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Ornithological Methods

Comparing and combining use of autonomous recording units and traditional counts to monitor Northern Bobwhite

Comparación y combinación del uso de unidades de registro autónomas y conteos tradicionales para monitorear a *Colinus virginianus*

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ABSTRACT. We examined the use of autonomous recording units for monitoring Northern Bobwhite (*Colinus virginianus*) in South Carolina and compared results with those of traditional point count surveys conducted simultaneously at overlapping points. We assessed seasonal patterns and quail encounter rates for traditional and recorded surveys and used random forest modeling to determine which location and survey-based variables are most important. We found both survey methods have similar encounter rates, but seasonal occupancy rates are significantly higher when the more extensive automated recording data are used. Both survey methods indicate that location-based variables are most important to encounter rate, and both adequately account for survey detectability, but the use of recordings reduces survey bias. The autonomous recording method also permits an increase in survey and season length without increasing the labor necessary for monitoring. Both survey methods indicate a peak encounter rate in June consistent with the current protocols and with similar studies in nearby regions. The use of recordings, however, allows for extensive tracking of seasonal patterns and would be beneficial for long-term monitoring. Overall, traditional methods are more conducive to abundance surveys, whereas recordings are more appropriate for occupancy or encounter rate studies. We suggest a combination of both point count and autonomous recording methods as a feasible way to expand and improve monitoring of bobwhite populations.

RESUMEN. Examinamos el uso de unidades de registro autónomas para monitorear a la especie *Colinus virginianus* en Carolina del Sur y comparamos los resultados con los monitoreos tradicionales de puntos de conteo realizados simultáneamente en puntos que se sobreponen. Evaluamos los patrones estacionales y las tasas de encuentro de codornices para censos tradicionales y muestreos grabados y utilizamos modelos forestales aleatorios para determinar cuáles ubicaciones y variables basadas en los muestreos son más importantes. Descubrimos que ambos métodos de muestreo tienen tasas de encuentro similares, pero las tasas de ocupación estacional son significativamente más altas cuando se utilizan datos de registros automatizados más extensos. Ambos métodos de muestreo indican que las variables basadas en la ubicación son las más importantes para las tasas de encuentro, y ambos explican adecuadamente la detectabilidad durante los muestreos, pero el uso de grabaciones reduce el sesgo de la encuesta. El método de registro automático también permite aumentar el muestreo y de la duración de la temporada sin aumentar la mano de obra necesaria para el seguimiento. Ambos métodos de muestreo indican una tasa máxima de encuentro en junio consistente con los protocolos actuales y con estudios similares en regiones cercanas. Sin embargo, el uso de grabaciones permite un seguimiento exhaustivo de los patrones estacionales y sería beneficioso para el seguimiento a largo plazo. En general, los métodos tradicionales son más propicios para los estudios de abundancia, mientras que las grabaciones son más apropiadas para estudios de ocupación o tasas de encuentro. Sugerimos una combinación de métodos de ambos, puntos de conteo y registro autónomo, como una forma factible de ampliar y mejorar el seguimiento de las poblaciones de codornices.

Key Words: *autonomous recording unit; Colinus virginianus; encounter rate; Northern Bobwhite; point count; population monitoring*

INTRODUCTION

The Northern Bobwhite (*Colinus virginianus*) is both a declining species of concern and a managed game species. Bobwhite decline has progressed for decades and is linked to habitat loss and population fragmentation due to urbanization and changes in agricultural practices (Brennan 1991, Church et al. 1993, Guthery et al. 2000, McKenzie 2009, Hernández et al. 2013). A range-wide adaptive management approach, including research, monitoring, education, and habitat management, is needed to increase populations (Brennan 1991, Palmer et al. 2011, Hernández et al. 2013). In accordance with recommendations from the National Bobwhite Conservation Initiative (NBCI), the South Carolina Department of Natural Resources is collaborating with other states to conduct breeding season monitoring via standardized point counts (Morgan et al. 2016, Chapman et al. 2020). In 2017, we added 14 autonomous recording units (ARUs) to supplement traditional point counts. We predicted that ARU and traditional surveys would produce similar occupancy results and could be an efficient way to expand survey efforts. Here, we provide a comparison of practicality and results using ARU and traditional point count methods. We use this assessment to make recommendations for how each survey technique could improve our ability to monitor bobwhite and other bird populations.

Population monitoring is especially important as it determines effectiveness of restoration and management strategies (Green et al. 2017). Despite improvement in research and monitoring techniques for bobwhite, we still need large-scale methods that can be implemented within an adaptive management strategy (Brennan 2002). Research suggests that the incorporation of

