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PREDICTING NORTHERN BOBWHITE HABITAT IN SEMIARID RANGELAND USING LANDSAT IMAGERY

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ABSTRACT

Multiple studies have attempted to model northern bobwhite (*Colinus virginianus*) distribution using classified remotely sensed imagery in combination with pattern recognition software. These models tend to be more accurate in humid subtropical regions. To identify bobwhite habitat in subhumid and semiarid rangeland, we performed our own classification on 4 LANDSAT scenes of Clay County, Texas, from July and December 2015. Stands of mature little bluestem (*Schizachyrium scoparium*) provide excellent bobwhite nesting cover and could be identified using LANDSAT imagery. Habitat was scored from 0 to 1.0 based on estimated range health, presence of little bluestem, and presence of brushy cover. We compared habitat score with the results of breeding season call counts from 2014 and 2015 and found significant correlation. When used in combination with other landscape data, this approach can provide a regional context to inform conservation and management decisions.

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Key words: call counts, *Colinus virginianus,* GIS, habitat, LANDSAT, modeling, northern bobwhite, populations, remote sensing, Texas

Northern bobwhite (*Colinus virginianus*) populations in the United States and Canada have declined >75% over the past 45 years and have been declining regionally for >100 years (Lewis 1863, Thorpe 1869, Judd 1905, Nice 1910, Errington and Hamerstrom 1936). The decline has been ascribed to many factors (Allen 1864, Nice 1910, Leopold 1937, Allen et al. 2004, Hernández et al. 2005) but research has generally implicated range-wide habitat loss, fragmentation, and degradation as the leading causes (Klimstra 1982; Brennan 1991, 1994; Williams et al. 2004; Hernández et al. 2012). Despite >75 years of habitat-driven research and management practices, northern bobwhite populations continue to decline (Hernández et al. 2012). Williams et al. (2004) suggested that this is because our current habitat management practices are implemented at the wrong spatial scale. Most bobwhite research on habitat to date has been done on a local (<25-km^2) scale (Kabat and Thompson 1963, Burger and Linduska 1967, Wiseman and Lewis 1981, Taylor et al. 1999a, Fies et al. 2002, Oakley et al. 2002, Riddle et al. 2008, Crosby et al. 2013) whereas harvest management is usually on a statewide scale (Williams et al. 2004). There is a need to transition from both local and statewide practices to more regional management (Peterson et al. 2002, Dimmick et al. 2002, Williams et al. 2004). One difficulty with regional management of bobwhite populations as proposed by Williams et al. (2004) is that quail managers do not know how large a bobwhite population is, or how large it must be to allow the population to persist for a set length of time. Estimates based on mathematical models range from 100 to 800 birds, depending on weather events and harvest (Guthery et al. 2000, DeMaso et al. 2011) but these estimates have not been tested. Quail managers need, also, to have a practical and reliable method to identify and prioritize bobwhite habitat on a regional level in order to determine the extent of the habitat loss and its implication for northern bobwhite populations. Our objective is to use freely available LANDSAT imagery to identify regions of northern bobwhite habitat and predict the distribution of bobwhite populations within the southern Great Plains region of Texas.

Scientists have attempted to generate models that relate bobwhite presence or abundance to local landscape cover using remotely sensed data for humid subtropical regions of the United States (Roseberry et al. 1994, Roseberry and Sudkamp 1998, Schairer et al. 1999, Peterson et al. 2002, Smith and Burger, Jr. 2004, Duren et al. 2011). Of these studies, only 2 performed their own landscape classification. Roseberry et al. (1994) performed a spectral classification on LANDSAT Thematic Mapper (TM) data and combined it with regions manually digitized from aerial photographs or mapped in the field. Smith and Burger, Jr. (2004) used LANDSAT Enhanced Thematic Mapper 7 data and Ikonos satellite 4-m-resolution imagery to divide their study area into 4 different land-cover categories, or classes. The other models used preclassified data such as US Geological

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Survey Land Use and Land Cover or the National Land Cover Database (Twedt et al. 2007), state land-cover databases (Roseberry and Sudkamp 1998), the Coastal Change Analysis Program (Duren et al. 2011), or the National Agricultural Statistics Service (Peterson et al. 2002), further aggregating the preclassified data into 5–9 broader classes. Although excellent for detecting trends in land use over time, these preclassified data are not particularly accurate at fine scales (Wickham et al. 2010, 2013). Even for level I classifications, such as distinguishing between urban, water, grassland and forest, National Land Cover Database accuracy averages approximately 85%. More specific classifications have <80% accuracy, with those separating grasslands or cropland from pasture far lower (Wickham et al. 2013). Another factor overlooked by most models is the varieties of habitat that are often lumped together under agriculture or grass. In their examination of Conservation Reserve Program effects on bobwhite habitat, Roseberry et al. (1994) did consider 5 different grass, range, or cropland classes; however, all of the other bobwhite habitat models used 1–3 classes. None looked at more than a single class of rangeland, such as distinguishing between native and nonnative (improved) pasture grasses.

