce interference from the vehicle (Rosene 1957). Immediately

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before or after the call count, local weather conditions were recorded at each DCP using the pocket weather meter, including temperature, dewpoint, relative humidity, wind speed, and barometric pressure. Cloud cover percentage was estimated visually (Wellendorf and Palmer 2005). Counts were discontinued when local wind speeds exceeded 16 km/hour (Hansen and Guthery 2001). Call counts were conducted regardless of cloud cover, but call counts were not conducted during rainfall.

To standardize counts for statistical analysis, calendar dates were converted to ordinal dates. Local sunrise times could vary by as much as 5 minutes between 2 DCPs 1.6 km apart. For purpose of analysis, "sunrise" was standardized to sunrise time at the Clay County Courthouse in Henrietta for Clay County DCPs and at the Montague County Courthouse in Montague for Montague County DCPs. Count times were converted to the number of minutes after sunrise that the 5-minute data collection period began.

Ambient sound can also affect point call counts (Simons et al. 2009). Accordingly, technicians were equipped with a hand-held sound meter (SD-200, 3M Co., Two Harbors, MN, USA), mounted on a 152-cm tripod adjusted to the technician's head height, beginning in May 2017. Sound levels were measured during the entire 5-minute call count. The sound meter could measure sound levels either A- or C-weighted, but minimum, maximum, and average sound levels were recorded in dB(A) on the data sheet since A-weighted is considered a better approximation of loudness levels for human hearing (Fletcher and Munson 1933).

For all months with >50 data points, monthly call count medians were compared with Palmer Drought Severity Index (PDSI; Palmer 1965) values for the Clay County region (NOAA National Centers for Environmental Information 2018). The PDSI uses temperature and precipitation data to estimate relative dryness, ranging from -4 (extreme drought) to +4 (extremely moist).

Statistical analyses were performed using SPSS (version 27.0.0.0, IBM, Endicott, NY, USA). Data were not normally distributed and best fitted an over-dispersed Poisson distribution. Transformation of count data is not recommended in most cases and can result in inconsistent coefficient estimates (O'Hara and Kotze 2010, St-Pierre et al. 2018). Correlations between the independent variables and the number of male bobwhites recorded per DCP were first examined using Spearman's rank correlation (Zar 1996). We used negative binomial regression with the log-link function to generate linear models (Hilbe 2011). Fit was compared using the Akaike Information Criterion (AIC). Model coefficient significance was evaluated using the t-statistic (within model) or Wald test (between models).The most important model components were used to generate regression models by year. Models were fitted using the least squares method. Model types (linear, quadratic, cubic) were chosen based on coefficient significance. Since data were not collected in Montague County 2014–2015, statistical comparisons between years were made using Clay County data only. We grouped call counts into 30-minute groups based on time since sunrise to aid in evaluating resource allocation decisions though this grouping was not biologically relevant. Groups were compared using Mann–Whitney *U* (2 groups) or Kruskal-Wallis (>2 groups) tests with Bonferroni correction (Cabin and Mitchell 2000). Decisions regarding negative binomial model fit were made at $\Delta AIC > 2.5$ for sample sizes >246 (Hilbe 2011). Statistical decisions were made at $\alpha = 0.05$.

Detection probability ($p_d$) analysis was performed using the unreconciled double observer method (Riddle et al. 2010*a*). Analysis was performed with Program PRESENCE, version 2.12.9 (U.S. Geological Survey, Patuxent, MD, USA), assuming variable site abundance and detection probability.

## RESULTS

Of 4,497 spring call counts conducted at 1,213 DCPs in Clay (2014–2017) and Montague (2016–2017) counties, Texas, 4,438 were included in this study, with 59 censored for missing or illegible data. Median number of male bobwhites per DCP was 2 (minimum [min] = 0, interquartile range [IQR] = 2–4, maximum [max] = 16) with data from both counties combined. Median number of males recorded per DCP for Clay County was 2 (min = 0, IQR = 3–5, max = 16) and 0 (min = 0, IQR = 0–1, max = 14) for Montague County (Figure 2), across all years.

By year, median number of male bobwhites recorded per DCP in Clay County was 2 (min = 0, IQR = 0–4, max = 11) in 2014, 3 (min = 0, IQR = 1–5, max = 16) in 2015, 3 (min = 1, IQR = 0–5, max = 16) in 2016, and 3 (min = 0, IQR = 0–5, max = 15) in 2017 (Figure 3a).

Median number of male bobwhites recorded per DCP in Montague County was 0 (min = 0, IQR = 0–1, max = 11) in 2016, and 0 (min = 0, IQR = 0–1, max = 14) in 2017 (Figure 3b).

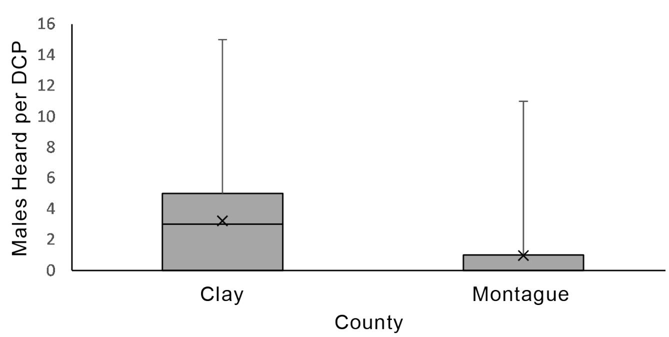


Fig. 2. Box-and-whiskers plot of male bobwhite (*Colinus virginianus*) calls recorded at data collection points during spring call counts in Clay and Montague counties, Texas, USA, 2014–2017. Crosses indicate means.