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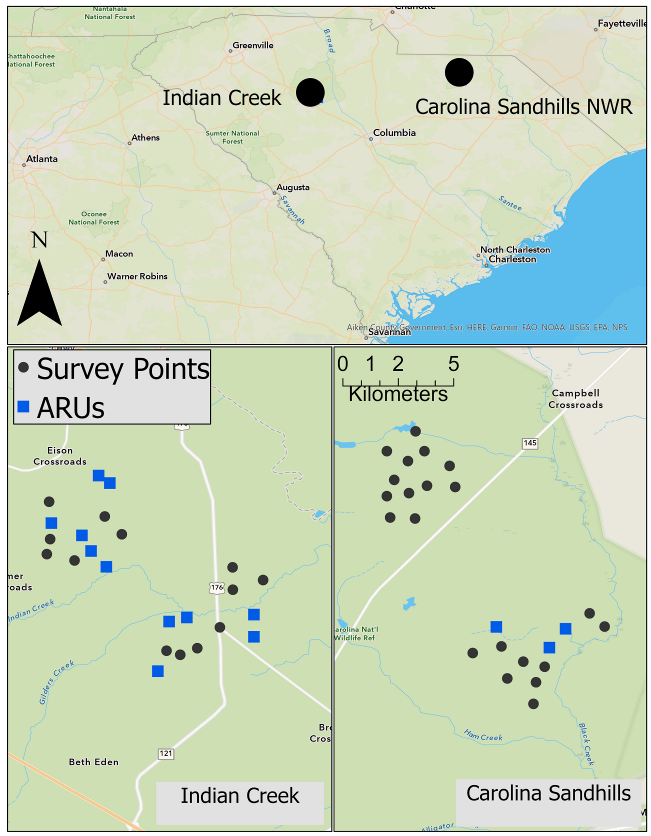
ARUs improves monitoring in situations including rare species, large geographical areas, or shortage of trained surveyors (Borker et al. 2015, Pankratz et al. 2017, Darras et al. 2019, Haselmayer and Quinn 2000).

Traditional monitoring is time consuming and requires technicians to travel to survey sites within a narrow range of dates and times. Variability in observer experience and hearing ability is often ignored (Brewster and Simons 2009, Digby et al. 2013). Recent technological advances have produced ARUs capable of results similar to, or better than, traditional surveys (Digby et al. 2013, Borker et al. 2015, Shonfield and Bayne 2017, Darras et al. 2019). Autonomous recording units can survey multiple points over large areas at the same time. Microphones can be left to record automatically for weeks. Files can be reviewed repeatedly by single or multiple observers to reduce identification errors and observer bias (Celis-Murrilo et al. 2009, Holmes et al. 2014, Darras et al. 2019). Observers can examine recordings and identify calls as quickly and accurately as a real-time survey (Digby et al. 2013, Darras et al. 2019). Furthermore, ongoing research is producing promising programs for automatically detecting bobwhite calls (Nolan et al. 2023).

Autonomous recording unit surveys require specialized equipment and software (Darras et al. 2019, Shonfield and Bayne 2017). They allow for collection of copious audio data, which is challenging to sort and archive (Digby et al. 2013, Darras et al. 2019, Shonfield and Bayne 2017). Individual ARUs cannot determine distance and direction, so it is difficult to estimate bird density or abundance. However, solutions to this problem are being studied (Celis-Murillo et al. 2009, Shonfield and Bayne 2017, van Wilgenburg et al. 2017, Pérez-Granados and Traba 2021). Density of birds per area is the current NBCI recommended metric for bobwhite population estimation (Evans et. al 2011). The utility of occupancy surveys for producing population estimates is under consideration (Evans et al. 2011). However, presence/absence surveys are already helpful in identifying study sites and in tracking changes in habitat use or calling phenology (Evans et al. 2011, Borker et al. 2015, Darras et al. 2019, Furnas and McGrann 2018).

Fig. 1. Location of survey points with and without autonomous recording units (ARUs) in South Carolina, USA during 2017. Points were located at two regional survey sites, Carolina Sandhills National Wildlife Refuge (Carolina Sandhills) and within the Indian Creek Woodland Savanna Restoration Initiative (Indian Creek). Each site had 24 survey points spaced at least 500 m apart. Indian Creek had 11 ARUs, and Carolina Sandhills had three.



METHODS

Autonomous Recorder Surveys

Fourteen Song Meter SM4 Bioacoustics Recorders (Wildlife Acoustics, Inc., Maynard, Massachusetts, USA) were deployed in areas of interest for bobwhite habitat management. Our study sites were at Carolina Sandhills National Wildlife Refuge (Carolina Sandhills) and within the Indian Creek Woodland Savanna Restoration Initiative area (Indian Creek) both located in South Carolina, USA (Fig. 1). Recording took place between 1 April and 31 August 2017. Microphones were located at existing bobwhite survey points. Three microphones were placed at Carolina Sandhills, which is ranked as a NBCI "Tier I" site. A "Tier I" site is a focal area of interest nested within a focal landscape and region, with all levels having appropriate habitat and potential to support a long-term bobwhite population (Morgan et al. 2016). Eleven microphones were placed at Indian Creek, a cooperatively managed area of public and private lands. Indian Creek is ranked as an NBCI "Tier II" site, a focal area nested within a focal landscape or region (Morgan et al. 2016).