This oversight is of particular importance to regions where most bobwhite habitat is located on rangeland because rangeland varies considerably in the quality of bobwhite habitat it provides based on the amount of woody cover, herbaceous cover, percentage of bare soil, grass height, and the relative diversity of grass and forb species (Rice et al. 1993, Kopp et al. 1998, Taylor et al. 1999a). When available, bobwhites tend to use mature stands of bunchgrass as nesting cover (Harshbarger and Simpson 1970, Taylor et al. 1999b), though other plants, such as prickly pear (*Opuntia* spp.), are also used (Hernández et al. 2003, Hernández and Peterson 2007). Posthatch, bobwhites require loafing cover for resting during the heat of the day (Stoddard 1931, Carroll et al. 2015b), such as brush and small trees (Johnson and Guthery 1988). The presence of brush can also be important for nest-site selection (Carroll et al. 2015a). Posthatch through maturity, bobwhites also require "brood cover" habitat consisting of shade, overhead protection from aerial predators, and food-producing forbs (Stoddard 1931, Handley 1931, Hurst 1972).

Little bluestem (*Schizachyrium scoparium*) is perhaps the most important plant in semiarid rangeland for northern bobwhites. In Texas and Oklahoma, mature little bluestem is by far the preferred bunchgrass for nesting cover (Lehmann 1984, Townsend et al. 2001). In some studies, bobwhites exhibited a >90% preference for little bluestem as a nesting site (Peoples et al. 1996, Hernández et al. 2003). Bobwhite are also associated with little bluestem stands outside of nesting season, preferring bluestem interspersed with shrubs or other woody cover (Johnson and Guthery 1988, Hernández and Peterson 2007, Richardson et al. 2008). Additionally, brood cover typically contains little bluestem (Wiseman and Lewis 1981, Hernández and Peterson 2007, Richardson et al. 2008), though bobwhites have a propensity for areas with more open ground along with taller vegetation to provide greater visual obstruction from above (Taylor et al. 1999b, Hernández and Peterson 2007). Little bluestem is a major focus of our study because of its near-exclusive use as nest sites for bobwhite in our study area and its strong association with other bobwhite habitat types.

Little bluestem is also expected to be quite detectible from satellite imagery. During the autumn and winter, little bluestem has a distinctive orange–bronze color (Kratsch and Hunter 2009, Davis 2011) that can improve the chance of distinguishing it from other grasses, particularly when viewing satellite imagery from >1 season (Guo et al. 2003). This means that locating ≥1 component of bobwhite habitat (i.e., nesting sites) based on the reflected color of vegetation may be easier in North Texas and western Oklahoma than in other parts of the bobwhite range where little bluestem is less common and other bunchgrasses are used for nesting cover.

There have been some attempts to categorize quality of rangeland as measured by grass height and percentage of bare ground (Guerschman et al. 2003, Röder et al. 2008) using LANDSAT or other satellite imagery. Reduced vegetation as produced by overgrazing increases surface albedo (Jackson et al. 1975), which can be detected both in the visible and infra-red spectrum (Michalek et al. 2001). Loafing cover types such as shrubs and other aerial cover are also identifiable in aggregate from satellite imagery (Boyd 1986, Afinowicz 2004), although we may not reliably be able to detect smaller scale brood cover. However, the limited range and movement of bobwhites (Terhune et al. 2006b, Brennan et al. 2014) would strongly imply that brood cover will be located near nesting and loafing cover. Based on this assumption, a bobwhite habitat model based on the presence–absence of little bluestem and other cover types that are detectable through satellite imagery is feasible for our study area.