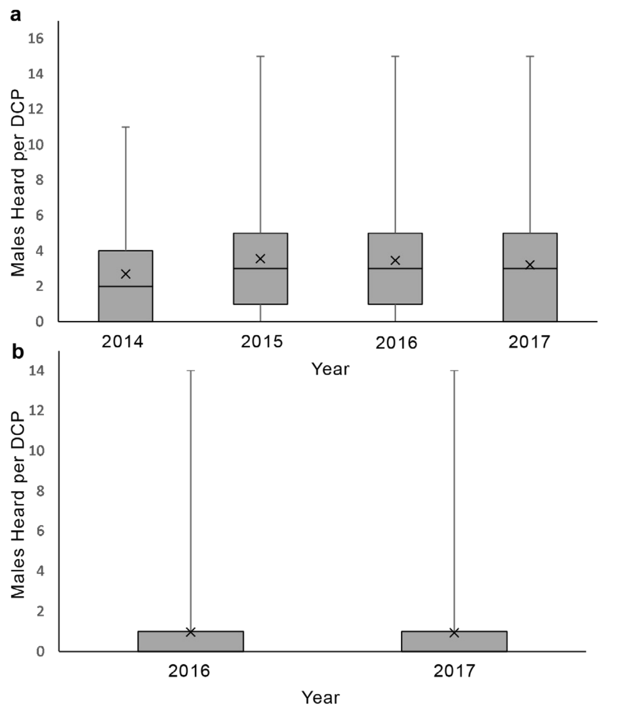


Fig. 3. Box-and-whiskers plots of male bobwhite (*Colinus virginianus*) calls recorded at data collection points during spring call counts in a) Clay County, Texas, USA, 2014–2017, and b) Montague County, Texas, 2016–2017. Crosses indicate means.

## Spearman's Rank Correlations

Relative humidity (ρ =0.275, $p < 0.001$, $N = 3{,}767$) and temperature (ρ =-0.252, $P < 0.001$, $N = 3{,}821$) had the highest correlation with the number of males calling during spring call counts, with data from all years and DCPs combined (Table 2). There were smaller negative correlations with time since sunrise (ρ = -0.200, $P < 0.001$, $N = 4{,}211$), and dewpoint temperature (ρ = -0.119, $P < 0.001$ $N = 3{,}643$), and a small positive correlation with cloud cover (ρ = 0.174, $P < 0.001$ $N = 3{,}638$). Of the 4,438 datasheets analyzed, approximately 860 had ≥1 weather variable missing for various reasons (e.g., weather meter battery failure); thus, n values differ among analyzed factors.

Correlations between temperature, relative humidity, cloud cover, and time of day with number of male bobwhites recorded were consistent in direction (positive or negative) from year to year, but varied in magnitude (Table 2). Cloud cover was positively correlated with number of male bobwhites recorded 2015–2017. There was no correlation between barometric pressure and number of male bobwhites recorded per DCP in 2014 ($P = 0.133$), but there were positive correlations for 2015–2017 (ρ = 0.075, $P = 0.031$; ρ = 0.064, $P = 0.020$; ρ = 0.120, $P = 0.001$, respectively). There was no correlation with wind speed and number of male bobwhites recorded in 3 of 4 years, and a negative correlation (ρ = -0.079, $P = 0.024$) in 2015.

Table 2. Spearman's rank correlation coefficient (ρ) for number of male northern bobwhites (*Colinus virginianus*) heard by year vs. recorded temporal and meteorological variables in Clay and Montague counties, Texas, USA, May–July 2014–2017. Date = Julian date; Time = number of minutes after estimated sunrise; Temp = temperature (ºC); RH = relative humidity (%), DP = dewpoint temperature (ºC); Wind = wind speed (m/second); BP = barometric pressure (mbar); Cloud = cloud cover (%).

| Year | | Date | Time | Temp | RH | DP | Wind | BP | Cloud |
|---|---|---|---|---|---|---|---|---|---|
| 2014[a] | ρ | 0.031 | -0.169 | -0.259 | 0.204 | - | -0.044 | -0.157 | - |
| | *p* | 0.406 | <0.001 | 0.001 | 0.028 | - | 0.431 | 0.133 | - |
| | *N* | 702 | 581 | 172 | 116 | 0 | 321 | 93 | 0 |
| 2015 | ρ | -0.022 | -0.299 | -0.232 | 0.216 | -0.112 | -0.079 | 0.075 | 0.132 |
| | *p* | 0.549 | <0.001 | <0.001 | <0.001 | 0.001 | 0.024 | 0.031 | <0.001 |
| | *N* | 760 | 825 | 820 | 820 | 819 | 821 | 820 | 815 |
| 2016 | ρ | -0.270 | -0.275 | -0.378 | 0.283 | -0.231 | -0.023 | 0.064 | 0.294 |
| | *p* | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.397 | 0.020 | <0.001 |
| | *N* | 1337 | 1332 | 1330 | 1329 | 1328 | 1329 | 1325 | 1316 |
| 2017 | ρ | 0.079 | -0.207 | -0.131 | 0.258 | -0.026 | -0.041 | 0.120 | 0.107 |
| | *p* | 0.002 | <0.001 | <0.001 | <0.001 | 0.307 | 0.110 | <0.001 | <0.001 |
| | *N* | 1553 | 1543 | 1499 | 1499 | 1496 | 1508 | 1459 | 1507 |
| All years | ρ | -0.093 | -0.200 | -0.252 | 0.275 | -0.119 | -0.036 | -0.111 | 0.174 |
| | *p* | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.25 | <0.001 | <0.001 |
| | *N* | 4352 | 4281 | 3821 | 3767 | 3643 | 3979 | 3697 | 3638 |