Stereo channel recordings were collected using a 24 kHz sampling rate and were saved as .WAV files. We used the unit's internal microphones set to a 16-dB gain (which includes 26 dB of pre-amplification). Autonomous recording units were programmed to start recording at sunrise in 15-min on/off intervals for two consecutive hours. Recording points were visited once to deploy ARUs and once to collect them. We only analyzed data from the interval starting 30 min after sunrise. This is consistent with the timing of traditional point counts and with the time frames determined in other studies to have the most bobwhite calling (Elder 1956, Hansen and Guthery 2001, Lituma 2017). A technician used Raven Pro Interactive Sound Analysis software (available from the Cornell Lab of Ornithology; Bioacoustics Research Program 2017) to identify bobwhite calls by visually scanning for calls and listening to audio to confirm suspected vocalizations. Each call was tagged with its start time. The analyst also ranked the quality of each recording: good recordings were clear with little to no background noise, fair had repetitive noise that did not interfere with spectrograms, and poor had noise that impeded observer ability to detect calls. Identifiable rainfall was ranked as light, moderate, or heavy. For detailed weather information, we used measurements from the Columbia South Carolina Metropolitan Airport, the closest weather station with comprehensive hourly data. The station was 65 km from Indian Creek and 108 km from Carolina Sandhills, so we averaged conditions from an hour before to an hour after recording time. We also examined the correlation of weather station wind and precipitation data with recording quality and occurrence of rain observed on audio files.

We used all available ARU data to test if recommended seasonal timing and survey length of traditional point counts are appropriate for our region. We summed the daily ARU calls from all points, then used a 7-d moving average to determine the seasonal peak of calling activity. Using recordings where at least one bobwhite was detected, we examined average time to detection and determined the proportion of calls that would have been detected using theoretical survey times of 5, 10, or 15 min. To assess the time required for audio file analysis, we re-analyzed a randomly selected sample of 100 5-min audio segments. The technician used a stopwatch to record the combined time required to navigate to the file in the Raven program, select and tag calls, and save the selection table.

Traditional Surveys

We conducted unlimited radius, 5-min, single-observer point counts based on NBCI guidelines (Morgan et al. 2016, Chapman et al. 2020). Surveys took place at 14 ARU points and 34 additional points. Two surveys were conducted at each point during the month of June for a total of 96 surveys. Observers recorded the number of bobwhites calling at any distance in 1-min time bands, as well as start times, temperature, percent cloud cover, ranked wind speed, and ranked noise. Surveys occurred within 3 h of sunrise and did not occur during rainfall, if windspeed was above 13 km/h, or with constant background noise.

Statistical Comparison of Survey Methods

To compare the performance of ARUs and traditional surveys as directly as possible, we limited the traditional survey data to points with corresponding ARU data. We limited ARU data to recordings within our observed seasonal calling peak (25 May–10 July). This time span is consistent with the approximately 6-wk range recommended by NBCI for point count surveys (Morgan et al. 2016). We compared presence/absence results for 658 peak season ARU and 28 traditional surveys using a two-tailed *t*-test as well as calculating average encounter rates for each survey type. We consider the encounter rate to be the probability of a surveyor finding at least one bird per survey (Strimas-Mackey et al. 2020). We also assessed seasonal ARU and traditional survey results using Wilcoxon signed rank tests paired by point to compare overall occupancy status and average encounter rate throughout the season at each of the 14 survey points. To determine if points where birds were detected on traditional surveys were those with higher calling rates, we used a two-tailed *t*-test to compare the number of ARU calls at points with and without birds detected on traditional surveys. Recording time of ARUs directly overlapped with an in-person survey on four occasions, which we compared to see if observers and ARUs located the same birds.

Random Forest Modeling

We used random forest modeling, a supervised machine learning approach, to build separate model sets exploring the relative importance of point and survey variables to traditional and ARU results. As we were primarily interested in comparing different methods to detect birds rather than modeling occupancy, it was appropriate to use random forest encounter rate models (Guillera-Arroita et al. 2015, Strimas-Mackey et al. 2020). For these analyses, we used the full set of 658 ARU survey occasions occurring at peak season and the full set of 96 traditional surveys from all 48 points. For both model sets, we built classification-type models using the randomForest package for R version 4.0.4 (Liaw and Wiener 2002). Random forest modeling is sensitive to class imbalance (Chen et al. 2004, Strimas-Mackey et al. 2020). Both traditional and ARU surveys resulted in fewer bird detections than non-detections, so we used the weighted random forest method, which penalizes incorrect classification of the minority class more strictly (Chen et al. 2004). We weighed the detection class inversely to the proportion in which it occurred (1:4 in traditional data and 1:3 in ARU data) so the model prioritized correct classification of detections three or four times higher, respectively, than non-detections. This allowed us to keep our full data sets rather than re-sampling the classes evenly, which was especially important for the smaller traditional data set.

Traditional survey variables included in model sets were point identity, survey start time, day of year, observer, and site type, as well as ranked windspeed, cloud cover, and noise. For ARU models, we considered point identity, day of year, recording quality, site type, and weather station variables (ranked cloud condition, wind speed, and precipitation). In both cases, temperature was positively correlated with day of year and was not included. We used mean decrease in accuracy (MDA) to determine variables with the greatest impact on encounter rate. During model testing, we began with the full model and dropped variables with MDA less than zero, or the lowest ranked variable, in each step until only two variables remained. If variables to be dropped had similar MDA, we tested all alternatives. For traditional surveys, site and observer were highly correlated, so we began with two full model sets. For both traditional and ARU models, point identity served as a surrogate for habitat differences. We assessed survey models using AICc rank (Akaike Information Criterion adjusted for small sample size), mean square error, percent accuracy, specificity (ability to correctly classify non-detections) and sensitivity (ability to correctly classify detections).