The LANDSAT program is one of the most commonly used sources of remote sensing imagery because of its >40-year history and low cost data (Jensen 2005, USGS 2013). LANDSAT 8 scenes include 11 bands of data (USGS 2013), each formatted as a black and white raster image and covering a different portion of the electromagnetic spectrum (Table 1). These bands can be used to gather information about vegetation type and vegetation health, including rangeland quality (Lauver and Whistler 1993; Harvey and Hill 2001; Sims and Gamon 2002, 2003; Schmidt and Skidmore 2003) though the discriminatory power may be lower in arid regions (Okin et al. 2001). Using LANDSAT imagery, we hypothesize that we can predict the location of specific components of bobwhite habitat and, therefore, bobwhite populations in our study area.

STUDY AREA

The study area for this project was Clay County, located in the Central Great Plains ecoregion of North Texas (Griffith et al. 2004). Clay County (2,844 km^2) consisted of >56% pasture, crop- and rangeland (Homer et al. 2015, USGS 2015). Clay County also had >1,800

Table 1. LANDSAT 8 bands, wavelengths, and resolutions (USGS 2013) acquired 11 July 2015 and 18 December 2015 in Clay County, Texas, USA, from which were derived land-cover classes to evaluate habitat use by northern bobwhites. Wavelength is in μm, resolution in m. Before classification, band 8 was discarded and bands 10 and 11 were resampled to the same 30-m resolution as bands 1–7 and 9 (Xian and Crane 2005, Deng and Wu 2013).

Band	Wavelength	Resolution (m)
1	0.43–0.45	30
2	0.45–0.51	30
3	0.53–0.59	30
4	0.64–0.67	30
5	0.85–0.88	30
6	1.57–1.65	30
7	2.11–2.29	30
8	0.50–0.68	15
9	1.36–1.38	30
10	10.60–11.19	100
11	11.50–12.51	100

km of publicly accessible roads from which to collect data in addition to access granted from private ranches. The vegetation was primarily Mesquite–Lotebush vegetation with portions of Post Oak Parks, Mesquite Brushland, cropland, and Cottonwood–Hackberry Forest to the north, along the Red River (McMahan et al. 1984).

Climate in Clay County was characterized by hot summers and cool winters. Mean monthly low temperatures in Henrietta, the county seat, ranged from –2° C in January to 22° C in July. Mean monthly high temperatures ranged from 12° C in January to 36° C in August. Mean annual precipitation in Henrietta 1981–2010 was 83 cm with May, June, and October the wettest months (Arguez et al. 2011). Monthly precipitation amounts as measured at the nearest official National Weather Service recording station ranged from 0 cm for May 2014 to 43 cm for May 2015 (National Weather Service 2015, 2016).

METHODS

We established data collection points for recording quail breeding calls and habitat information along public and private roads across Clay County. We selected points based on the local landscape to avoid establishing points in areas that would prohibit hearing calls (i.e., behind trees or in low-lying areas). Bobwhite vocalizations can be heard up to 1 km away under ideal conditions (Rusk et al. 2007) with mean distances of 500–800 m as determined by field tests (Bennitt 1951). To minimize overlap, we placed points 1–2 km apart at a suitable location, usually the top of a hill or small rise, nearest to a 1.6-km straight-line distance from a previously established point. We recorded coordinates (latitude and longitude) of each point with a handheld Global Positioning System (GPS; Garmin, GPSMAP® 64st, Olathe, KS, USA).

To create a Clay County population index, field technicians recorded bobwhite breeding season calls at each point. The date of peak bobwhite calling activity can vary from year to year. Peaks typically occur between 1 June and 10 July (Bennitt 1951; Rosene 1957, 1969; Robel et al. 1969). We recorded calls from 16 May to 24 June 2014 and 19 May to 30 June 2015 because calling begins earlier in southern latitudes (Rosene 1969). All field technicians were trained by accompanying experienced observers in the field prior to the start of call counts. Each technician was assigned a region each day and provided with a pen, map, compass to determine cardinal directions, clip board with data recording sheets, hand-held GPS with the coordinates of each point, and Kestrel 3500 Weather Meter (Nielsen-Kellerman, Boothwyn, PA, USA). Beginning at sunrise, technicians recorded the approximate distance and direction of each male bobwhite heard for a 5-minute duration (Terhune et al. 2006a). Technicians were instructed to move >20 m from the vehicle before recording. Technicians recorded local weather conditions at each stop using the Pocket Weather Meter. Listening times in the third hour after sunrise give negligible undercounts for lower density sites (Hansen and Guthery 2001) and calling activity drops significantly after the third hour (Bennitt 1951); therefore, we limited data collection to a 3-hour period following sunrise. An increase in wind speed is significantly negatively correlated with the number of bobwhites audible (Bennitt 1951, Robel et al. 1969, Hansen and Guthery 2001) so technicians did not record if local winds exceeded 16 km/hour. Call counts were not conducted during rain (Hansen and Guthery 2001). A replicate survey of all points was logistically unfeasible but 80.9% (545/673) were visited two or more times. The number of male bobwhites recorded at each point was averaged before analysis.