[a] Dewpoint and cloud cover not recorded in 2014

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## Regression Models

The distribution parameter for negative binomial regression was 1.51. Log relative humidity (B = 0.003, $P < 0.001$), time (in minutes) since sunrise (B = -0.005, $P < 0.001$), and log temperature (B = -0.071, $P < 0.001$) had the best single-factor fit with the number of males calling during spring call counts when data from all years were combined (Table 3). Other significant factors were ordinal date (B = -0.007, $P < 0.001$), wind speed in m/second (B = -0.061, $P = 0.004$), and barometric pressure in mbar (B = -0.022, $P < 0.001$). Independent variables producing the most relevant multifactor models were, in decreasing order of explanatory power, relative humidity, temperature, wind speed, time since sunrise, and barometric pressure. The 5-factor model did not improve upon the 4-factor model.

When call count data were separated by year, relationships between the numbers of male bobwhites recorded and log temperature, log relative humidity, log time since sunrise, log ordinal date, and log wind speed were not different in 3 of the 4 study years (Table 4). The 95% confidence interval [CI] for slope included zero for relative humidity in 2014, temperature in 2016, and time since sunrise in 2017. The 95% CIs for slope for ordinal date and wind speed included zero in years 2014–2016 and were negative in 2017.

There was no difference in the relationship between log relative humidity and number of male bobwhites recorded in 2014, 2016, and 2017, but the slope of increase in number of male bobwhites heard at higher relative humidity (Figure 4) was lower in 2015 (Wald $\chi^2 = 15.4$, $P < 0.001$). The number of male bobwhites heard declined more as temperature increased in 2014 than in the other 3 years (Figure 5), and less in 2015 (Wald $\chi^2 = 13.4, 26.7$, $P < 0.001$). All 4 years showed a decline in number of male bobwhites heard over 3 hours (Figure 6), but the curve for 2015 was steeper (Wald $\chi^2 = 41.5$, $P < 0.001$) than in 2014, 2016, and 2017.

## Palmer Drought Severity Index

A nearly 5-year North Texas drought ended early in 2015 (Shaw 2015, National Weather Service Forecast Office 2018). There was a small correlation between number of male bobwhites recorded and PDSI for Clay County 2014–2017 ($\rho = 0.087$, $P < 0.001$), but this correlation was not present ($P =$

Table 3. Selected log link (y = a + b*log[x]) negative binomial regression models for number of male northern bobwhites (*Colinus virginianus*) heard by year vs. temporal and weather variables recorded May–July 2014–2017 in Clay and Montague counties, Texas, USA. All significant single-factor models are shown along with the best-fitting 2,-, 3-, 4-, and 5-factor models. A lower ΔAkaike Information Criterion (ΔAIC) indicates a better model fit. Distribution parameter = 1.51; CI = confidence interval; RH = relative humidity (%); Time = number of minutes after sunrise; Temp = temperature (ºC); Date = ordinal date; ; Wind = wind speed (m/second); Cloud = cloud cover (%); BP = barometric pressure (mbar).

| Model | B | 95% CI | *P* | K | AIC | ΔAIC |
|---|---|---|---|---|---|---|
| RH | 0.033 | 0.005 | <0.001 | 3 | 15371.668 | 80.057 |
| Time | -0.005 | 0.001 | <0.001 | 3 | 15396.806 | 105.195 |
| Temp | -0.071 | 0.013 | <0.001 | 3 | 15419.594 | 127.983 |
| Date | -0.007 | 0.003 | <0.001 | 3 | 15519.887 | 228.276 |
| Wind | -0.061 | 0.04 | 0.004 | 3 | 15529.537 | 237.926 |
| Cloud | 0.005 | 0.001 | <0.001 | 3 | 15530.118 | 238.507 |
| BP | 0.022 | 0.09 | <0.001 | 3 | 15530.989 | 239.378 |
| Intercept only | 0.957 | 0.45 | <0.001 | 2 | 15535.875 | 244.264 |
| Temp | -0.041 | 0.015 | <0.001 | 4 | 15340.832 | 49.221 |
| RH | 0.026 | 0.006 | <0.001 | | | |
| Temp | -0.027 | 0.006 | <0.001 | 5 | 15326.669 | 35.058 |
| RH | -0.042 | 0.014 | <0.001 | | | |
| Time | -0.085 | 0.04 | <0.001 | | | |
| RH | 0.022 | 0.005 | <0.001 | 6 | 15292.915 | 1.304 |
| Temp | -0.029 | 0.007 | <0.001 | | | |
| Time | -0.024 | 0.011 | <0.001 | | | |
| Wind | -0.004 | 0.003 | 0.047 | | | |
| RH | 0.023 | 0.006 | <0.001 | 7 | 15291.611 | 0 |
| Temp | -0.019 | 0.019 | 0.035 | | | |
| Time | -0.05 | 0.044 | <0.001 | | | |
| Wind | -0.003 | 0.001 | 0.025 | | | |
| Date | -0.004 | 0.004 | 0.049 | | | |