RESULTS

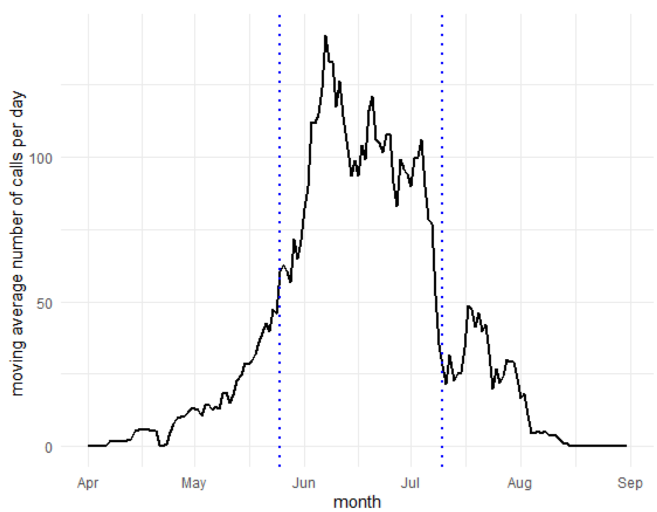
Autonomous Recorder Data

We analyzed 30,015 min of automated recordings from the full April–August data set. Of the 2,001 surveys, the analyst rated 74.26% as good recording quality, 22.14% as fair, and 4.10% as poor. The most common noise interference was from rainfall and accompanying wind. Of the poor-quality recordings, 74.39% had moderate or heavy rainfall, whereas only 0.03% of the good-quality recordings had even moderate rainfall. Other interference included insects, frogs, traffic, calling from other species, and microphone static.

In 15-min recordings where bobwhites were detected, we found that the mean time to first detection was 5.76 min (median 5.34, range 0.002–14.98). We divided the recordings into 5-min time bands and found 48.45% of first detections occurred in the first 5 min, and 77.02% within 10 min. This implies that had we used a 5-min recording time, comparable to in-person surveys, we would have detected birds on less than half of the occasions found using a 15-min recording.

We determined the length of the calling season at each point by calculating the number of days between the first and last bobwhite calls detected. Mean calling season was 74 d (median 70, range 32–105). Seasonal variation in calling, smoothed by a 7-d moving average, shows that peak calling occurs in June and early July (Fig. 2). There is a small secondary peak in late July (Fig. 2). The highest average call rate was 141 calls per day centered around 14 June. For statistical comparisons using ARU data, we used data from 25 May–10 July to encompass the peak observed calling season. The June survey window for our traditional point counts fits within the peak calling period and should appropriately sample bobwhite populations in our area (Fig. 2). However, surveys limited to June may, over time, miss any seasonal shift in calling phenology and do not include the secondary peak in July.

Fig. 2. A 7-d moving average of daily number of Northern Bobwhite calls across 14 South Carolina recording points from April through August 2017 shows a strong seasonal peak in calling in late May through early July. A rapid increase in calling occurs during May, and a more staggered decrease in calling from mid-July through mid-August. Dotted lines indicate the ARU dates (25 May–10 July) used for comparison with traditional surveys conducted in June.



Our timed trials indicated that, on average, it took an analyst 1 min, 34 sec (median 1:20, range 0:31–5:04) to select bobwhite calls within a 5-min recording. The average difference in number of calls detected between the timed re-analysis and the original analysis was 0.33 calls per file, with 95% showing no difference in occupancy status.

Comparison of Autonomous and Traditional Surveys

When we compared raw occupancy results from individual surveys (658 ARU and 28 traditional) at the same 14 points, we found no significant difference between the two methods (t = -1.26, df = 29.92, p = 0.22). However, when point occupancy after multiple surveys is considered, the ARU method produced a higher number of occupied points. Birds were detected by ARU at 13 of the 14 points (Table 1). At the five points where birds were detected by traditional surveys, they were also detected by ARUs. The two methods agreed on raw occupancy status at six points (Table 1). At the remaining eight, the ARU method located calling, whereas no birds were detected using the traditional method. The average probability of encountering at least one bird per point over the course of a season using our traditional method was 0.36, whereas the probability using our more survey-intensive ARU method was 0.93 (Table 1). A Wilcoxon signed rank test, with observations paired by point, indicates that birds are significantly more likely to be detected using our ARU method than our traditional method (V = 0, p = 0.006). When we performed a similar paired Wilcoxon signed rank test using average point-based encounter rates, to account for differences in survey effort, we again found no significant difference between the methods (V = 26, p = 0.18). The mean point-based encounter rate was 0.32 (range 0.00–0.51) for ARUs, and 0.21 (range 0.00–1.00, Table 1) for traditional surveys.

Table 1. Occupancy and encounter rates, call totals logged using autonomous recording units, and individuals counted on traditional point count surveys for 14 points in South Carolina during 2017 show that both methods consistently detected bobwhites. Traditional surveys were able to estimate numbers of individuals per point, whereas ARU surveys provide a measure of relative calling activity. Methods agreed on bobwhite presence at six points (42.86%). Encounter rates based on ARU surveys were slightly higher than rates based on traditional surveys, and the occupancy rate as estimated by ARU surveys was significantly higher (92.86%) than the rate estimated by traditional surveys (35.71%).