For improved visualization, the call count data were interpolated (Valley et al. 2005), a transformation of point measurements into a 2-dimensional x–y raster surface with pixel "brightness" values representing the z-axis. In this case, we used the number of bobwhites recorded as the z-value. Converting the call count data to raster format has another advantage in that it is easier to make regional comparisons between different years. There are >15 methods for interpolation (Triebel 1995). The numbers of bobwhites heard per listening station can vary, so interpolation was performed by Kriging (Krige 1951), which is an interpolation method designed to accommodate multiple values for single points (Matheron 1963) to estimate a variable local mean (Saito et al. 2005). Kriging was performed in ArcMap 10.1 at the default resolution (∼270 m on this map) using the nearest 6 points, based on bobwhite detection probability from Riddle et al. (2010) and Pellet and Schmidt's (2005) method to determine the number of site visits required to infer absence. The maximum radius was set at 6 km, the maximum seasonal distance travelled by bobwhites as reported by Fies et al. (2002).

To address habitat assessment for the model, we downloaded imagery acquired by LANDSAT 8 from 2 different seasons (11 Jul 2015 and 18 Dec 2015) from the US Geological Survey Earth Explorer website (http://earthexplorer.usgs.gov). Dates were determined by the

Table 2. Land-cover classes, subclasses, and relative habitat suitability scores for northern bobwhite habitat in Texas, USA (Jul and Dec 2015). Subclasses were scored based on division of bobwhite habitat requirements into nesting cover, shade (overhead cover), and food and range from 0 (poor) to 1.0 (excellent).

Class	Subclass	Value
Water	Water	0.0
	Silty water	0.0
	Flooded regions	0.25
Forest	Bottomland hardwood	0.375
	Other deciduous	0.5
	Mixed or Unclassified	0.5
	Scattered trees	0.5
Brush	Brush	0.5
Grasses	Cropland	0.25
	Rangeland, (<10 cm)	0.25
	Rangeland, with brush	0.375
	Rangeland, (10–20 cm)	0.375
	Rangeland, with brush	0.50
	Rangeland (>20 cm)	0.75
	Rangeland, with brush	0.875
Little bluestem	Bluestem	0.875
	Bluestem, with brush	1.0
No vegetation	Concrete or Urban	0.0
	Bare soil	0.125

availability of high summer images (brush assessment) and early winter images (locating stands of little bluestem) with 0% cloud cover. For analysis, we resampled the thermal infra-red bands to the same 30-m-resolution as bands 1–7 and 9 (Xian and Crane 2005, Deng and Wu 2013) using the nearest neighbor interpolation to retain original brightness values. To make the data easier to use, we combined individual raster layers into a single file for each season using the GeoTIFF format. Although the LANDSAT panchromatic layer can result in improved classification because of more precise positional location of features, the effect is greatest in urban environments (Sunar and Musaoglu 1998). Masek et al. (2001) found the difference in classified areas to be ≤3%. The panchromatic band was discarded and National Agriculture Imagery Program imagery (30 Jun 2014) with ≤1-m resolution was used to assist with classification and location. Because Clay County lies on a boundary between 2 horizontal LANDSAT rows, each season required 2 LANDSAT scenes to be combined: path 28, row 36 and path 28, row 37, and path 27 row 37. We combined 2 scenes for each date into one using the Mosaic to New Raster tool in ArcMap v. 10.1 (Environmental Systems Research Institute, Redlands, CA, USA) and the blend option so each pixel value in the overlapping region was determined by the image with the viewing angle closest to 90°. We then cropped the new rasters to the area of interest to create 2 single-date 30-m-resolution coverages of Clay County with a 1-km buffer.