Table 4. Selected log link (y = a + b*log[x]) negative binomial regression models for the number of male northern bobwhites (*Colinus virginianus*) heard during 2014–2017 vs. relative humidity (%), ambient temperature (°C), ordinal date, number of minutes after sunrise that the call counting period began, and wind speed (m/second). CI = confidence interval.

| Year | B[a] | 95% CI | Wald $\chi^2$ | DF | P |
|---|---|---|---|---|---|
| Relative humidity | | | | | |
| 2014 | 0.018 | ±0.027 | 1.674 | 1 | 0.196 |
| 2015 | 0.024 | ±0.011 | 18.904 | 1 | <0.001 |
| 2016 | 0.016 | ±0.012 | 7.128 | 1 | 0.008 |
| 2017 | 0.026 | ±0.010 | 23.608 | 1 | <0.001 |
| Temperature | | | | | |
| 2014 | -0.071 | ±0.061 | 5.085 | 1 | 0.024 |
| 2015 | -0.052 | ±0.026 | 15.251 | 1 | <0.001 |
| 2016 | -0.013 | ±0.026 | 0.9 | 1 | 0.343 |
| 2017 | -0.099 | ±0.031 | 40.579 | 1 | <0.001 |
| Ordinal date | | | | | |
| 2014 | 0.001 | -0.007 | 0.138 | 1 | 0.711 |
| 2015 | 0.005 | -0.008 | 1.379 | 1 | 0.24 |
| 2016 | 0.006 | -0.006 | 2.639 | 1 | 0.104 |
| 2017 | -0.012 | -0.006 | 14.605 | 1 | <0.001 |
| Minutes after sunrise | | | | | |
| 2014 | -0.003 | -0.002 | 8.161 | 1 | 0.004 |
| 2015 | -0.006 | -0.002 | 32.423 | 1 | <.001 |
| 2016 | -0.005 | -0.002 | 24.807 | 1 | <.001 |
| 2017 | -0.000005 | -0.00002 | 0.198 | 1 | 0.656 |
| Wind speed | | | | | |
| 2014 | -0.054 | -0.11 | 0.907 | 1 | 0.341 |
| 2015 | -0.084 | -0.089 | 3.472 | 1 | 0.062 |
| 2016 | -0.039 | -0.093 | 0.698 | 1 | 0.404 |
| 2017 | -0.091 | -0.079 | 5.011 | 1 | 0.025 |

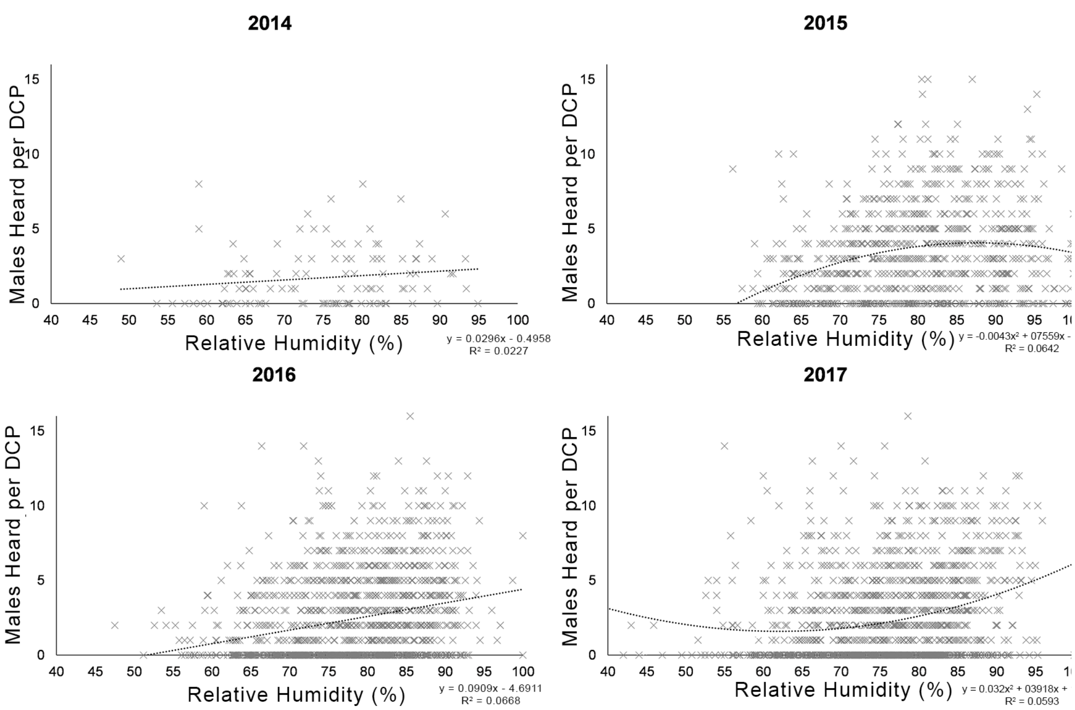


Fig. 4. Scatterplot (crosses) of number of male bobwhite (*Colinus virginianus*) calls recorded at each data collection point by relative humidity during spring call counts in Clay and Montague counties, Texas, USA, 2014–2017. Dashed line indicates line of best fit. All parameter coefficients were significant at $P < 0.001$.