Site-Point	Traditional raw occ.	ARU raw occ.	Traditional encounter rate	ARU encounter rate	Traditional min # individuals	ARU # calls
IC-F1	0	1	0.0	0.32	0	250
IC-F5	0	1	0.0	0.26	0	346
IC-F7	1	1	0.5	0.47	1	671
IC-F8	0	1	0.0	0.45	0	688
IC-F9	0	0	0.0	0.00	0	0[†]
IC-R2	0	1	0.0	0.38	0	364
IC-R4	1	1	0.5	0.51	1	1257
IC-R6	0	1	0.0	0.09	0	101
IC-R8	0	1	0.0	0.15	0	132
IC-R11	0	1	0.0	0.23	0	395
IC-R12	0	1	0.0	0.51	0	379
CS-F1	1	1	0.5	0.11	2	87
CS-F4	1	1	1.0	0.45	1	540
CS-F12	1	1	0.5	0.51	2	677
Totals:	5	13	-	-	7	5887
Avg. rate:	0.36	0.93	0.21	0.32	-	-

[†] Microphone function at IC-F9 was normal based on presence of calls from non-target species.

Of the 28 sets of surveys that occurred at the same place and time, both methods returned six detections for equal encounter rates of 0.21. However, survey sets did not agree on which points were occupied on which days. Only four survey occasions had a 5-min traditional survey that occurred fully within a 15-min ARU recording. Of these occasions, three agreed, with neither in-person observers nor ARU analysis detecting any birds. On one occasion, a bobwhite call was found by the ARU method but was not simultaneously detected by the observer in the field.

Points varied in calling activity from no calls to 1,125 calls per point, with an overall total of 5,887 calls detected by ARUs. The mean number of birds detected per point on in-person surveys was 0.50 (range 0–2) birds (Table 1). There was no significant difference in the number of calls detected by ARUs at points where no birds were detected on in-person surveys and at points where one or more birds were detected (t = -1.92, df = 4.63, p = 0.12). However, at points where traditional surveys detected one or more birds, the mean count of calls from ARUs was higher, (mean 510.00) than the mean at points without birds (mean 210.22).

Random Forest Model Results (Traditional Surveys)
For traditional surveys, random forest models were relatively poor at predicting actual survey outcomes, however, our main interest was in relative importance of survey variables. Patterns emerged indicating that point-based variables, survey timing, and observer were most important. The top ranked model includes point identity, survey start time, and day of year. The top model has the best mean square error (MSE = 0.46), the highest percentage correct (54.17%), and the highest specificity (0.60) in the model set but has low sensitivity (0.25) (Table 2). The second and third models (*id+obs* and *id+site*) are interchangeable and are competitive with the top model within 1.49 AICc. Site and observer were highly correlated, as each observer surveyed at only one site. The second ranked models have slightly worse MSE (0.54), lower percentage correct (45.83%), and lower specificity (0.40), but much higher sensitivity (0.75) (Table 2). The top model maximizes the ability to classify negative detections, whereas the secondary models maximize the ability to classify positive detections. Point identity is in all three models and contributes the most to within-model mean decrease in error (MDE). This is to be expected as it accounts for the unmodeled differences in habitat.

In the top model, point identity contributes 10.45 toward MDE, survey day contributes 6.71, and survey start time contributes 3.54. A partial dependence plot for survey day of year shows that surveys taking place earlier in the June survey window have a higher relative probability of detecting birds, with the probability declining most steeply around 28 June (Fig. 3*a*). A partial dependence plot for survey time indicates that surveys conducted at least 50 min after sunrise have a higher relative probability of detecting birds, with a slight decrease in probability of detection around 135 min (ca. 2.5 h) after sunrise (Fig. 3*b*).

In the competitive *id+obs* and *id+site* models, point identity contributes 20.48 and 19.38, respectively, toward MDE. Observer contributes 8.96, and site contributes a similar 7.93. The Carolina Sandhills site had a higher relative probability of bird detection than the Indian Creek site (Fig. 4*a*). Observers A and B, who surveyed at Carolina Sandhills had a higher relative chance of detecting birds than observer C, who surveyed at Indian Creek site, although there is overlap in range between observers B and C, who conducted most surveys (Fig. 4*b*).

Random Forest Model Results (ARU Surveys)
Random forest models for ARU surveys had better fit and better predictive ability than models for traditional surveys. Fit, accuracy, and specificity were moderate, and sensitivity was high (Table 3). Models also provided a clear pattern of variable importance. There was only one top ARU model, including point identity and survey day of year. The top model has the best MSE (0.30), the highest percentage correct (69.51%), the highest specificity (0.63), and good sensitivity (0.85) (Table 3). Point identity again contributes the most toward MDE within individual models.

Within the top model, point identity contributed 44.97 toward MDE, whereas day of year contributed 23.95. As expected, different points have different relative probabilities of detection. The partial plot for survey day of year shows that surveys taking place between approximately 26 May–20 June (days 145–170) have a higher and more consistent relative probability of detecting birds than surveys outside this window (Fig. 5).

Table 2. Traditional survey variables assessed in the full random forest model set included point identity (id), survey start time (time), day of year (day), observer (obs), site type (site), windspeed ranking (wind), percent cloud cover, and noise ranking. The top model is id+time+day. The id+obs or id+site models are interchangeable and competitive within delta 2 AICc. Mean square error is relatively poor throughout the set, and model accuracy (percent correct) is generally average. Ability to classify true positives (sensitivity) and ability to classify true negatives (specificity) tend to trade off, so a model with high sensitivity generally has lower specificity.