We performed an unsupervised ISO classification on each GeoTIFF in ArcMap. We grouped pixels into 100 clusters mathematically based on their reflective properties (Jensen 2005). We then assigned clusters to land-cover categories by analysis of National Agriculture Imagery Program aerial photography and Google Earth v. 7.1.5.1557 (Google, Menlo Park, CA, USA). To evaluate the classification, we selected 200 pixels (100 for little bluestem due to scarcity in accessible regions) from each of the major classes at random for those that could be assessed from high-resolution aerial imagery (water, forest, brush, bare ground) or at random within accessible areas for classes that had to be evaluated *in situ* (grasses, bluestem). We exported these into a shapefile and then converted them into Keyhole Markup Language (KML) and GPS Exchange Format (GPX) files using DNR GPS v. 6.1.0.6 (Minnesota Department of Natural Resources, St. Paul, MN, USA). We assessed accuracy through Google Earth imagery and by *in situ* evaluation by automobile or all-terrain vehicle using a handheld GPS for navigation. Local heterogeneity made classification more problematic. Pixels evaluated by aerial imagery were considered correctly classified if >50% of the pixel in question matched the predicted land cover. The same threshold was used for pixels evaluated *in situ*, excepting those divided by fences or ranch roads. For divided pixels, the threshold was 33%.

In order to score each land-cover type based on its utility for bobwhite, we simplified the bobwhite habitat requirements into nesting cover, shade (overhead cover), and food. We weighted little bluestem (nesting cover) at 0.5 because bobwhites almost exclusively use this plant for nesting in the southern Great Plains (Peoples et al. 1996, Hernández et al. 2003) and it was relatively rare, occurring in detectable amounts in <8% of our study area. We weighted shade and food at 0.25 each. In theory, any plant taller than a bobwhite can provide overhead cover and the bobwhite diet is so varied in plants and insects (Judd 1905, Nice 1910, Brennan and Hurst 1995, Butler et al. 2012) that most land-cover types provide one or both of those requirements for at least part of the year. We gave each land-cover type a score based on which requirements were met and whether those requirements were provided for part of the year (×0.5) or for the entire year (×1.0). For example, cropland can provide both shade and food but LANDSAT imagery shows that cropland is bare or near bare in December during planting season, and in July following a harvest so neither food nor shade is available year round. This applies both to wheat and to cool-season grasses that make up the vast majority of crops grown in Clay County, so cropland was scored as $[0.25(0.5) + 0.25(0.5)]$, or 0.25 total. Bare soil provides no shade but can provide food at least part of the year (Baker and Guthery 1990) because seeds from nearby plants are exposed. Where this was applicable, we scored bare ground as $0.25(0.5) = 0.125$. Individual habitat-type scores ranged from 0.0 to 1.0 (Table 2).

Once scored, we created 2 new rasters—one for July and one for December—using the habitat suitability score as the pixel values through the ArcMap Lookup tool. To combine the 2 rasters into a single value, we multiplied the value of each pixel in one raster by the value in the corresponding pixel in the other raster to create a new raster of estimated year-round habitat suitability (Fig. 1). We chose multiplication to increase the variance while

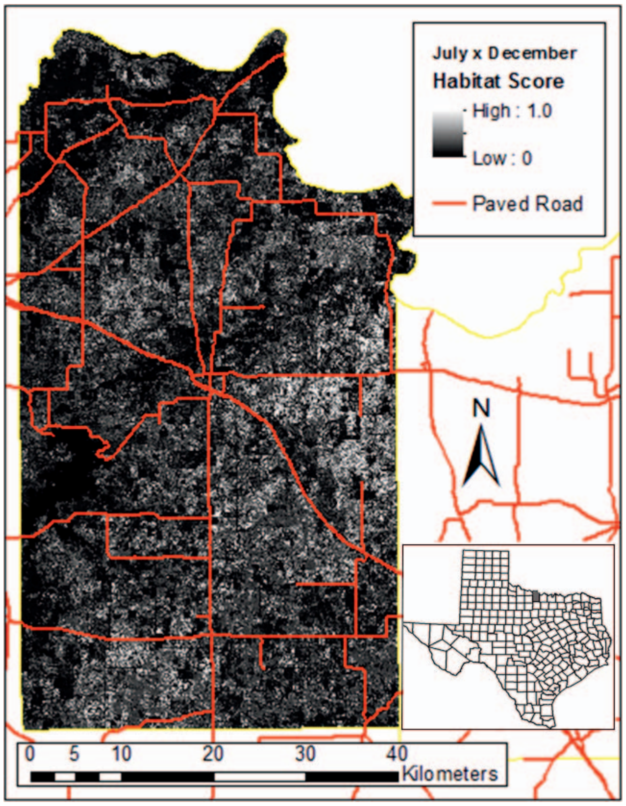

Fig. 1. Clay County habitat scores based on land-cover classes derived from 30-m resolution LANDSAT 8 imagery acquired 11 July 2015 and 18 December 2015. Value is based on utility for northern bobwhite where nesting cover = 0.5, year-round brood–loafing–aerial cover = 0.25, and year-round food availability = 0.25. Inset shows study area location within Texas, USA.