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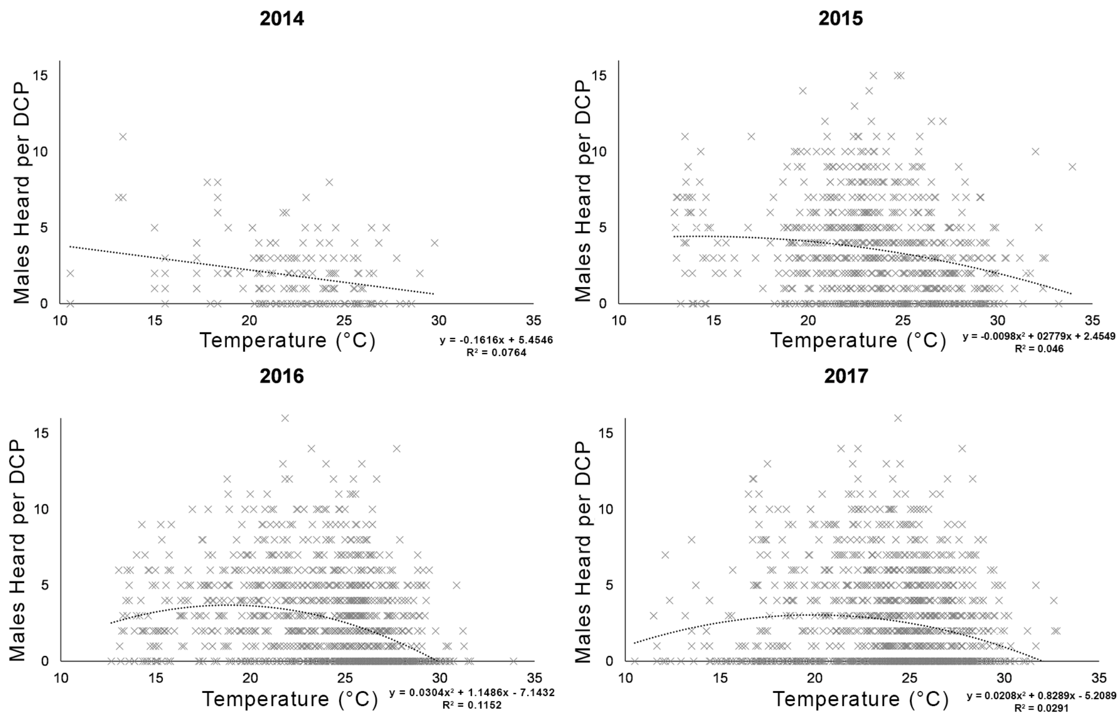


Fig. 5. Scatterplot (crosses) of number of male bobwhite (*Colinus virginianus*) calls recorded at each data collection point by ambient temperature during spring call counts in Clay and Montague counties, Texas, USA, 2014–2017. Dashed line indicates line of best fit. All parameter coefficients were significant at $P < 0.001$.

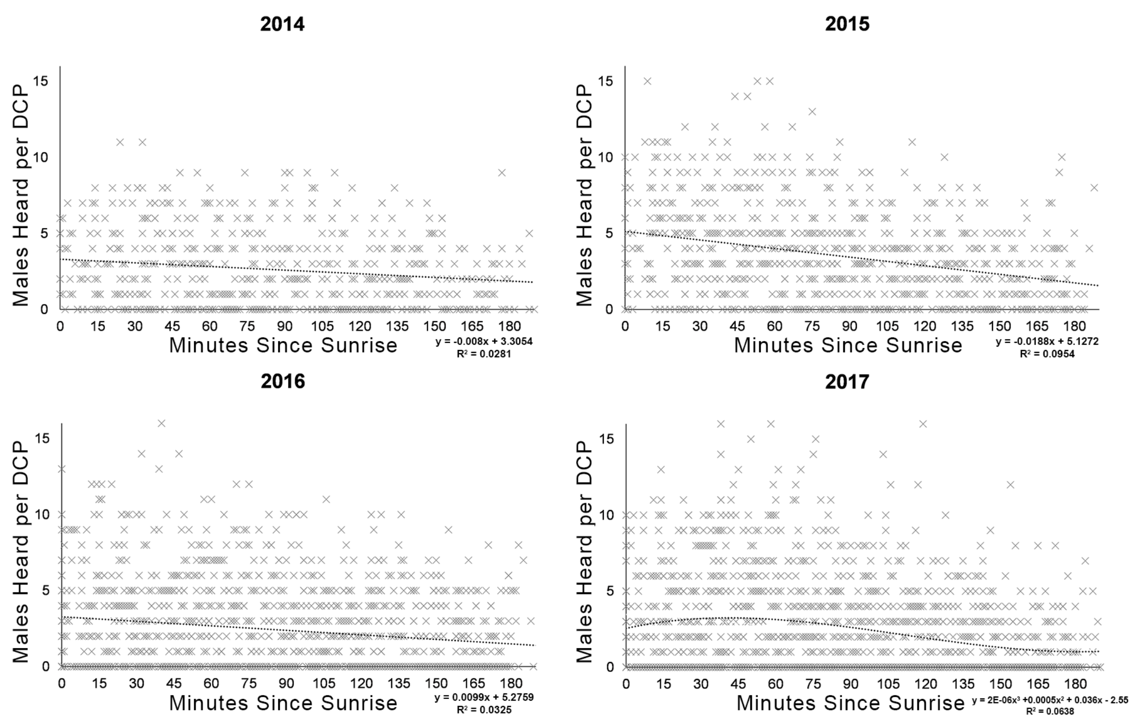


Fig. 6. Scatterplot (crosses) of number of male bobwhite (*Colinus virginianus*) calls recorded at each data collection point (DCP) by number of minutes after sunrise that the counting period began for spring call counts in Clay and Montague counties, Texas, USA, 2014–2017. Dashed line indicates line of best fit. All parameter coefficients were significant at $P < 0.001$.