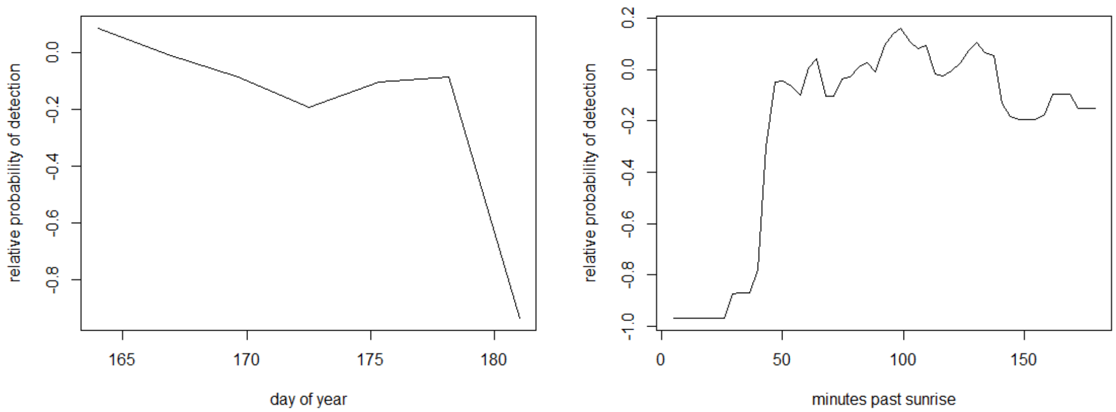
Model	k	MSE fit	Percent correct	Sensitivity	Specificity	AICc	Delta AICc
id+time+day	3	0.46	54.17	0.25	0.60	64.45	0.00
id+obs	2	0.54	45.83	0.75	0.40	65.94	1.49
id+site	2	0.54	45.83	0.75	0.40	65.94	1.49
id+obs+wind	3	0.54	45.83	0.75	0.40	68.46	4.01
id+time+day+site	4	0.50	50.00	0.25	0.55	69.32	4.87
id+day	2	0.67	33.33	0.75	0.25	70.92	6.47
id+time+day+wind+site	5	0.50	50.00	0.25	0.55	72.42	7.97
id+time+day+wind+obs	5	0.50	50.00	0.75	0.45	72.42	7.97
id+obs+wind+day	4	0.58	41.67	0.75	0.35	73.02	8.57
Full_A (with site†)	7	0.46	54.17	0.25	0.60	77.67	13.23
Full_B (with obs†)	7	0.54	45.83	0.75	0.40	81.68	17.23

† Observer and site were highly correlated—model A includes site, and model B includes observer.

DISCUSSION

Practicality of Autonomous Recorder Surveys
Overall, ARUs were reliable, with no malfunctions, and produced a high proportion of good-quality recordings. For bobwhite detection at our sites, a moderate amount of background noise was not problematic, and only rain consistently caused poor recording quality. Much like the restrictions placed on traditional surveys, poor-quality recordings, or those from days with adverse weather conditions, could be removed from an ARU analysis. The time required to process a 5-min section of recorded data averaged only 1 min, 34 sec, considerably less than the 5 min required to do the survey in person plus the additional time needed to move between points. As we could conduct at least three ARU surveys for every in-person survey, ARUs would be helpful for increasing survey effort.

Fig. 3. The partial dependence plots for day of year (a) and start time (b) within the top-ranking random forest model shows that the model is more likely to predict bobwhites on traditional surveys earlier in the June survey window and on surveys beginning at least 50 min after sunrise. The highest relative detection probabilities occur closest to day 165 (15 June) and around 100 min after sunrise. Relative probability of detection represents the relative logit contribution of the variable to the model's probability of classifying an occasion as a detection.



Pros and Cons of Autonomous and Traditional Surveys

Our data suggest that a point count or recording session should probably be longer than the 5-min counts commonly used in roadside transects and currently recommended by the NBCI (Elder 1956, Rollins et al. 2005, Morgan et al. 2016). On average, recording for only 5 min would result in detecting occupancy at less than half of points found to be occupied using a 15-min ARU survey. A 5-min in-person survey might also be expected to detect fewer than half of occupied points on a given day. As birds react to human presence and take time to return to normal calling behavior, two or three 5-min surveys over multiple days may not be an equivalent effort to one 10- or 15-min ARU survey (Shonfield and Bayne 2017). Use of ARUs can increase survey effort by increasing the number of days surveyed and the length of each survey as well as removing the constraints of covering many points within a short time.