maintaining habitat values ≤ 1.0. The habitat suitability map had a 30-m-pixel resolution derived from 30-m-resolution raster data while the call count maps had an approximately 270-m-pixel resolution derived from points 1–2 km apart. The habitat suitability map also needed to be smoothed to moderate the negative habitat bias of gravel or bare soil and mowed right-of-ways associated with the roads where most call-count data were collected. Terhune et al. (2006b) reported a maximum mean daily movement of 298 m for resident bobwhites so we gave each cell in the habitat map the mean score of a 300-m-radius circle surrounding the cell using the Focal Statistics tool. We assumed this to represent the aggregate quality of habitat any particular male may have traveled through that day. We then resampled the habitat suitability map to the same pixel resolution as the call count raster. We extracted the habitat value at each point to give a series of values to statistically compare with the bird count data taken at the same points. Like the aforementioned call count data, the habitat values at the points were then interpolated using Kriging through the nearest 6 points. Performing the same operation used for the call count data provided an easily interpreted conservation tool for visualizing the estimated quality of bobwhite habitat across multiple properties.

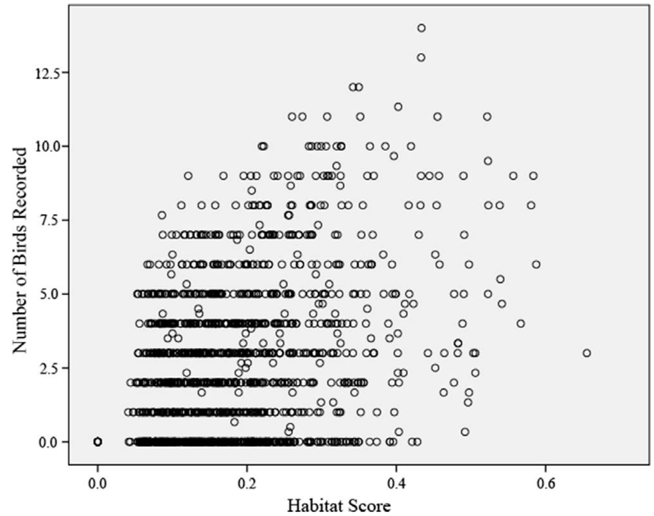

Fig. 2. Raw number of northern bobwhites recorded at each data collection point (DCP) in Clay County, Texas, USA (Jul and Dec 2015), as a function of mean estimated habitat score based on LANDSAT 8 imagery.

RESULTS

Bobwhite calls were recorded at 545 locations in 2014. An additional 128 points were added in 2015 for a total of 673. The mean number of bobwhite calls per location was correlated (Spearman's rank correlation coeff., $n = 673$, $\bar{x} = 2.88$, $\rho = 0.31$, $P < 0.0001$) with the estimated (smoothed) habitat value (Fig. 2), indicating that the location of bobwhite populations can be predicted using LANDSAT imagery. For visual comparison, the map generated using only the estimated habitat data from the same points as where the call count data were recorded (Fig. 3B) looks remarkably like the map generated from the call count data (Fig. 3A).

Accuracy for the land-cover classification ranged from 100% for water to 66% for brush (Table 3). The accuracy for little bluestem was 73%. Interestingly, 24 of the 27 false positives for little bluestem were broomweed (*Amphiachyris* spp.), which is not nesting cover but still a potentially useful brood cover plant (Chenault 1940, Lehmann and Ward 1941). Subcategory classification within the grasses was less successful. Rangeland was distinguished correctly from cropland 85% of the time but only 68% of the rangeland classes were correctly identified with differences in plant height accounting for most of the error. Surface completely lacking plant cover could be identified correctly 93.5% of the time the classification process could not reliably distinguish between concrete and bare soil or rock.