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0.13) when including call count data for Montague County (2016–2017). In Clay County, fewer male bobwhites per DCP were recorded in the drought year of 2014 (median = 2, min = 0, IQR = 1–3, max = 11) than in subsequent years (median = 3, min = 0, IQR = 1–5, max = 15).

### Ambient Noise

Ambient sound levels were recorded 905 times at DCPs during 2017. Minimum levels ranged from 43–91.2 dB(A) minimum, 43–95.5 dB(A) mean, and 43–102 dB(A) maximum. There was a negative correlation between number of male bobwhites recorded and minimum ($\rho$ = -0.165, $P$ < 0.001, N = 905), mean ($\rho$ = -0.098, $P$ = 0.004, N = 886), and maximum ($\rho$ = -0.11, $P$ = 0.004, N = 756) ambient noise levels. However, there was no significant relationship between the number of male bobwhites recorded and log minimum ($P$ = 0.223), log mean ($P$ = 0.282), or log maximum ($P$ = 0.457) sound levels, as the 95% CI for slope included zero.

### Detection Probabilities

Using the unreconciled double observer method (Riddle et al. 2010*a*) on 558 sites, $p_d$ was calculated to be 0.82.

## DISCUSSION

We conducted a large-scale examination of relationships between meteorological, temporal, and other variables and the number of male bobwhites heard calling. Key findings were that the number of males recorded calling decreased ≥120 minutes after sunrise, decreased as temperature increased, and increased with relative humidity and cloud cover. There was no correlation between wind speed and the number of males recorded overall, or during individual years, except during 2017. However, larger numbers (>10) of males were recorded disproportionately when wind speed was too low to measure ($\chi^2$ = 5.374, DF = 1, $P$ = 0.020). We did not see a peak in calling activity. The number of males recorded did not increase or decrease during the study period (May–Jul) for 2014–2016, or when all years were pooled, but decreased slightly during 2017 (B = 0.018 ± 0.006, $P$ < 0.001).

There is strong agreement among published studies that the number of bobwhites calling peaks by about 1 hour after sunrise, though day-to-day variations are common. The median number of male bobwhites recorded in this study did not decrease until ≥120 minutes (Figure 7). Based on our results, 90 minutes after sunrise is sufficient for fairly consistent results, and study length should not exceed 120 minutes after sunrise.

An assumption that temperature is a major factor in the relationships between weather variables and number of male bobwhites recorded would be reasonable. The timing of bobwhite reproduction in our study area may be an adaptation to avoid harsher conditions of mid- to late summer (Guthery et al. 1988). A link between drought and bobwhite population declines in semiarid regions has long been hypothesized (Henika 1947, Jackson 1951, Robinson and Baker 1955, Reyna and Burggren 2017, Reyna 2019). While bobwhite mortality during drought does not appear to increase significantly, bobwhite population numbers tend to decrease during drought years (Stoddard 1931, Robinson and Baker 1955, Jackson 1962, Reyna et al. 2012). Drought or high temperature reduces bobwhite calling activity and shortens the bobwhite breeding season (Guthery et al. 1988, 2000; Reyna et al. 2012). The decrease in reproductive effort may be due to interruption of reproductive hormone cycles caused by heat stress (Cain and Lien 1985, Guthery et al. 1988, Giuliano et al. 1998), thus reducing calling behavior.

It is unclear why relative humidity was more strongly correlated with the number of bobwhites recorded than temperature when the opposite is more common in the literature. This may reflect a greater relative importance of

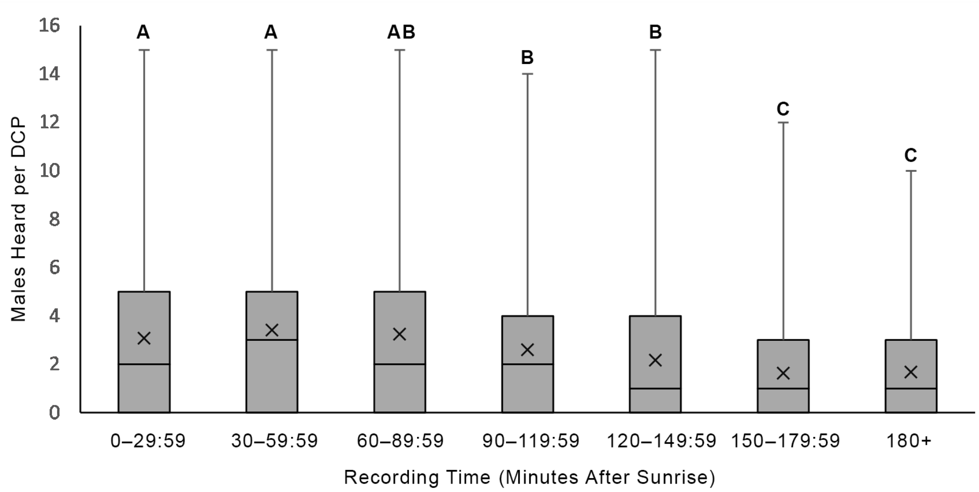


Fig. 7. Number of male bobwhites (*Colinus virginianus*) recorded at data collection points for each 30-minute period after sunrise during spring call counts in Clay and Montague counties, Texas, USA, 2014–2017. Crosses indicate means; letters indicate statistical grouping.