The peak calling season observed in our ARU data is similar to the mid-June to July peaks observed in research conducted in Missouri, Kansas, Oklahoma, Georgia, and Florida (Bennitt 1951, Robel et al. 1969, Wilson 2000, Hansen and Guthery 2001, Terhune et al. 2009). Our study, like several others, shows a later secondary calling peak (Robel et al. 1969, Hansen and Guthery 2001, Terhune et al. 2009). If calling is associated primarily with breeding and nesting, the highest calling rates should correspond to peak breeding season (Speak and Haugun 1960, Terhune et al. 2009). The secondary calling observed in July could be a result of birds re-nesting after a failed attempt or producing a second brood (Sermons and Speake 1987, Terhune et al. 2009). The peak calling season, according to ARU data, occurs during the June survey window used for traditional surveys. Calling season, however, may vary from year to year. Researchers in several regions have concluded that variation in site, year, and weather had an impact on breeding, call timing, and behavior (Speake and Haugen 1960, Wilson 2000, Hansen and Guthery 2001, Terhune et at. 2009). There is also evidence for changes in bird breeding phenology based on long-term climate change (Forchhammer et al. 1998, Parmesan and Yohe 2003, Charmantier and Gienapp 2014). Using ARU surveys that extend to the edges of the calling season would ensure that peak season data are captured every year and could be used to track shifts in breeding season timing.

On a point-by-point basis throughout the year, the ARU method outperforms the traditional method by finding birds at 57% more survey points. On a survey-by-survey basis, however, when the same number of surveys on the same days of the year are compared, both methods provide similar results. Both methods had the same number of detection occasions and had equal encounter rates of 0.21, but daily comparisons did not agree on which points were occupied on which days. On any given day, the probability of detecting a bird at a point is low, so when survey times do not match exactly, we would not necessarily expect equal results. The combination of similar success rate of individual surveys, higher success rate of ARUs throughout the season, and low encounter rate suggests that the difference in seasonal results between methods is primarily due to the larger number of repeated surveys possible with the ARU method.

Traditional surveys allow for more direct estimation of bobwhite abundance as it is possible for observers to identify several birds calling simultaneously. The number of birds estimated on traditional point counts was low, ranging from zero to two. This means the occupancy rate may not differ drastically from abundance. Additionally, for easily detectable species, encounter rate closely approximates actual occupancy (Strimas-Mackey et al. 2020). Based on their loud and identifiable call, it is possible that encounter rates for bobwhite do closely reflect occupancy and abundance. In our results, sites where at least one bird was detected by a traditional survey did not have significantly more ARU calls than sites only found to be occupied by ARU surveys. However, each ARU season consisted of 47 survey replicates, whereas each in-person season consisted of only two. If birds are not calling reliably within the 5-min in-person surveys, this could easily confound results. Further study into the relationship between occupancy and abundance for bobwhites is needed.

Random Forest Model Interpretation

Random forest models indicated that for both traditional and ARU surveys, the point identity was most important in modeling relative probability of encountering bobwhites. This suggests that, regardless of survey type, habitat variables are the main drivers

Fig. 4. Plots of the influence of site (a) and observer (b) on the relative probability of detecting bobwhites on traditional surveys show that detection was generally higher and with a narrower range of probabilities at Carolina Sandhills (CS) than at Indian Creek (IC) and that observers varied in relative probability and in range of probability. The patterns for site and observer are similar because the two variables are highly correlated. Observers A and B surveyed only at Carolina Sandhills, and observer C surveyed only at Indian Creek. Relative probability of detection represents the relative logit contribution of the variable to the model's probability of classifying an occasion as a detection.

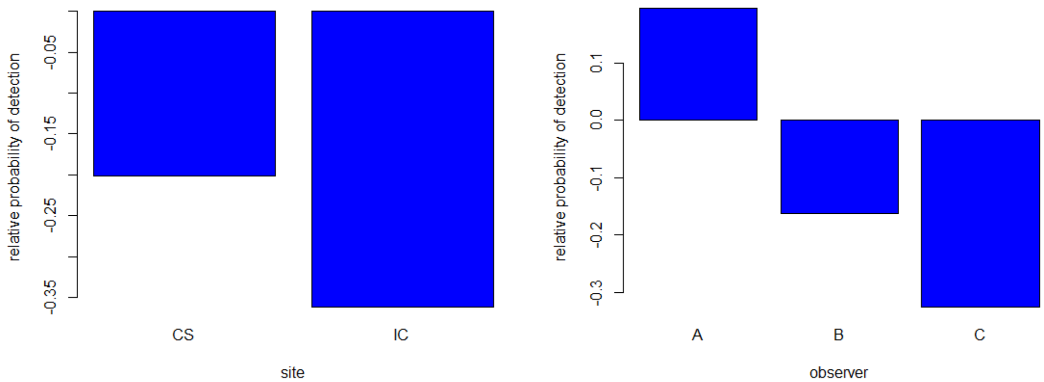
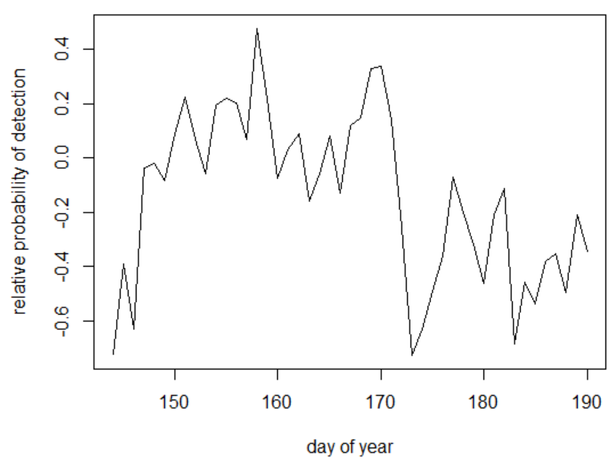


Table 3. Variables for autonomous recording unit surveys as assessed in the full random forest model set included point identity (id), day of year (day), site type (site), recording quality (quality), average wind speed (wind), cloud cover conditions, and average rainfall. Based on statistics presented, the top and only competitive model is id+day. Mean standard error is similar throughout the set, and model accuracy (percent correct) is generally just above 50%. The ability to classify true positives (sensitivity) is high, and ability to classify true negatives (specificity) is average. The top model balances high sensitivity with moderate specificity.