DISCUSSION

Although the model generated from the 2015 data significantly correlated with the number of male bobwhites heard, the overall correlation was relatively low ($\rho = 0.31$). We demonstrated that little bluestem, as detected from satellite imagery, could predict bobwhite presence when combined with additional land-cover data in a

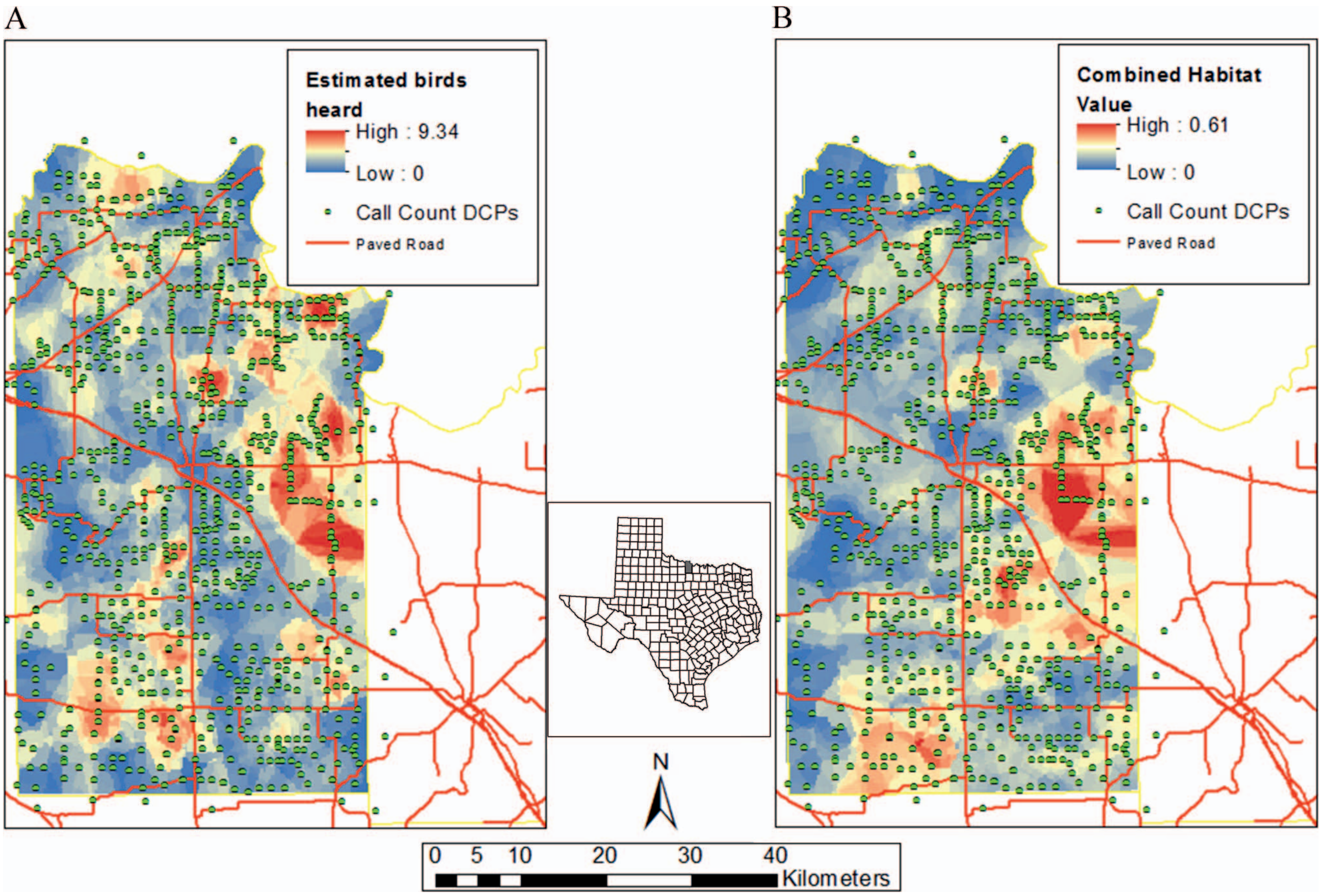

Fig. 3. Estimate of surface values interpolated via Kriging from 1,218 call counts at 673 data collection points during July and December 2015. (A) Interpolation based on number of male northern bobwhites heard at each data collection point. (B) Mean estimated habitat values within a 300 m of point based on classification of LANDSAT 8 imagery. Inset shows study area location within Texas, USA.