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moisture to quail in semiarid rangeland (Guthery 1999), as all previous studies except Hansen and Guthery (2001) were conducted in more humid subtropical continental regions (Kottek et al. 2006). More calling activity and juvenile production have been observed in years with more moisture and less heat as compared to more hot and dry conditions (Bridges et al. 2001, Reyna et al. 2012). Alternatively, relative humidity may be functioning as a proxy for temperature in our analysis as air temperature and relative humidity are inversely related (Eagleman 1985).

Covariance between the multiple individual independent variables confounds more precise determination of how independent variables relate to the number of male bobwhite calls heard. Curiously, except for a brief statement linking light intensity and temperature to the time of day (Hansen and Guthery 2001), these relationships have not been previously addressed. Air temperature and wind speed tend to increase after sunrise. Morning cloud cover and relative humidity decrease as air temperature rises (Eagleman 1985). Air temperature tends to increase with ordinal date through May, June, and July in the bobwhite's range, due primarily to increased insolation (Eagleman 1985, Arguez et al. 2011). With the exception of dewpoint and barometric pressure, which are largely independent of temperature, correlations between weather variables and the number of male bobwhites recorded per DCP cannot be completely differentiated from an increase in temperature over the course of a morning.

## Regression Models

Unsurprisingly, the independent variables with the highest correlation with the number of male bobwhites recorded had the best fit in negative binomial regression models. However, variables with low or marginally significant correlation (e.g., wind speed and ordinal date) produced improved models. One caveat when dealing with large (>1,000) sample sizes is overparameterization of regression models (Heckmann et al. 2014), which can produce a model that is highly accurate in describing the data that generated it but performs poorly elsewhere. Overparameterization is unlikely here, as our negative binomial regression model saw no improvement with >4 independent variables. However, caution should be given when using coefficients generated here, as they are unlikely to apply universally to spring bobwhite call counts, and their calculated values coefficients are less important than their direction (positive or negative) and their magnitude relative to each other.

We saw no major differences in the relationship between number of male bobwhites recorded and relative humidity, ambient temperature, or the number of minutes after sunrise. When comparing number of male bobwhites heard with log relative humidity, we noted that the negative coefficient for $x^2$ for 2015 stands out (Figure 4), but it may be an artifact of the lack of lower relative humidity readings that year. Spring and summer rains were unusually heavy in the study area during 2015 and <1% of call counts had relative humidity measurements <60%, with none <55%.

## Ambient Noise

The most common source of measurable ambient noise in Clay County (other than technician movements) was vehicular traffic, most notably at DCPs near U.S. Highways 82 and 287. In Montague County, the most common source of ambient noise was natural gas compressor stations. The number of male bobwhites recorded did not appear to vary with recorded sound levels. High numbers of birds (≥10) were recorded only at DCPs with minimum ambient noise levels ≤43 dB(A), but this result was not significant ($\chi^2$ = 2.10, DF = 1, $P$ = 0.15). The volume of bobwhite calls has been estimated at approximately 100 dB (Rusk et al. 2009) and the audibility radius from <500 m (Bennitt 1951) to 900 m (Rusk et al. 2009), depending on wind, atmospheric conditions, and terrain. Ambient sound capable of masking faint bobwhite calls was clearly audible at ≤43 dB(A), the lower limit for our sound meters. It seems intuitively clear that ambient noise may interfere with detecting the faintest bobwhites, most likely when the noise level is greater than the detected sound level of the quail, but more data are needed to determine to what degree and at what sound intensity this occurs. For future studies involving ambient sound and bird calls, we recommend a more sensitive sound meter.

## Detection Probabilities

Our calculated $p_d$ of 0.82 was consistent with the 0.69–0.84 estimated by Murray et al. (2011) and the 0.80–0.90 given by Riddle et al. (2010b).

## Challenges

There are numerous critiques of point call counts and spring call counts for bobwhites in particular. The most well-founded critiques are those regarding indices in general (Anderson 2001, 2003). There are also critiques specific to spring call counts, primarily discrepancies between count results and fall quail populations or hunter harvest (Rosene 1957, Norton et al. 1961, Reyna et al. 2012, Sisson and Terhune 2017, Kubečka et al. 2019).

One of the difficulties with spring call counts is that researchers are attempting to produce long-term regional population information by collecting data at microscales (Hernández 2020). This problem may be compounded by other microscale effects, such as weather, noise levels, and the dates on which the data are collected.

Another difficulty is that spring call counts, while conducted at a time of biological significance, are valued primarily for their ability to predict populations during a time of economic significance, the hunting season. This predictive value ranges from near zero (Labisky and Preno 1971), to useful but not necessarily reliable (Rosene 1957, Norton et al. 1961, Schwartz 1974), to very high (Curtis et al. 1989). Correlation between spring call counts and fall harvest is often lower in semiarid regions than humid subtropical regions. In the Great Plains, it is stronger during non-drought years (Bennitt 1943, Reyna et al. 2012, Sisson and Terhune 2017).

Bennit (1951) found a correlation between whistle counts and the percentage of adult male birds in the hunter's bag, but there does not seem to be a clear correlation between spring call counts and fall age ratios (Kabat and Thompson 1963, Schwartz 1974). Spring call counts represent, at best, an index of breeding potential. Spring call counts cannot indicate how successful the breeding season—and by extension, the fall hunting season—will be.