Model	k	MSE fit	Percent correct	Sensit-ivity	Specif-icity	AICc	Delta AICc
id+day	2	0.30	69.51	0.85	0.63	645.62	0.00
id+day+site+quality	4	0.31	68.90	0.87	0.62	653.02	7.40
Full Model	7	0.32	68.29	0.81	0.64	662.63	17.01
id+day+site+ quality+wind	5	0.33	67.07	0.74	0.64	664.51	18.89
id+day+site	3	0.35	65.24	0.83	0.58	669.17	23.55
id+quality	2	0.36	64.02	0.81	0.57	672.77	27.14
id+site+quality	3	0.38	62.20	0.83	0.53	682.96	37.34
id+site	2	0.41	59.15	0.83	0.50	693.62	48.00

of encounter rate. Variables having to do with weather conditions and other survey-based variables were less important than point-based variables in final models. Although it would be better to use weather data from a closer station for ARU models, Pearson tests showed slight correlation between greater precipitation at the weather station and severity of rain heard on recordings (r = 0.305, df = 2009, $p < 0.00$) and between higher windspeed at the weather station and lower recording quality (r = -0.17, df = 2009, $p < 0.00$). Weather variables from in-person surveys were taken directly at the time of the survey and were also unimportant in top models. It is likely that point occupancy rather than survey-based detectability is the primary driver of encounter rate. In traditional surveys, site type was also an important modeling

Fig. 5. The partial dependence plot for day of year within the top-ranking ARU random forest model shows that the model is more likely to predict bobwhites on surveys in late May to mid-June. Day 150 is 31 May, and day 190 is 10 July. The relative probability of detection represents the relative logit contribution of the day of year variable to the model's probability of classifying an occasion as a detection.



variable. However, site and observer were related, so it is difficult to determine if site type, observer ability, observer bias, or a combination affected encounter probability. In ARU models, we eliminated observer bias by using the same recording units and having a single observer analyze all data. Site type was not important in ARU models.

Survey timing was important to traditional surveys. Results showed that relative probability of encounter rate increased about 50 min after sunrise and started to decline about 2.5 h after sunrise. This suggests that it may be necessary to adjust the current protocol in which surveys begin at sunrise and to narrow the 3-h time window. The ARU method allows for all surveys to occur at the same time so it can maximize effort at the optimal time. We examined ARU data from 30–45 min post sunrise, which is slightly before peak detection, so timing of future ARU studies could also be adjusted. In both traditional and ARU models, survey day of year was an important factor. Traditional surveys were limited to June, but relative probability of encountering birds decreased throughout the month, and sharply toward the end. Automated recording unit surveys analyzed were limited to 25 May–10 July based on the peak season from the entire data set. Surveys conducted in late May to mid-June had higher and more consistent relative probabilities of encounter than those earlier in May or in late June or July. Both methods agree that the best survey dates for our region of South Carolina are from early to mid-June. However, the actual study period should likely extend beyond this time period.

CONCLUSIONS

Automated recording units and human observers are both able to detect presence of bobwhites on individual surveys with similar results. The increased number of replicates possible with ARUs allows for significantly better estimates of occupancy, whereas traditional surveys allow for estimation of abundance. Both methods could be combined into a powerful bobwhite monitoring program.

There are many advantages to ARU use, including the ability to survey more points, for longer surveys, and over a longer season. As analysis of ARU data takes less time than a comparable in-person survey, monitoring efforts could be expanded without adding personnel or hours. Automated recording unit surveys are also able to eliminate most survey-based variation in detectability. Whereas observer, survey day of year and survey start time are important for traditional surveys, ARUs eliminate observer differences and ensure that all surveys occur at the same times. We also found ARU recordings to be a practical way to track seasonal calling patterns, which would be ideal for tracking long-term changes in calling phenology.

As it is difficult to estimate counts of birds with ARUs, they are best deployed for presence/absence surveys. They could easily be used to determine occupancy of marginal sites where bobwhites are not known to occur, or where populations are known to be lower. Current efforts focus on relatively small areas within high priority focal sites, generally with higher occupancy. Automated recording units could be used to expand the survey zone and to target new areas for study or habitat management. Traditional methods could be incorporated to conduct abundance and habitat surveys at sites of interest. New analytical methods under development are improving the ability to automate the ARU call identification process and are on the verge of making it possible to use call counts to model population size. Such advances would allow the ARU technique to be viable as a lone-use method. However, for now, we recommend ARU use as a supplemental method for expanding the spatial and temporal range of traditional bobwhite monitoring.

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Data Availability:

The datal code that support the findings of this study are available in Open Science Framework at https://osf.io/4zuhj/?view_only=fea63087100d43879a73978facba2b5b

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