simplified additive model. Future model performance may be improved by considering additional factors. For example, bobwhite density may be inversely correlated with mean land-parcel size (Patten et al. 2005) or oil well density (Doherty et al. 2008, Carpenter et al. 2010). Habitat models vary greatly in predictive ability and are typically limited to a single region (Fielding and Haworth 1995). An increase in accuracy locally may decrease the applicability of the model to other regions, a factor that must be considered as we refine and test this model in additional locations within the Central Great Plains ecoregion of North Texas

One source of error for our current model was classification inaccuracies due to factors such as grass height. Little bluestem can be detected using freely available LANDSAT imagery but quality of rangeland is more difficult to distinguish, at least with the techniques described here. Error rates were higher in the landscape categories most likely to contain bobwhite (rangeland and rangeland with brush), particularly with regards to grass height. There may also be limitations on the utility of the image data for performing detailed, large-scale analyses. For example, brush was more reliably detectable in the eastern portion of the study area than in the western portion, suggesting that subtle differences in satellite viewing angle influence reflected color. Future classifications may be made using data provided by The ESA's Sentinel program, which had a higher orbital altitude and narrower sensor footprint than LANDSAT (Malenovský et al. 2012, Drusch et al. 2012).

The weather in 2015 presented another confounding factor. Spring and summer rains in 2015 caused widespread flooding throughout Clay County after 4 years of extreme drought (Wang et al. 2015). Some data points were inaccessible for days or weeks. Above-average precipitation continued into December and several misclassified pixels were directly attributable to higher than normal soil moisture. In an extreme example, 4 test pixels in low-lying portions of recently planted cropland were classified as forest.

The limitations of single-observer roadside counts are well-documented (Anderson 2001, Rosenstock et al. 2002, Royle and Nichols 2003, Applegate et al. 2011). The number of birds heard at each point represent an unknown fraction of the true number of birds within hearing range. However, single-observer counts are often the most efficient way to survey a large area, despite the variance. In order to determine the true number of birds at

Table 3. Land-cover classification accuracy for northern bobwhite habitat in Texas, USA (Jul and Dec 2015). Main class accuracy is a percentage. For subclasses, ratios are shown. Test pixels were selected from each class either at random (water, forest, brush, bare ground) or at random within 30 m of roads or on properties that allowed access (grasses, bluestem). Accuracy for water, brush, and forest was assessed using Google Earth. Accuracy for grasses was assessed by travel to the test pixel.

Class	Accuracy (%)	Subclass	Accuracy
Water	100	Water	178/178
		Silty water	18/18
		Flooded regions	3/3
Forest	93	Bottomland hardwood	74/79
		Other deciduous	22/29
		Mixed or Unclassified	66/86
		Scattered trees	4/6
Brush	66	Brush	132/200
Grasses	87.5	Cropland	34/40
		Rangeland, (<10 cm)	19/28
		Rangeland, with brush	4/8
		Rangeland, (10–20 cm)	20/33
		Rangeland, with brush	6/9
		Rangeland (>20 cm)	11/17
		Rangeland, with brush	3/5
Little Bluestem	73	Bluestem	52/76
		Bluestem, with brush	17/24
No cover	93.5	Concrete or Urban	105/138
		Bare soil	35/62

each point, one must know the probability of detecting an individual bird (Nichols et al. 2000). Going forward, point counts will make use of multiple observer (Nichols et al. 2000, Alldredge et al. 2006) and removal model (Farnsworth et al. 2002) techniques to estimate the probability of detection.

It should also be noted that this is a landscape-level evaluation. It can identify regions with probable bobwhite populations, or at least those with potential, but it may be of little use on a finer scale within those areas. Although Duren et al. (2011) found that landscape-level factors had a greater influence on distribution than local variables, there is still considerable variation in local distribution. The factors influencing local distribution may not be known or, if known, may not be detectable from satellite imagery.

MANAGEMENT IMPLICATIONS

The National Bobwhite Technical Committee (2011) recommended conservation policies be considered at ecoregion levels of 25,000–300,000 km^2. As management focus moves from a local to a regional scale, there is an increased need for regional data on habitat quality and bobwhite populations as well as data that can be used across multiple scales. This analysis is on a smaller scale, <3,000 km^2; however, the techniques used in this study can be applied on an ecoregion scale, with the potential to identify focal areas across all of the Cross Timbers region in Texas and much of the Central Great Plains to assist with prioritizing use of scarce resources in identifying these focal areas. It can also help with locating populations susceptible to local extirpation as well as regions of marginal habitat to consider for rehabilitation (Williams et al. 2004).

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