There is also a spatial component to the difficulty of using spring call counts to predict fall hunting success. Though bobwhites do not migrate, winter habitat is different from breeding season habitat. Bobwhites disperse into different habitat between spring call counts and autumn (Murphy and Baskett 1952, Urban 1972, Townsend et al. 2003), with the greatest movements in more fragmented landscapes (Fies et al. 2002). This behavior suggests why index values constructed closer to harvest time, or on larger scales, are considered more accurate predictors of the fall population abundance (Kozicky et al. 1956, Rosene 1957, Kubečka et al. 2019). It is difficult to describe variation in call counts in terms of any single factor or group of factors. While even the most influential of weather conditions here produced a Spearman's rank correlation coefficient of <0.3, it is sufficient that protocols for spring call counts should include recording weather conditions at both the time and location of each point count. These correlations can be highly variable, but could also be region-specific.

Sisson and Terhune (2017) recommended that breeding season counts be conducted at the peak of calling activity. This may be logistically unfeasible for large-scale surveys and is complicated by the variability in peak bobwhite calling activity from year to year, ranging from May (Terhune et al. 2006) to late July (Robel et al. 1969). Even in a single location, breeding season peak timing can vary by as much as 2 months in consecutive years (Hansen and Guthery 2001). Additionally, one of the predicted effects of climate change is that breeding season will begin earlier in the year (Crick and Sparks 1999, Marra et al. 2005), requiring a corresponding change in the timing of call counts. Our data do not suggest a peak time for call counts in our study area. We recommend that replicate call counts be spaced out over the breeding season to increase the likelihood of listening during the breeding season peak. For North Texas, this study suggests beginning before 15 May.

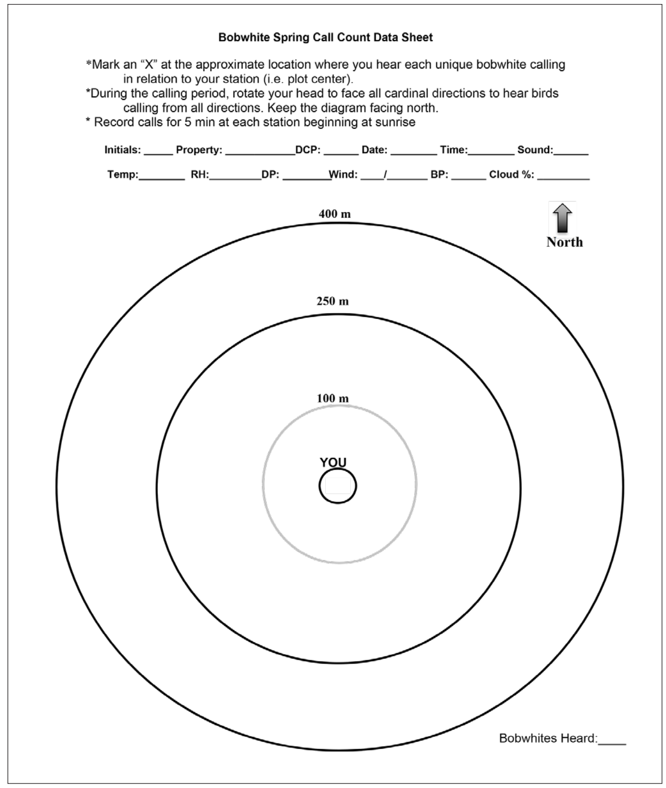


Fig. 8. Example data sheet for recording bobwhite spring call counts. Initials = technician initials; property = ranch name (if applicable); DCP = Data Collection Point number (if applicable); Date = calendar date; Time = clock time; Temp = ambient temperature in ºC; RH = relative humidity (%); DP = dewpoint temperature (ºC); Wind = wind speed in km/hour and direction; BP = barometric pressure (mbar); Cloud = cloud cover (%).

## MANAGEMENT IMPLICATIONS

The results of this study suggest a few key considerations when conducting spring call counts for northern bobwhites. First, we recommend using a data sheet with blanks for each variable (Figure 8) to facilitate consistency in data collection. Recording meteorological, temporal, and sound variables can help clarify variation in annual spring call counts recorded. Second, we recommend conducting call counts <120 minutes after sunrise. Because it was proscribed by our protocol, we have limited data on call counts at wind speeds >16 km/hour. However, we see little evidence either from our data or in the literature, that call counts should be prohibited above certain cloud cover percentages or at wind speeds <16 km/hour. We recommend such restrictions be removed from spring call count protocols, at least for those on semiarid rangeland.

Quail management, research, and conservation require an accurate assessment of population numbers to aid decision making and to evaluate the results of those decisions. With climate change predicted to have major impacts on the bobwhite's range (Wilsey et al. 2019, Strauss et al. 2021), there is an increasing need to assess and monitor bobwhite populations. Population censuses often involve tradeoffs between accuracy and the amount of resources required (Rusk et al. 2007, Kubečka et al. 2019). Researchers have addressed this limitation by either resorting to the use of indices (e.g., morning covey-call surveys. Spring call counts are a relatively low-cost census method for bobwhites and can be useful in assessing long-term trends as long as deficiencies inherent in point counts are mitigated. Incorporating recommendations from this study into spring call count protocols could help managers more accurately assess bobwhite population numbers.

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